# Rose-Hulman Institute of Technology Course Catalog

# Biomedical Engineering

Biomedical engineers use science, engineering, and mathematics to understand and solve medical problems. We focus on improving people's quality of life. Biomedical engineers who specialize in biomechanics design and analyze biological systems or medical devices that have to do with forces, stresses, and strains. This includes studying the motions of bodies or joints, fluid flow, the deformation of tissues or materials, and the transport of molecules and chemicals through tissues and across membranes.

Biomedical engineers who specialize in bioinstrumentation use electronics and signal analysis to take measurements from and deliver stimuli to living cells and tissues. Examples include cochlear implants, pacemakers, and patient monitoring equipment. Biomedical engineers who specialize in biomaterials design and study materials to replace, repair, and interact with cells and tissues in the body. Examples include metal, ceramic, polymer, or tissue-engineered implants; these implants can be permanent or biodegradable. The United States Bureau of Labor Statistics has projected that jobs for biomedical engineers will increase by 23% between the years 2014 and 2024.

The biomedical engineering program at Rose-Hulman produces engineers with the medical and biological expertise needed to solve health care problems during careers in technical and health-related industries, as well as in government or industrial laboratories. Alumni wishing to continue their studies in graduate/professional school or health professions programs will be well-qualified to do so.

### Biomedical Engineering Program Educational Objectives

**Objectives are defined as "expected accomplishments of graduates during the first several years following graduation from the program."**

- Graduates will apply the theories and concepts of biology, mathematics, physical science and engineering science essential to being a successful biomedical engineer.
- Graduates will apply practical and technical skills required for biomedical engineering practice.
- Graduates will work and communicate effectively with all of the people around them.
- Graduates will exercise their professional responsibilities towards society.
- Graduates will apply design principles to open-ended problems subject to technical, practical and societal constraints.

### Biomedical Engineering Student Outcomes

By the time students graduate with an undergraduate Biomedical Engineering degree from Rose-Hulman, they will have:

1. An ability to apply knowledge of mathematics, science, and engineering.
2. An ability to design and conduct experiments, as well as to analyze and interpret data.

3. An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. An ability to function on multidisciplinary teams.
5. An ability to identify, formulate, and solve engineering problems.
6. An understanding of professional and ethical responsibility.
7. An ability to communicate effectively.
8. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. A recognition of the need for, and an ability to engage in life-long learning.
10. A knowledge of contemporary issues.
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The biomedical engineering program is accredited by the Engineering Accreditation Commission of ABET, www.abet.org.

**Biomedical Engineering Areas of Concentration**

To receive the B.S. Degree Program in Biomedical Engineering, each student must satisfy the requirements of one of three Biomedical Engineering Areas of Concentration: Biomaterials, Biomechanics or Biomedical Instrumentation. The course options for each of these Areas are given below. A total of 16 credits (including required courses) from one of the lists must be taken.

**It is not permissible to "mix and match" courses from different area lists without written permission from the BBE department head.**

Biomedical courses that are offered as special topics courses (e.g. BE491 or BE597) may be used with the written permission of the department head. Students should work out their schedule in advance to ensure that all graduation requirements are met.

**BIOMATERIALS CONCENTRATION**

| Course | Title |
|---|---|
| BE 516 | Introduction to MEMS |
| BE 539 | Multiscale Biomechanics |
| BE 560 | Tissue-Biomaterial Interactions |
| BE 570 | Introduction to Tissue Engineering |
| CHE 315* | Materials Science and Engineering |
| CHE 441 | Polymer Engineering |
| ME 317 | Design for Manufacturing |
| ME 328* | Materials Engineering |

*CHE 315 OR ME 328 may be used, but not both

**BIOMEDICAL INSTRUMENTATION CONCENTRATION**

| Course | Title |
|---|---|

| | |
|---|---|
| BE 340 | Biomedical Instrumentation and Signal Processing |
| BE 350 | Biocontrols |
| BE 435/535 | Biomedical Optics |
| BE 516 | Introduction to MEMS |
| BE 520 | Introduction to Brain-Machine Interfaces |
| BE 541 | Medical Imaging |
| BE 543 | Neuroprosthetics |
| BE 555 | Electrophysiology |
| ECE 230 | Introduction to Embedded Systems |
| ECE 480 | Introduction to Image Processing |
| ME 430 | Mechatronic Systems |

