BIOMEDICAL ENGINEERING, BACHELOR OF SCIENCE (B.S.)

Biomedical engineering applies engineering expertise to analyze and solve problems in biology and medicine in order to enhance health care. Students involved in biomedical engineering learn to work with living systems and to apply advanced technology to the complex problems of medical care. Biomedical engineers work with other health care professionals including physicians, nurses, therapists and technicians toward improvements in diagnostic, therapeutic and health delivery systems. Biomedical engineers may be involved with designing medical instruments and devices, developing medical software, tissue and cellular engineering, developing new procedures or conducting state-of-the-art research needed to solve clinical problems.

There are numerous areas of specialization and course work within biomedical engineering. These include:

1. Bioinstrumentation: the application of electronics and measurement techniques to develop devices used in the diagnosis and treatment of disease, including heart monitors, intensive care equipment, cardiac pacemakers and many other electronic devices.
2. Biomaterials: the development of artificial and living materials used for implantation in the human body, including those used for artificial heart valves, kidney dialysis cartridges, and artificial arteries, hips and knees.
3. Biomechanics: the study of motion, forces and deformations in the human body, including the study of blood flow and arterial disease, forces associated with broken bones and their associated repair mechanisms, mechanisms of blunt trauma including head injuries, orthopedic systems, and the forces and movement associated with human joints such as the knee and hip.
4. Tissue and cellular engineering: the application of biochemistry, biophysics and biotechnology toward the development of new cellular and tissue systems and an understanding of disease processes, including development of artificial skin and organs, cell adherence to artificial materials to prevent rejection by the body, and the development of new genetic cellular systems to treat diseases.
5. Medical imaging: the development of devices and systems to image the human body to diagnose diseases, including the development and data processing of the CAT scan, MRI (magnetic resonance imaging), medical ultrasound, X-ray and PET (positron emission tomography).
6. Rehabilitation and human factors engineering: the development of devices and prosthetics to enhance the capabilities of disabled individuals, including design of wheelchairs, walkers, artificial legs and arms, enhanced communication aids, and educational tools for people with disabilities.

A unique aspect to the undergraduate biomedical engineering is the practicum series, EGRB 101 and EGRB 301, which involves biomedical engineering students participating in medical rounds at the VCU Medical Center’s MCV Hospitals, in medical research laboratories throughout the medical center and the Virginia BioTechnology Research Park, and in medical seminars, case studies and medical laboratories. This unique opportunity is the only one of its kind in the nation and involves the cooperation of the VCU Medical Center, one of the nation’s largest and most prestigious medical centers.

Learning outcomes

Upon completing this program, students will know and know how to do the following:

- Identify and apply recent knowledge, and analyze and solve problems in the foundation areas of mathematics, the sciences and statistics.
- Identify and apply recent knowledge, and analyze and solve problems in the foundation engineering areas of electrical circuits, mechanics, biomedical engineering, and engineering systems and design.
- Identify and apply recent knowledge, and analyze and solve problems in the life sciences, including biology, physiology and anatomy, and understand the relationship between the life sciences, mathematics and engineering.
- Design and conduct lab experiments, collect, analyze and interpret data from physical and simulated systems to solve technical problems, and analyze physiology and life science laboratory experiments to integrate engineering and physiology/biology.
- Design and implement a system, component or process to meet the desired needs within a set of realistic specifications and constraints; design systems used in biomedical applications that involve the interconnection between engineering and the life sciences, including issues of health, safety and medical ethics.
- Organize ideas and write well-organized and accurate reports, including appropriate citations; deliver oral presentations to peers and supervisors using the latest presentation technologies.
- Understand the need for the various elements and facets of a career in biomedical engineering and related fields; have a recent understanding of the knowledge tools necessary to achieve lifelong learning and career development.
- Understand the nature of, and have the ability to, function on multidisciplinary and interdisciplinary teams, and understand the role that each team member brings to the overall goal.
- Attain and further master the ability to formulate, analyze and solve problems, analytically and/or experimentally, in biomedical engineering industry, in the clinical setting or in biomedical research within a few years of graduation. The career paths of BME graduates in these arenas would be enhanced as a result of these skills.
- Attain and further master the ability to understand the life and health sciences and the interconnection between engineering and the life/health sciences including biology, anatomy, physiology and biomedical engineering, with particular reference to biomedical engineering industry, in the clinical setting or in biomedical research within a few years of graduation. The career paths of BME graduates in these arenas would be enhanced as a result of these skills.
- Attain and further master the ability to articulate ideas and communicate in a clear and effective manner appropriate to their audience, in both written and and/or oral forms, with particular reference to biomedical engineering industry, in the clinical setting or in biomedical research within a few years of graduation. The career paths of BME graduates in these arenas would be enhanced as a result of these skills.
- Attain and further master the ability to work effectively in teams to solve biomedical and/or clinical problems, including the interconnection of engineering and clinical personnel toward the solution of problems of compelling clinical and biomedical interest and need, with particular reference to biomedical engineering industry, in the clinical setting or in biomedical research within a few years of graduation. The career paths of BME graduates in these arenas would be enhanced as a result of these skills.
years of graduation. The career paths of BME graduates in these arenas would be enhanced as a result of these skills.