**BIOMECHANICS CONCENTRATION**

| Course | Title |
|---|---|
| ME 317 | Design for Manufacturing |
| BE 525 | Biomedical Fluid Mechanics |
| BE 531 | Biomechanics II |
| BE 534 | Soft Tissue Mechanics |
| BE 539 | Multiscale Biomechanics |
| BE 545 | Orthopaedic Biomechanics |
| BE 550 | Research Methods in Biomechanics |
| EM 403 | Advanced Mechanics of Materials |
| ME 422 | Finite Elements for Engineering Applications |
| ME 520 | Computer-Aided Design and Manufacturing |
| ME 522 | Advanced Finite Element Analysis |

**Biomedical Engineering Thesis Option:**

The biomedical engineering thesis option is intended for students who complete a substantive research project in this field. In order to complete this thesis option a student must:

1. Pass a minimum of 8 credit hours of BE 492.

2. Perform research in BE492 that involves the same research project and is completed under the direction of a departmental faculty mentor. None of these credits may be used to fulfill the biomedical engineering area elective requirement.
3. Complete the course, BE 499 Thesis Research, in which the thesis is written and submitted to the department, and an oral research presentation is given to a minimum of three departmental faculty members, including the student's advisor. Successful completion of the biomedical engineering thesis will be noted on the student's transcript.

**Biomedical Engineering Minor**

The biomedical engineering minor is intended to provide a biomedical engineering background to undergraduate students who are interested in pursuing careers in the biomedical industry and healthcare related fields.

In order to complete the requirements of the biomedical engineering minor, a student must complete either BIO 110-Cell Structure & Function or BIO 120-Comparative Anatomy & Physiology AND complete four courses from the list shown below. Other BE courses may be substituted with approval by the BBE Department Head. At least three of the courses must have a BE prefix.

| Course | Title |
|---|---|
| BIO411 | Genetic Engineering |
| BE310 | Analysis of Physiological Systems I |
| BE320 | Analysis of Physiological Systems II |
| BE331 and BE352 | Biomechanics and Biomechanics Lab |
| BE340 * | Biomedical Signal Processing * |
| BE350 ** | Biocontrol Systems ** |
| BE361 and BE353 | Biomaterials and Biomaterials Lab |
| BE435/535 | Biomedical Optics |
| BE/MA482 | Bioengineering Statistics |
| BE520 | Introduction to Brain Machine Interfaces |
| BE525 | Biomedical Fluid Mechanics |
| BE531 | Biomechanics II |
| BE534 | Soft Tissue Mechanics |
| BE539 | Multiscale Biomechanics |
| BE543 | Neuroprosthetics |
| BE545 | Orthopaedic Biomechanics |
| BE560 | Tissue-Biomaterial Interactions |
| BE570 | Introduction to Tissue Engineering |

* BE340 cannot be used for a BE minor by students majoring in electrical or computer engineering.
** BE350 cannot be used for a BE minor by students who have taken ECE320 or ME406.

**In addition to courses in the above area concentration, students are required to have completed at least 12 credits of basic engineering courses. These courses may be chosen from the list below:**

| Course | Title |
|---|---|
| BE201 | Biomedical Instrumentation and Measurements |
| EM121 | Statics & Mechanics of Materials I |
| EM204 | Statics & Mechanics of Materials II |
| EM301 | Fluid Mechanics |
| ECE180 | Introduction to Signal Processing |
| ECE203 * | DC Circuits |
| ECE204 | AC Circuits |
| ES201 | Conservation & Accounting Principles |
| ES202 | Fluid Systems |
| ES203 * | Electrical Systems |
| ES204 | Mechanical Systems |
| CHE201 | Conservation Principles and Balances |
| CHE202 | Basic Chemical Process Calculations |
| CHE301 | Fluid Mechanics |

* Students may use either ECE203 or ES203 for a BE minor, but not both of these courses.