**Degree requirements for Biomedical Engineering, Bachelor of Science (B.S.)**

**General Education requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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</thead>
<tbody>
<tr>
<td>UNIV 111</td>
<td>Play course video for Focused Inquiry I</td>
<td>3</td>
</tr>
<tr>
<td>UNIV 112</td>
<td>Play course video for Focused Inquiry II</td>
<td>3</td>
</tr>
<tr>
<td>UNIV 200</td>
<td>Inquiry and the Craft of Argument</td>
<td>3</td>
</tr>
<tr>
<td>Approved humanities/fine arts</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Approved natural/physical sciences</td>
<td></td>
<td>3-4</td>
</tr>
<tr>
<td>Approved quantitative literacy</td>
<td></td>
<td>3-4</td>
</tr>
<tr>
<td>Approved social/behavioral sciences</td>
<td></td>
<td>3-4</td>
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**General Education requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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</thead>
<tbody>
<tr>
<td>PHYS 207</td>
<td>University Physics I</td>
<td>5</td>
</tr>
<tr>
<td>PHYS 208</td>
<td>University Physics II</td>
<td>5</td>
</tr>
</tbody>
</table>

Total Hours 31-34

**Collateral requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 151</td>
<td>Introduction to Biological Sciences I</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 101</td>
<td>General Chemistry I</td>
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</tr>
<tr>
<td>&amp; CHEZ 101</td>
<td>and General Chemistry Laboratory I</td>
<td></td>
</tr>
<tr>
<td>CHEM 102</td>
<td>General Chemistry II</td>
<td>4</td>
</tr>
<tr>
<td>&amp; CHEZ 102</td>
<td>and General Chemistry Laboratory II</td>
<td></td>
</tr>
<tr>
<td>MATH 200</td>
<td>Calculus with Analytic Geometry I (fulfills approved quantitative literacy)</td>
<td>4</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Calculus with Analytic Geometry II</td>
<td>4</td>
</tr>
<tr>
<td>MATH 301</td>
<td>Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 310</td>
<td>Linear Algebra</td>
<td>3</td>
</tr>
<tr>
<td>PHIL 201</td>
<td>Critical Thinking About Moral Problems (fulfills approved humanities/fine arts)</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 207</td>
<td>University Physics I (fulfills General Education requirement)</td>
<td>5</td>
</tr>
<tr>
<td>PHYS 208</td>
<td>University Physics II (fulfills General Education requirement)</td>
<td>5</td>
</tr>
<tr>
<td>STAT 210</td>
<td>Basic Practice of Statistics</td>
<td>3</td>
</tr>
<tr>
<td>or STAT 441</td>
<td>Applied Statistics for Engineers and Scientists</td>
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Total Hours 24

**Major requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>EGRB 101</td>
<td>Biomedical Engineering Practicum</td>
<td>2</td>
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<tr>
<td>EGRB 102</td>
<td>Introduction to Engineering</td>
<td>4</td>
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<tr>
<td>EGRB 203</td>
<td>Statics and Mechanics of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 209</td>
<td>Applied Physiology for Biomedical Engineers</td>
<td>4</td>
</tr>
<tr>
<td>EGRB 215</td>
<td>Computational Methods in Biomedical Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 301</td>
<td>Biomedical Engineering Design Practicum</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 303</td>
<td>Biotransport Processes</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 307</td>
<td>Biomedical Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>EGRB 308</td>
<td>Biomedical Signal Processing</td>
<td>4</td>
</tr>
<tr>
<td>EGRB 310</td>
<td>Biomechanics</td>
<td>4</td>
</tr>
<tr>
<td>EGRB 315</td>
<td>Device Design Methods</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 401</td>
<td>Biomedical Engineering Senior Design Studio</td>
<td>6</td>
</tr>
<tr>
<td>&amp; EGRB 402</td>
<td>and Biomedical Engineering Senior Design Studio</td>
<td></td>
</tr>
<tr>
<td>EGRB 427</td>
<td>Biomaterials</td>
<td>3</td>
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<tr>
<td>EGR 206</td>
<td>Electric Circuits</td>
<td>4</td>
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<tr>
<td>ENGR 395</td>
<td>Professional Development</td>
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Total Hours 51

**Open electives**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved 200-level or higher open engineering elective or a technical elective course selected from any BME track below.</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical electives within declared track</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

Total Hours 24

The minimum total of credit hours required for this degree is 131.

**Technical electives**

Biomedical engineering students must select 21 credits of electives from one of the five technical elective tracks: cellular, tissue and regenerative engineering; biomechanics and biomaterials; rehabilitation and human factors engineering; biomedical instrumentation and imaging; or premedical.