Successful completion of an area minor is indicated on the student's transcript. A student interested in pursuing an area minor in biomedical engineering should consult with the head of the Department of Biology and Biomedical Engineering.

# Plan of Study

## Freshman

**Fall**

| Course | Credit |
|---|---|
| BIO 110 Cell Structure and Function | 4 |
| PH 111 Physics I | 4 |
| MA 111 Calculus I | 5 |
| CLSK 100 College & Life Skills | 1 |
| EM 104 Graphical Communication | 2 |
| | **Total Credits: 16** |

**Winter**

| Course | Credit |
|---|---|
| BIO 120 Comparative Anatomy & Physiology | 4 |
| PH 112 Physics II | 4 |
| MA 112 Calculus II | 5 |
| EM 121 Statics and Mechanics of Materials I | 4 |
| | **Total Credits: 17** |

**Spring**

| Course | Credit |
|---|---|
| PH 113 Physics III | 4 |
| RH 131 Rhetoric & Composition | 4 |
| MA 113 Calculus III | 5 |
| BE 100 Problem Solving in the Biological Sciences & Engineering | 4 |
| | **Total Credits: 17** |

## Sophomore

**Fall**

| Course | Credit |
|---|---|
| ES 201 Conservation & Accounting Principles | 4 |
| CHEM 111 General Chemistry I | 4 |
| MA 211 Differential Equations | 4 |
| ES 203 Electrical Systems | 4 |
| | **Total Credits: 16** |

**Winter**

| Course | Credit |
|---|---|
| ES 202 Fluid & Thermal Systems | 3 |
| ES 204 Mechanical Systems | 3 |
| MA 212 Matrix Algebra & Systems of Differential Equations | 4 |
| CHEM 113 General Chemistry II | 4 |
| HSS Elective | 4 |
| | **Total Credits: 18** |

**Spring**

| Course | Credit |
|---|---|
| BE 201 Biomedical Measurements | 4 |

| | |
|---|---|
| BIO 130 Evolution & Diversity | 4 |
| ES 205 Analysis & Design of Engineering Systems | 4 |
| MA 223 Engineering Statistics | 4 |
| | **Total Credits: 16** |

## Junior

### Fall

| Course | Credit |
|---|---|
| HSS Elective | 4 |
| BIO 205 Cellular Physiology | 4 |
| RH330 Tech & Profess'l Comm or HSS Elective | 4 |
| EM 204 Statics & Mechanics of Materials II | 4 |
| | **Total Credits: 16** |

### Winter

| Course | Credit |
|---|---|
| BE 310 Physiological Systems I | 4 |
| BE 331 Biomechanics | 3 |
| BE 351 Biomedical Engineering Lab | 2 |
| BE 361 Biomaterials | 3 |
| RH330 Tech & Profess'l Comm or HSS Elective | 4 |
| | **Total Credits: 16** |

### Spring

| Course | Credit |
|---|---|
| SV 304 Bioethics | 4 |
| BE 320 Physiological Systems II | 4 |
| BE 390 Principles of Biomedical Engineering Design | 2 |
| BE Area | 4 |
| | **Total Credits: 14** |

## Senior

### Fall

| Course | Credit |
|---|---|
| BE 410 Biomedical Engineering Design I | 4 |
| HSS Elective | 4 |
| Free Elective | 4 |
| BE Area Elective | 4 |
| | **Total Credits: 16** |

**Winter**

| Course | Credit |
|---|---|
| BE 420 Biomedical Engineering Design II | 4 |
| HSS Elective | 4 |
| Free Elective | 4 |
| BE Area Elective | 4 |
| | **Total Credits: 16** |

**Spring**

| Course | Credit |
|---|---|
| BE 430 Biomedical Engineering Design III | 2 |
| HSS Elective | 4 |
| Free Elective | 4 |
| BE Area Elective | 4 |
| | **Total Credits: 14** |

# Biomedical Engineering - Course Descriptions

**BE 100 Problem Solving in the Biological Sciences & Engineering 3R-3L-4C S**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
This course introduces students to computational tools for solving problems in biology and biomedical engineering. The primary thrust of the course is structured programming in MatLab. In addition, we will explore data description, the proper presentation of data, effective use of spreadsheet tools in data analysis, structured programming, and an introduction to bioinformatics and Working Model.