**Cellular, tissue and regenerative engineering track**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 301</td>
<td>Organic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 403</td>
<td>Biochemistry I</td>
<td>3</td>
</tr>
<tr>
<td>CHEZ 301</td>
<td>Organic Chemistry Laboratory I</td>
<td>2</td>
</tr>
<tr>
<td>EGMN 309</td>
<td>Material Science for Engineers</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 403</td>
<td>Tissue Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 406</td>
<td>Artificial Organs</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 410</td>
<td>Cellular Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 411</td>
<td>Cell Mechanics and Mechanobiology</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 412</td>
<td>Regenerative Engineering and Medicine</td>
<td>3</td>
</tr>
<tr>
<td>EGRB 491</td>
<td>Special Topics (When Appropriate)</td>
<td>1-4</td>
</tr>
<tr>
<td>EGRB 513</td>
<td>Cellular Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 497</td>
<td>Vertically Integrated Projects</td>
<td>1,2</td>
</tr>
<tr>
<td>or INNO 460</td>
<td>Product Innovation: da Vinci Project</td>
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**Biomechanics and biomaterials track**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>CHEM 301</td>
<td>Organic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>CHEZ 301</td>
<td>Organic Chemistry Laboratory I</td>
<td>2</td>
</tr>
<tr>
<td>EGMN 201</td>
<td>Dynamics and Kinematics</td>
<td>3</td>
</tr>
<tr>
<td>EGMN 300</td>
<td>Mechanical Systems Design</td>
<td>3</td>
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</table>
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EGMN 309 Material Science for Engineers 3
EGMN 420 CAE Design 3
EGMN 421 CAE Analysis 3
EGMN 427 Robotics 3
EGRB 403 Tissue Engineering 3
EGRB 405 Finite Element Analysis in Solid Mechanics 3
EGRB 406 Artificial Organs 3
EGRB 411 Cell Mechanics and Mechanobiology 3
ENGR 497 Vertically Integrated Projects 1,2

Rehabilitation and human factors engineering track
Course Title Hours
CMSC 245 Introduction to Programming Using C++ 3
or CMSC 255 Introduction to Programming
CMSC 246 Advanced Programming Using C++ 3
or CMSC 256 Data Structures and Object Oriented Programming
EGRB 405 Finite Element Analysis in Solid Mechanics 3
EGRB 406 Artificial Organs 3
EGRB 420 Assistive Technology 3
EGRB 421 Human Factors Engineering 3
EGRB 422 Human Performance Measurement Engineering 3
EGRB 423 Rehabilitation Engineering and Prostheses 3
EGRB 491 Special Topics (if subject is appropriate; see adviser for approval) 1-4

EGMN 201 Dynamics and Kinematics 3
EGMN 416 Mechatronics 3
EGMN 420 CAE Design 3
EGMN 421 CAE Analysis 3
EGMN 427 Robotics 3
EGMN 525 Feedback Control 3
ENGR 497 Vertically Integrated Projects 1,2
or INNO 460 Product Innovation: da Vinci Project
PSYC 406 Perception 3

Biomedical instrumentation and imaging track
Course Title Hours
EGRE 207 Electric Circuits II 4
EGRE 245 Engineering Programming 4
EGRE 246 Advanced Engineering Programming 3
EGRE 254 Digital Logic Design 4
EGRE 306 Introduction to Microelectronics 4
EGRE 307 Integrated Circuits 4
EGRE 335 Signals and Systems I 4
EGRE 337 Signals and Systems II 3
EGRE 364 Microcomputer Systems 4
EGRE 365 Digital Systems 4
EGRE 454 Automatic Controls 4
EGRB 407 Physical Principles of Medical Imaging 3
EGRB 408 Advanced Biomedical Signal Processing 3
EGRB 409 Microcomputer Applications in Biomedical Engineering 3
ENGR 497 Vertically Integrated Projects 1,2
or INNO 460 Product Innovation: da Vinci Project

Pre-medical track
Course Title Hours
BIOZ 151 Introduction to Biological Science Laboratory I 1
BIOZ 152 Introduction to Biological Science Laboratory II 1
CHEM 301 Organic Chemistry 3
CHEM 302 Organic Chemistry 3
CHEM 403 Biochemistry I 3
CHEZ 301 Organic Chemistry Laboratory I 2
CHEZ 302 Organic Chemistry Laboratory II 2
EGRB 403 Tissue Engineering 3
EGRB 406 Artificial Organs 3
EGRB 410 Cellular Engineering 3
ENGR 497 Vertically Integrated Projects 1,2
or INNO 460 Product Innovation: da Vinci Project

What follows is a sample plan that meets the prescribed requirements within a four-year course of study at VCU. Please contact your adviser before beginning course work toward a degree.

Freshman year
Fall semester
Course Title Hours
BIOL 151 Introduction to Biological Sciences I 3
CHEM 101 General Chemistry I 4
& CHEZ 101 and General Chemistry Laboratory I
EGRB 101 Biomedical Engineering Practicum 2
MATH 200 Calculus with Analytic Geometry I 4
UNIV 111 Play course video for Focused Inquiry I 3

Term Hours: 16

Spring semester
Course Title Hours
CHEM 102 General Chemistry II 4
& CHEZ 102 and General Chemistry Laboratory II
EGRB 102 Introduction to Engineering 4
ENGR 395 Professional Development 1
MATH 201 Calculus with Analytic Geometry II 4
UNIV 112 Play course video for Focused Inquiry II 3

Term Hours: 16

Sophomore year
Fall semester
The minimum total of credit hours required for this degree is 131.

- Biomedical engineering (p. 4)
- Engineering (p. 7)
EGRB 215. Computational Methods in Biomedical Engineering. 3 Hours. Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. Corequisite: MATH 301, MATH 310 or permission of instructor. Enrollment is restricted to students with sophomore standing in biomedical engineering. The goal of this course is to enhance students' software skills for subsequent biomedical engineering courses and laboratories, as well their careers. The course covers the basic fundamentals of programming in MATLAB, as well as data analysis of biomedical data. An important component of this course is developing problem-solving skills.

EGRB 301. Biomedical Engineering Design Practicum. 3 Hours. Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 101, EGRB 102, EGRB 203, EGRB 209, EGRB 215, EGRE 206 (or equivalent), each with a minimum grade of C. Restricted to students with junior standing in the biomedical engineering program. Explores the professional and ethical responsibilities of a biomedical engineer. Emphasis will be placed on design issues associated with biomedical engineering, teamwork, regulatory issues and human and animal subjects.

EGRB 303. Biotransport Processes. 3 Hours. Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 209, MATH 301 and MATH 310, each with a minimum grade of C. Course involves the study of fundamental principles of fluid mechanics and mass transport as well as application of these principles to physiological systems. Fluid mechanics principles covered will include conservation of mass and momentum, laminar and turbulent flow, Navier-Stokes equations, dimensional analysis, Bernoulli's equation, and boundary layer theory. Mass transport principles will include diffusion, convection, transport in porous media and transmembrane transport. Concepts will be applied to studying diffusion in biological tissues, electrolyte transport, vascular transport, blood flow mechanics and cardiovascular flow. The course will also cover organ-specific transport processes, including oxygen transport in the lungs and blood and mass transport in the kidney.

EGRB 307. Biomedical Instrumentation. 4 Hours. Semester course; 3 lecture and 3 laboratory hours. 4 credits. Prerequisites: EGRB 102, EGRB 209, EGRB 215 and EGRE 206, each with a minimum grade of C. A study of the physical principles, design and clinical uses of biomedical instrumentation. Analysis and design of low frequency electronic circuits, which are most frequently used in biomedical instruments, will be conducted. Analysis of biosensors, biopotential electrodes, the measurements of biopotential signals including electrocardiogram, electroencephalogram and electromyogram, blood pressure, blood flow, and respiratory system will be conducted. Laboratory work on basic biomedical electronics and instrumentation will be performed.

EGRB 310. Biomechanics. 4 Hours. Semester course; 3 lecture and 3 laboratory hours. 4 credits. Prerequisites: EGRB 203, EGRB 209 and EGRB 215; MATH 200 and MATH 201, all with a minimum grade of C. Corequisites: MATH 301 and MATH 310. A study of the forces, stresses and strains in the human body during normal function. Emphasis is placed on the mechanics of various components of the body including hard (bone) and soft (skin, vessels, cartilage, ligaments, tendons) tissues from a structure-function perspective. Stress and strain relationships for these biomaterials will be analyzed based upon the fundamentals of engineering mechanics. In addition, the distinctive features of biological materials will be studied with respect to their differences from nonliving materials and elaborated upon in laboratory exercises using material evaluation protocols.

EGRB 315. Device Design Methods. 3 Hours. Semester course; 2 lecture and 3 laboratory hours. 3 credits. Prerequisites: EGRB 203, EGRB 215, EGRB 307, MATH 301 and MATH 310, all with a minimum grade of C. The main goal of the course is to introduce a variety of design and prototyping methods for biomedical devices. The focus will be on: (1) using first approximations and Solidworks for mechanical design and (2) using Arduino microcontrollers for controlling sensors and actuators.

EGRB 401. Biomedical Engineering Senior Design Studio. 3 Hours. Semester course; 9 laboratory hours. 3 credits. Prerequisites: EGRB 101, EGRB 102, EGRB 209, EGRB 215, EGRB 301, EGRB 303, EGRB 307, EGRB 308, EGRB 310, EGRB 315 and EGRB 427, all with a minimum grade of C. Enrollment is restricted to students with senior standing in the Department of Biomedical Engineering or by permission of instructor. A minimum of nine laboratory hours per week is dedicated to the design, development and execution of the senior design (capstone) project for biomedical engineering under the direction of a faculty research advisor in biomedical engineering or an acceptable substitute as determined by the course coordinator. Tasks include team meetings (for team projects), brainstorming, sponsor advising, designing, fabrications, assembling, reviewing, studying, researching, testing and validating projects. Monthly progress reports are due to the research advisor and course coordinator. At the end of the first semester, each team will orally present to the BME faculty project background information and discuss potential technical approaches and deliverables.