**BE 201 Biomedical Instrumentation & Measurements 3R-3L-4C W,S**
**Prerequisites:** BE 100 S, and ES 203 S
**Corequisites:** There are no corequisites for this course.
Discussion of measurement principles for biomedical engineering. Topics include op-amp circuit analysis, frequency analysis, fundamentals of digital gates and flip-flops, different types of biomedical sensors (temperature, force, pressure, velocity, etc), and basics of microcontrollers and embedded system.

**BE 310 Analysis of Physiological Systems I 3R-3L-4C W**
**Prerequisites:** BIO 120 W, and BIO 205 F
**Corequisites:** There are no corequisites for this course.
An analysis of neural, muscular, and endocrine physiology from a quantitative, systems-based approach.

**BE 317 Design for Biomedical Manufacturing 1R-0L-1C W**
**Prerequisites:** EM 104 F
**Corequisites:** There are no corequisites for this course.
This BE course is to be taken concurrently with ME317, Design for Manufacturing. This course presents manufacturing methods associated with biomedical products and situates Design for Manufacturing within the larger context of cradle to cradle design processes. Current biomedical industry processes and issues are emphasized. Taking ME317 and BE317 simultaneously, and passing both courses, will fulfill the requirement for a 4-credit BE biomechanics or biomaterials concentration elective.

**BE 320 Analysis of Physiological Systems II 3R-3L-4C S**
**Prerequisites:** BE 310 W
**Corequisites:** There are no corequisites for this course.
An analysis of cardiovascular, pulmonary, and renal physiology from a quantitative, systems-based approach.

**BE 331 Biomechanics 3R-0L-3C W**
**Prerequisites:** ES 201 W, and EM 204 F, S, and BE 201 W,S *or consent of instructor
**Corequisites:** BE 351 1R-3L-2C or BE 352 0R-3L-1C, and BE 361 3R-0L-3C W
This course introduces students to the various interdisciplinary fields in biomechanics - such as orthopaedic biomechanics, biofluid mechanics, soft tissue mechanics, and the biomechanics of human movement. Specific topics include: statics/dynamics of the human body, kinematics during activity; the analysis of forces and stresses/strains in biological structures under loading; constitutive models for biological materials (e.g. bone, cartilage, tendon/ligament); and the relationship between structure and function in tissues and organs. Non-majors interested in taking this course should see the instructor.

**BE 340 Biomedical Signal Processing 3R-3L-4C F**
**Prerequisites:** BE 201 W,S, ES 203 W,S
**Corequisites:** There are no corequisites for this course.
This course introduces the fundamental of biomedical signal processing strategies. Topics include data acquisition, A/D and D/A conversion, digital filter design, time-frequency analysis, and I/O interfaces. Multichannel data processing and high dimensional data analysis techniques are also covered. Lectures will be accompanied by data analysis assignments and projects using MATLAB, LabVIEW, and microcontrollers.

**BE 350 Biocontrol Systems 4R-0L-4C**
**Prerequisites:** ES 205 W,S
**Corequisites:** There are no corequisites for this course.
Biomedical engineers use science, engineering, and mathematics to understand and solve medical problems. The biomedical engineering program at Rose-Hulman produces engineers with the medical and biological expertise needed to solve health

care problems during careers in technical and health-related industries, as well as in government or industrial laboratories.