EGRB 402. Biomedical Engineering Senior Design Studio. 3 Hours. Semester course; 9 laboratory hours. 3 credits. Prerequisites: Completion of EGRB 401 with a minimum grade of C. A minimum of nine laboratory hours per week is dedicated to the design, development and execution of the senior design (capstone) project for biomedical engineering under the direction of a faculty research advisor in biomedical engineering or an acceptable substitute as determined by the course coordinator. Tasks include team meetings (for team projects), brainstorming, sponsor advising, designing, fabrications, assembling, reviewing, studying, researching, testing and validating projects. Monthly progress reports are due to the research advisor and course coordinator. Final project reports must be submitted before the end of the semester. All design teams must participate in the College of Engineering public poster session. At the end of the semester and conclusion of the two-semester design process, teams must present their final designs and deliverables before the BME faculty.
EGRB 403. Tissue Engineering. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: EGRB 209 with a minimum grade of C or permission of instructor. Enrollment is restricted to students with junior standing in engineering. Study of the design, development and clinical application of tissue engineered components for use in the human body. Analysis of biology, chemistry, material science, engineering, immunology and transplantation as pertains to various tissue engineered components including blood vessels, bone, cartilage, pancreas, liver and skin.

EGRB 405. Finite Element Analysis in Solid Mechanics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 310 and MATH 301, each with a minimum grade of C. Finite element analysis as presented in this course is a numerical procedure for solving continuum mechanics problems that cannot be described by closed-form mathematical solutions. Emphasis will be placed on understanding the theoretical basis for the method, using a commercial software program, and understanding the volume of information that can be generated. Applications to both one- and two-dimensional problems in solid mechanics and biomechanics will be explored.

EGRB 406. Artificial Organs. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 209, EGRB 303, EGRB 307 and EGRB 310, each with a minimum grade of C, or permission of instructor. This course explores the design, operating principles and practices regarding artificial organs and their use in the human body. Analysis of dialysis systems for kidney replacement, artificial hearts and heart assist devices, cardiac pacemakers, sensory organ assist and replacement devices, and artificial liver and pancreas devices. Design aspects, legal ramifications, regulatory issues and clinical implantation issues will be addressed.

EGRB 407. Physical Principles of Medical Imaging. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: PHYS 208 with a minimum grade of C. Enrollment is restricted to students with junior standing in the College of Engineering. A study of the physical principles and basic clinical uses of medical imaging. Analysis of radiation and interaction of radiation, generation and control of X-rays, X-ray diagnostic methods, X-ray computed tomography (CT), magnetic resonance imaging (MRI) and ultrasonic imaging will be conducted. Basic principle of radionuclide imaging also will be introduced.

EGRB 408. Advanced Biomedical Signal Processing. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: EGRB 308. This course will briefly review the basic theory of discrete-time signal processing techniques in biomedical data processing. Advanced signal processing techniques including adaptive signal processing, wavelets, spectral estimation and multirate signal processing will be employed. Specific examples utilizing electrocardiogram (ECG) and other biological signals are provided. Topics covered are alterneance phenomenon in biological systems, late potential in ECG, intrapotential in ECG and coherence analysis.

EGRB 409. Microcomputer Applications in Biomedical Engineering. 3 Hours.
Semester course; 2 lecture and 3 laboratory hours. 3 credits. Prerequisite: EGRB 307. Covers microcomputer applications (hardware and software) as applied to biomedical science and biomedical engineering. Basic hardware components of a microcomputer are discussed with particular reference to configurations needed for analyzing biomedical events. Software applications including data encoding, data storage, graphical interfaces and real-time processing are explored for analysis of physiological and biomedical signals. Students will develop algorithms using LabView and MatLab to solve problems in biomedical engineering in the laboratories.

EGRB 410. Cellular Engineering. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: EGRB 209 with a minimum grade of C. This course will be a detailed study of the structure and function of the cell from an engineering perspective. Fundamental molecular biology, cell biology and biochemistry topics (cellular structure, signal transduction, cell adhesions, cytoskeleton) will be introduced. Engineering principles (kinetics, transport, mechanics, thermodynamics, electrochemical gradient) will be applied to these topics. Emphasis is placed on methods to disrupt, enhance or mimic in vivo cellular function in biomedical applications.

EGRB 411. Cell Mechanics and Mechanobiology. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 310 and EGRB 410 with minimum grades of C or permission of instructor. Focusing on cellular-extracellular matrix interactions, students will gain a quantitative understanding of the way cells detect, modify and respond to the physical properties within the cell environment. Coverage includes the mechanics of single-molecule polymers, polymer networks, two-dimensional membranes, whole-cell mechanics and mechanobiology. Mechanobiology topics include cancer and development, pulmonary system, cardiovascular system, and the nervous system. Students will gain understanding of techniques in cellular manipulation and quantification of cellular forces.