**BE 351 Biomedical Engineering Lab 1R-3L-2C**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** BE 331 3R-0L-3C W, and BE 361 3R-0L-3C W
This course emphasizes the fundamental concepts in biomechanics and biomaterials through hands-on experience with standard testing equipment. Laboratory projects will be assigned which will require the students to use basic instrumentation to determine and execute effective test methods. Non-majors interested in taking this course should see the instructor

**BE 352 Biomechanics Lab 0R-3L-1C**
**Prerequisites:** ES 201 W,S, EM 204 F, S, and BE 201 W,S or consent of instructor
**Corequisites:** BE 331 3R-0L-3C W
This course emphasizes the fundamental concepts in biomechanics through hands-on experience with standard testing equipment. Laboratory projects will be assigned which will require the students to use basic instrumentation to determine and execute effective test methods.

**BE 353 Biomaterials Lab 0R-3L-1C**
**Prerequisites:** ES 201 W,S, EM 204 F, S, and BE 201 W,S
**Corequisites:** BE 361 3R-0L-3C W
This course emphasizes the fundamental concepts in biomaterials through hands-on experience with standard testing equipment. Laboratory projects will be assigned which will require the students to use basic instrumentation to determine and execute effective test methods.

**BE 361 Biomaterials 3R-0L-3C W**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
Structure-property relationships for metallic, polymeric, and ceramic biomaterials. Study of the interactions of these materials with the body and factors affecting the selection and design of materials for medical implants and devices.

**BE 385 Quality Methods 4R-0L-4C S**
**Prerequisites:** MA 223 F,W,S or MA 382 F
**Corequisites:** There are no corequisites for this course.
Introduction to various aspects of statistical quality control and statistical process control to include the following topics: importance of variance reduction and probability concepts influencing product quality and reliability; development and application of control charts (Pcharts, NP-charts, C-charts, U-charts, individual's charts, moving range charts, X-bar and R as well as X-bar and S charts); process capability indices (their use and misuse); introduction to acceptance sampling. Other topics to be included as time allows: 6 sigma thinking, gauge reproducibility and repeatability, and total quality management with the philosophies of Deming, Juran, and Crosby. Review of fundamental prerequisite statistics will be included as necessary. Same as MA 385

**BE 390 Principles of Biomedical Engineering Design 1R-3L-2C S**
**Prerequisites:** BE 201 W,S
**Corequisites:** EM 204 4R-0L-4C F, S or consent of instructor

In this course, junior BE majors are introduced to the engineering design methodology as utilized in biomedical engineering. Students will learn engineering design through completion of a team design project with realistic constraints. This course serves as the entry point for the four-quarter sequence in which students undertake and complete their capstone design project.

**BE 400 Consulting Engineering Seminar 2R-0L-2C S**
**Prerequisites:** Junior class standing
**Corequisites:** There are no corequisites for this course.
Discusses problems in the field of consulting engineering; includes seminars presented by practicing consulting engineers and a suitable project to practice consulting skills. Cross-listed with CE420, ME420, CHE420, ECE466.

**BE 410 Biomedical Engineering Design I 3R-3L-4C F**
**Prerequisites:** BE 390 S
**Corequisites:** There are no corequisites for this course.
This course begins the year-long capstone design project and continues to investigate the process of design in biomedical engineering by having student teams initiate the design process for a relevant problem in biomedical engineering. This includes developing the design problem from a set of client needs, establishing specifications, planning the project, scheduling, efficient use of resources, examining ethics and safety in engineering design, and working within explicit (or implicit) constraints such as social, fiscal, manufacturing, etc. The course culminates with the presentation of the preliminary proposal for the capstone design project in biomedical engineering.

**BE 420 Biomedical Engineering Design II 2R-6L-4C W**
**Prerequisites:** BE 410 F
**Corequisites:** There are no corequisites for this course.
This course is a continuation of BE410 by having student teams implement their design plan. This will include development of a test plan, modifications to the design project as needed, and assessment of design performance relative to initial specifications. This course culminates in the submission of the final design document.

**BE 430 Biomedical Engineering Design III 1R-3L-2C S**
**Prerequisites:** BE 420 W
**Corequisites:** There are no corequisites for this course.
This course is a continuation of BE420 and introduces students to the skills necessary for professional practice in biomedical engineering including project management, review of critical design decisions, mentoring design teams, etc. The biomedical engineering design sequence culminates in the formal oral presentation of the capstone design report.