EGRB 412. Regenerative Engineering and Medicine. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: EGRB 209 or equivalent with minimum grade of C. Students will apply fundamental concepts of cell and molecular biology, biochemistry, medicine and pathology, as well as material science and engineering principles to design novel strategies for cell and drug delivery, tissue engineering and regenerative medicine. Emphasis will be placed on designs and methods to solve current complex biomedical problems.

EGRB 413. Computational and Experimental Models of Cellular Signal Transduction. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 215 and EGRB 410 with minimum grades of C. Students will study the process by which an extracellular protein binding event is transduced and interpreted as an incoming signal into a cell. Students will learn the biology of cellular signal transduction and will also learn how to apply computational models and experimental techniques to predict and investigate these pathways. Students will follow the course of a protein within a signal transduction cascade, from binding to a receptor, activating intracellular pathways, inducing new transcription and translation and targeting of the protein to its final location. Students will develop MATLAB-based mathematical models to predict signal transduction dynamics, and then will study experimental techniques that are used to both disrupt and measure signal transduction.

EGRB 420. Assistive Technology. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRE 206, EGRB 209, EGRB 215, EGRB 307, EGRB 308 and EGRB 310, all with a minimum grade of C. Enrollment is restricted to biomedical engineering students or with permission of instructor. This course explores the principles and practice regarding the development of assistive technology for individuals with disabilities. The course will address the human user considerations that need to be taken into account in developing technology for individuals with different disabilities or multiple disabilities. It will also provide a general overview of current technology and software algorithms used. The four main areas of assistive technology that will be considered are for the deaf and hard of hearing, individuals who are blind and visually impaired, individuals with cognitive impairments, and individuals with motor impairments.
EGRB 421. Human Factors Engineering. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 209 and EGRB 310, both with a minimum grade of C. This course explores the principles and practices regarding ergonomics and human factors engineering and the interaction of biomedical engineering with human function. Analysis of the functions of the human body regarding motion, sensory mechanisms, cognition and interaction with the environment will be included. Interactions of the human body with technology, workplaces, equipment and computers will be examined. Design of workplaces for optimal human performance will be discussed. Analysis of the design and arrangement of controls and displays will be covered.

EGRB 422. Human Performance Measurement Engineering. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 209, EGRB 307, EGRB 308 and EGRB 421, each with a minimum grade of C. Enrollment is restricted to biomedical engineering majors or with permission of instructor. Course explores the principles and practices of human performance measurement including direct and indirect measurement techniques and analysis. Course addresses the subjective, psychophysical and physiological methods related to the measurement, analysis and quantification of human performance.

EGRB 423. Rehabilitation Engineering and Prostheses. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: EGRB 203 and EGRB 209, both with a minimum grade of C. Enrollment is restricted to biomedical engineering majors or with permission of instructor. This course explores the principles and practices regarding the development of rehabilitation therapy devices and prostheses. The course will further address the human user and factors that must be considered when developing devices and engineering solutions for individuals with different therapy and prosthetic needs. The course will also provide a general overview of current technologies and the engineering principles behind these designs.

EGRB 427. Biomaterials. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: EGRB 209 with a minimum grade of C. Enrollment is restricted to students with junior standing in biomedical engineering or with permission of the instructor. Principles of materials science as it relates to the use of materials in the body. Characterization of biomaterials. Study of the properties of biomedical materials used as implants, prostheses, orthosis and as medical devices in contact with the human body. Analysis of physical, chemical, thermal and physiological response factors associated with materials and implant devices used in the human body.

EGRB 491. Special Topics. 1-4 Hours.
Semester course; 1-4 lecture hours. 1-4 credits. May be repeated with different topics. Advanced study of a selected topic in biomedical engineering. See the Schedule of Classes for specific topics to be offered each semester and prerequisites, corequisites or restrictions.

Engineering
ENGR 100. Engineering Student Success. 0 Hours.
Semester course; seminar hours. 0 credits. Enrollment is restricted to new first-year students in the School of Engineering; required for students admitted conditionally. Students will meet for a 90-minute class once per week for five weeks. The course is dedicated to helping students understand the expectations and responsibilities of being a college student. Presentations will center on planning the semester, academic professionalism, study skills and test-taking strategies, financial literacy, health and wellness, time management, and the Honor Code. Seminars will be supplemented throughout the semester with online assignments to reinforce the discussions. Graded as pass/fail.

ENGR 101. Introduction to Engineering. 4 Hours.
Semester course; 3 lecture and 3 laboratory hours. 4 credits. Prerequisites: admission to the School of Engineering or permission of instructor. Introduces basic circuits including resistors, diodes, transistors, digital gates and motors. Simple electromechanical systems are considered including motors, gears and wheels. The laboratory introduces fundamental circuit testing and measurement, and proper laboratory notebook writing; students are required to analyze, build and test a digitally controlled robot.

ENGR 111. Innovation Shop Training I. 0.5 Hours.
Semester course; 1 laboratory hour. 0.5 credits. Enrollment restricted to students in the School of Engineering. The course provides training on innovation shop safety, includes a tour of the shop, measuring and layout tools and techniques, use of general manual and powered hand tools. Students will be instructed on the use of a bench-top drill press, deburring and finishing tools, 3D printing, laser engraving and thermoforming equipment. Students need to achieve a minimum score of 76% in the class to attain Level I (Blue) certification. Only certified students have permission to use tools and equipment covered in this training. Graded as Pass/Fail.

ENGR 121. Engineering Fundamentals. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: permission of instructor. Open only to non-engineering majors in Certificate in Product Innovation program. Introduces engineering fundamentals to students from non-engineering disciplines. Particular focus is the engineering problem-solving process as applied to open-ended problems. Students will be introduced to the different types of engineering, examine engineering issues and apply the engineering problem-solving process.

ENGR 211. Innovation Shop Training II. 1 Hour.
Semester course; 2 laboratory hours. 1 credit. Prerequisite: ENGR 111. Enrollment restricted to students in the School of Engineering. The course provides training on machine/innovation shop safety, blueprint reading, measuring and layout tools and techniques, and use of general and powered hand tools. Students will be instructed on sawing, sanding, drilling and tapping operations, 3D printing and laser engraving/cutting equipment. Hands-on graded assignment is the part of the course.

ENGR 291. Special Topics in Engineering. 1-5 Hours.
Semester course; variable hours. 1-5 credits. Prerequisite: to be determined by the instructor. Specialized topics in engineering designed to provide a topic not covered by an existing course or program. General engineering or multidisciplinary. May be repeated with different content. Graded as pass/fail or normal letter grading at the option of the instructor. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

ENGR 296. Part-time Internship Experience. 0 Hours.
Semester course; 0 credit. Students may attempt this course a total of six times. Enrollment restricted to School of Engineering majors. The student works part time in an approved internship and must work a minimum of 90 hours, but less than 300 hours during the semester. The student works to meet learning objectives while gaining practical experience relevant to their major. The student completes assignments to document, assess and reflect on their learning experience. The supervisor and student both complete evaluations of the learning experience. Graded pass/fail.
ENGR 303. Junior Seminar. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: permission of instructor. This course provides students an opportunity to explore business and leadership topics. Topics include the fundamentals of product design and new product development, manufacturing and quality systems, finances and financial reports, ethics in the workplace, intellectual property, teamwork, leadership and communications.

Students will be assigned selected readings, written compositions and oral presentations. This course prepares the student to participate in the Engineering Laboratory/Manufacturing Internship.

ENGR 311. Innovation Shop Training III. 1 Hour.
Semester course; 2 laboratory hours. 1 credit. Prerequisite: ENGR 211. Enrollment is restricted to students with Level II (Red) certification. The Level III (Green) course provides basic training on set-up and operation of manual milling machines and the lathe. The course covers cutting tool, speed and feed calculation. Students must develop a technological process and machine metal parts per assigned drawings on vertical mill and lathe. They will also use other techniques and equipment that were covered in previous levels. Students need to achieve a minimum score of 76 per cent in the class to attain Level III (Green) certification. Only certified students have permission to use tools and equipment covered in this training.

ENGR 395. Professional Development. 1 Hour.
Semester course; 1 lecture and 1 workshop hour. 1 credit. Enrollment is restricted to majors in the School of Engineering. Professional development course to help prepare students to find a job and succeed in a professional environment, and specifically to work as an intern or in a cooperative education position. Topics covered include career paths; job searches; resume and cover letter writing; preparing for the interview; personal assessment of interests, values and strengths; networking; professional and ethical behavior in the job; overview of legal issues related to hiring, such as nondisclosure agreements and noncompete clauses; overview of personal finance management at the first job; workplace safety; and expectations and requirements for internships and cooperative education positions.

ENGR 396. Internship Experience. 0 Hours.
Semester course; 0 credit. Students may attempt this course a total of three times. Enrollment restricted to School of Engineering majors. The student works in an approved internship and must work a minimum of 300 hours during the semester. The student works to meet learning objectives while gaining practical experience relevant to their major. The student completes assignments to document, assess and reflect on their learning experience. The supervisor and student both complete evaluations of the learning experience. Graded pass/fail.

ENGR 398. Cooperative Education Experience. 0 Hours.
Semester course; 0 credits. Students may attempt this course a total of four times. Prerequisite: ENGR 395. Restricted to School of Engineering majors in good academic standing. The student works full-time in an approved cooperative education position. The student works to meet specific learning objectives while gaining practical experience relevant to their major. The student completes assignments to document, assess and reflect on their learning experience. The supervisor/mentor and student both complete midterm and final evaluations of the learning experience. Graded pass/fail.

ENGR 399. Cooperative Education Experience II. 3 Hours.
Semester course; 3 credits. Prerequisite: ENGR 398. Restricted to School of Engineering majors in good academic standing. A student that has completed at least one work term in a full-time approved cooperative education position completes an additional full-time work term. The student works to meet specific learning objectives while gaining practical experience relevant to their major. The student completes assignments to document, assess and reflect on their learning experience. The supervisor/mentor and student both complete midterm and final evaluations of the learning experience.