**BE 435 Biomedical Optics 3.5R-1.5L-4C**
**Prerequisites:** PH 113 S,F,W, and MA 223 F,W,S or Senior/Graduate standing or consent of instructor
**Corequisites:** There are no corequisites for this course.
Optical techniques for biomedical applications and health care; laser fundamentals, laser interaction with biological cells, organelles and nanostructures; laser diagnostics and therapy, laser surgery; microscopes; optics-based clinical applications; imaging and spectroscopy, biophotonics laboratories. For graduate credit, students must do additional project work on a topic selected by the instructor. Cross-listed with OE 435.

**BE 482 Bioengineering Statistics 4R-0L-4C**
**Prerequisites:** MA 223 F,W,S or MA 382 F and consent of instructor (cross listed with MA 482)
**Corequisites:** There are no corequisites for this course.
Hypothesis testing and confidence intervals for two means, two proportions, and two variances. Introduction to analysis of variance to include one factor and two factors (with interaction) designs. Presentation of simple linear and multiple linear regression modeling; development of analysis of contingency table to include logistic regression. Presentation of Log odds ratio as well as several non-parametric techniques of hypothesis testing and construction of non-parametric confidence intervals and correlation coefficients. Review of fundamental prerequisite statistics will be included as necessary.

**BE 491 Special Topics in Biomedical Engineering XR-0L-XC**
**Prerequisites:** Arranged prerequisite consent of instructor
**Corequisites:** There are no corequisites for this course.
Covers upper-level, undergraduate material of mutual interest to student and instructor which cannot be acquired in any other listed undergraduate BE course.

**BE 492 Directed Study in Biomedical Engineering XR-XL-XC**
**Prerequisites:** Arranged prerequisite consent of instructor
**Corequisites:** There are no corequisites for this course.
Covers biomedical engineering material of mutual interest to the student and instructor which cannot be experienced in any other listed BE course. A student may take between 1-4 credits in any given term.

**BE 499 Thesis Research 0R-6L-2C F,W,S**
**Prerequisites:** Junior or senior standing
**Corequisites:** There are no corequisites for this course.
Culmination of biomedical engineering thesis research in which a student writes and submits the senior thesis, following departmentally established guidelines, and gives an oral research presentation to at least three departmental faculty members, including the student's adviser. BE499 may not be used as a biomedical engineering area elective.

**BE 510 Biomedical Signal & Image Processing 3R-3L-4C W**
**Prerequisites:** BE 201 W,S JR, SR or Graduate standing or consent of instructor
**Corequisites:** There are no corequisites for this course.
Provides a comprehensive survey of signal and image processing tools for biomedical applications. Major biological signals (e.g., ECG), biomedical imaging techniques (e.g., MRI), their origin and importance, and the commonly used processing techniques with an emphasis on physiology and diagnostic applications will be discussed.

**BE 511 Analysis of Physiological Systems I 3R-3L-4C W**
**Prerequisites:** Junior, Senior, Graduate standing or consent of instructor
**Corequisites:** There are no corequisites for this course.
An analysis of neural, muscular, endocrine, and digestive physiology from a quantitative, systems-based approach. Both recent and classical journal articles will be discussed in class. Students enrolled in BE511 must complete a project not covered in BE310. Students may not receive credit for both BE511 and BE310.

**BE 512 Analysis of Physiological Systems II 3R-3L-4C S**
**Prerequisites:** Graduate standing or consent of instructor

**Corequisites:** There are no corequisites for this course.
An analysis of cardiovascular, pulmonary, and renal physiology from a quantitative, systems-based approach. Both recent and classical journal articles will be discussed in class. (Note: BE511 is not a prerequisite for BE512). Students enrolled in BE512 must complete a project not covered in BE320. Students may not receive credit for both BE512 and BE320.