ENGR 402. Senior Design Studio (Seminar). 1 Hour.
Continuous courses; 1 lecture hour. 1-1 credit. Prerequisites: senior standing and participation in a senior design (capstone) project; completion of ENGR 402 to enroll in ENGR 403. This weekly seminar presents and discusses topics relevant to senior-level engineering students in support of the capstone project and upcoming graduation. A single course coordinator manages and administers the course and schedules the various faculty lectures and guest speakers. Topics include, but are not limited to, the following: proposal writing, project planning and management, scheduling resources and budgeting for technical projects, patents and intellectual property, quality systems (six sigma, ISO standards, statistical process control), entrepreneurship, creativity and innovation and professional registration.

ENGR 403. Senior Design Studio (Seminar). 1 Hour.
Continuous courses; 1 lecture hour. 1-1 credit. Prerequisites: senior standing and participation in a senior design (capstone) project; completion of ENGR 402 to enroll in ENGR 403. This weekly seminar presents and discusses topics relevant to senior-level engineering students in support of the capstone project and upcoming graduation. A single course coordinator manages and administers the course and schedules the various faculty lectures and guest speakers. Topics include, but are not limited to, the following: proposal writing, project planning and management, scheduling resources and budgeting for technical projects, patents and intellectual property, quality systems (six sigma, ISO standards, statistical process control), entrepreneurship, creativity and innovation and professional registration.

ENGR 410. Review of Internship. 1 Hour.
Semester course; 1 credit. Prerequisites: chemical, electrical and computer, or mechanical engineering major and experience to satisfy the engineering internship requirements. Students complete oral presentations and written reports summarizing the internship experience.

ENGR 411. Fundamentals of Engineering Exam Preparation. 1 Hour.
Semester course; 1 lecture hour. 1 credit. Prerequisite: senior or graduate standing, or permission of instructor. This course prepares students for taking the fundamentals of Engineering Exam. Passing the FE Exam is the first step to getting a Professional Engineering license. This course is not intended to teach the various subject matters, but to review the subject areas and help students prepare as well as possible for the examination.

ENGR 490. Engineering Seminar. 1-3 Hours.
Semester course; variable hours. 1-3 credits. May be repeated with different content. Prerequisite: permission of the instructor. A series of specialized topics in engineering that are of general interest but not covered by an existing course or program. Lectures will be presented in seminar format by speakers from business, industry, government and academia. Subjects will be multidisciplinary in nature. Graded as pass/fail or normal letter grading at the option of the instructor.
ENGR 491. Special Topics in Engineering. 1-5 Hours.  
Semester course; variable hours. 1-5 credits. Prerequisite: determined by the instructor. Specialized topics in engineering designed to provide a topic not covered by an existing course or program. General engineering or multidisciplinary. May be repeated with different content. Graded as pass/fail or normal letter grading at the option of the instructor. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

ENGR 492. Independent Study in Engineering. 1-5 Hours.  
Semester course; variable hours. 1-5 credits. May be repeated with different content. Prerequisite: permission of the instructor. Students must submit a written proposal to be approved by the supervising instructor prior to registration. Investigation of specialized engineering problems that are multidisciplinary or of general interest through literature search, mathematical analysis, computer simulation and/or laboratory experimentation. Written and oral progress reports as well as a final report and presentation are required. Graded as pass/fail or normal letter grading at the option of the instructor.

ENGR 496. Internship Review. 0 Hours.  
Semester course; 0 credits. Prerequisite: ENGR 296 or ENGR 396. Restricted to School of Engineering majors. This course is to be taken following the completion of a minimum of 300 hours of approved internship experience relevant to the student's major and documents that a student has fulfilled all internship requirements, including a final evaluation by the employer, a final self-evaluation, a final report describing the experience and a final oral presentation about the experience. Graded pass/fail.

ENGR 497. Vertically Integrated Projects. 1,2 Hour.  
Semester course; 3 or 6 laboratory hours. 1 or 2 credits. May be repeated for a maximum total of 8 credits Prerequisites: permission of the project faculty adviser. This course provides undergraduate students the opportunity to participate in multiyear, multidisciplinary projects under the guidance of faculty and graduate students in their areas of expertise. As they address research and development issues, students learn and practice many different professional skills, make substantial technical contributions to the project, and experience many different roles on a large, multidisciplinary design/discovery team. Students must earn a minimum of 4 credits in ENGR 497 with a minimum grade of C in order for these credits to be eligible to count toward a technical or departmental elective. More restrictive requirements may be imposed by individual departments.

ENGR 498. Review of Cooperative Education Experience. 0 Hours.  
Semester course; 0 credits. Prerequisite: ENGR 398. Restricted to School of Engineering majors. This course is completed following the final work term of a cooperative education experience and is required to obtain transcript notation to document that a student has fulfilled all the requirements of the school's cooperative education program. The requirements include a final evaluation by the employer, a final self-evaluation, a final report describing the experience and a final oral presentation about the experience.