**BE 516 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S**
**Prerequisites:** JR or SR standing
**Corequisites:** There are no corequisites for this course.
Properties of silicon wafers, wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS application: capacitive accelerometer, cantilever and pressure sensor. Students enrolled in BE516 must do project work on a topic selected by the instructor. Cross-listed with CHE 505, ECE 516, EP 510, and ME 516.

**BE 520 Introduction to Brain Machine Interfaces 3R-3L-4C S**
**Prerequisites:** BE 340 F or ECE 480 F
**Corequisites:** There are no corequisites for this course.
This course is an introduction to the basics of motor cortical functions related to voluntary and imagery movements, evoked response potentials, invasive vs. noninvasive electrode design considerations, quantitative EEG analysis techniques used in clinical settings, and the applications of brain-machine interfaces/brain-computer interfaces in the restoration of mobility, communication and motor function.

**BE 525 Biomedical Fluid Mechanics 3R-3L-4C**
**Prerequisites:** EM 301 S or CHE 301 F,S or ES 202 F,S or consent of instructor
**Corequisites:** There are no corequisites for this course.
Includes cardiovascular physiology, Poiseuille flow, pulsatile flow in rigid tubes, pulsatile flow in large arteries, blood flow in the microcirculation, flow and pressure measurement, prosthetic heart valves, prosthetic arteries, dimensional analysis and modeling.

**BE 531 Biomechanics II 3R-3L-4C**
**Prerequisites:** BE 331 W or consent of instructor
**Corequisites:** There are no corequisites for this course.
Covers statics, dynamics and deformable body mechanics of biological systems. Topics include joint anatomy, muscle physiology, biomechanics of distance running, physiological response to acceleration, mechanics of bone, joint biomechanics and selected topics from current literature. The course includes a lab covering the use of a motion analysis system and force platforms.

**BE 534 Soft Tissue Mechanics 3 R-3L-4C**
**Prerequisites:** EM 203 F, W, and EM 204 F, S or BE 331 W or consent of instructor
**Corequisites:** There are no corequisites for this course.
This course provides an introduction to the various approaches used in modelling soft tissues, with particular attention paid to those of the musculoskeletal system (e.g. ligament, tendon, cartilage). Particular emphasis will be placed on the theoretical and experimental consequences of the large deformation behavior of these tissues. This course will serve as a Biomechanics track elective.

**BE 535 Biomedical Optics 4R-0L-4C W**
**Prerequisites:** PH 113 S,F,W, MA 212 F,W,S and SR standing or GR standing
**Corequisites:** There are no corequisites for this course.
Optical techniques for biomedical applications and health care; imaging modalities; laser fundamentals, laser interaction with biological cells, organelles and nanostructures; laser diagnostics and therapy, laser surgery; microscopes; optics-based clinical applications; imaging and spectroscopy; biophotonics. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both OE 435 and OE 535. Cross-listed with OE 535.

**BE 539 Multiscale Biomechanics 3R-3L-4C**
**Prerequisites:** EM 203 F, W or EM 204 F, S, and BE 331 W or consent of instructor
**Corequisites:** There are no corequisites for this course.
This course provides a comprehensive exploration/overview of the multiple approaches available for the analysis of multiscale media, beginning from classical approaches in composite theory and moving on to various structure-function and homogenization models. Specific attention will be placed on the application of these ideas to heterogeneous and finite deformation biological tissues (e.g. bone, cartilage, ligament, vessels, etc.). This course will serve as a Biomechanics track elective.

**BE 541 Medical Imaging Systems 4R-0L-4C**
**Prerequisites:** BE 340 F* *Graduate standing; or with a grade of B or better; or consent of instructor.
**Corequisites:** There are no corequisites for this course.
Engineering principles of major imaging techniques/modalities for biomedical applications and health care including diagnostic x-ray, computed tomography, nuclear techniques, ultrasound, and magnetic resonance imaging. Topics include general characteristics of medical images; physical principles, signal processing to generate an image, and instrumentation of imaging modalities. Clinical applications of these technologies are also discussed. Same as ECE584.

**BE 543 Neuroprosthetics 3R-3L-4C**
**Prerequisites:** BE 310 W, and BE 201 W,S
**Corequisites:** There are no corequisites for this course.
This course takes a detailed look at the state of the art in Neuroprosthetics design and applications. Topics include electrode design, sensory prosthetics, functional electrical stimulation, deep brain stimulation and other contemporary research topics.

**BE 545 Orthopaedic Biomechanics 4R-0L-4C**
**Prerequisites:** EM 203 F, W or EM 204 F, S, and BE 331 W or consent of instructor
**Corequisites:** There are no corequisites for this course.
This course covers current topics in orthopaedic biomechanics including the application of solid mechanics principles to musculoskeletal activities, orthopaedic implants, and fracture fixation devices. Topics include joint loading; composition and mechanical behavior of orthopaedic tissues; design/analysis of artificial joints and fracture fixation prostheses; osteoporosis and osteoarthritis; and finite element modeling.

**BE 550 Research Methods in Biomechanics 3R-3L-4C W**
**Prerequisites:** BE 331 W or consent of instructor
**Corequisites:** There are no corequisites for this course.

Focuses on the wide range of research methods used in the field of biomechanics. Current literature will be reviewed to analyze the advantages and disadvantages of various research methodologies. Topics will vary based on student interests and background, but may include topics such as motion/force analysis, soft tissue and bone mechanics, joint biomechanics, analysis of joint replacements, and fracture fixation. Laboratory activities will reinforce the lecture topics and students will have the opportunity to investigate a biomechanics research topic in their area of interest.

**BE 555 Electrophysiology 3R-3L-4C**
**Prerequisites:** Junior, Senior, Graduate standing or consent of instructor
**Corequisites:** There are no corequisites for this course.
Introduces students to concepts of electrical activity in cells and organs of the body. Topics include: origin of membrane potential, membrane channels, synaptic signaling, recording techniques, gross electrical potentials (e.g. electrocardiogram, electroencephalogram, electromyogram, electroretinogram). Emphasis will be placed on how these signals are used to probe physiological function in the clinic and in the research laboratory.

**BE 560 Tissue-Biomaterial Interactions 4R-0L-4C**
**Prerequisites:** BE 361 W or consent of instructor
**Corequisites:** There are no corequisites for this course.
Addresses interactions between living cells/tissues and implant biomaterials, stressing the importance of molecular- and cellular-level phenomena in initiating and propagating clinically relevant tissue- and systemic- level results.

**BE 565 Experimental Methods in Tissue-Biomaterial Interactions 3R-3L-4C S**
**Prerequisites:** BE 361 W or consent of instructor
**Corequisites:** There are no corequisites for this course.
This course focuses on teaching students experimental methods used for investigations of tissue-biomaterial interactions. Topics include bioethics issues associated with experiments on cells, tissues, animals, and people; biosafety issues associated with cells/tissues from animals and humans; the design, critique, and statistical analysis of experiments. Students conduct hands-on investigations of cell-biomaterial interactions which require the use of common laboratory equipment, aseptic technique, mammalian cell culture, and current molecular methods to investigate cell viability, structure, and function.

**BE 570 Introduction to Tissue Engineering 4R-0L-4C**
**Prerequisites:** Junior, Senior, or Graduate standing or permission of instructor
**Corequisites:** There are no corequisites for this course.
This course provides a broad overview of the latest developments in the field of tissue engineering. Normal structure and function of tissues and organs such as bone, cartilage, nerve, skin, and liver are discussed. Methods of engineering these tissues, or encouraging healing or regeneration that would not otherwise occur, is the focus of the course. The course takes the format of a graduate seminar, with students taking an active role in presenting material to the class and leading discussions.

**BE 590 Thesis Research Credits as assigned F,W,S**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.

Credits as assigned: however, not more than 12 credits will be applied toward the requirements of an M.S. degree.

**BE 597 Selected Topics Credits as assigned F,W,S**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
Selected Topics for Graduate Students Credits as assigned. Maximum 4 credits per term.

**BE 621 Microbiology and Immunology 6C**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
Lectures, conferences and laboratories covering the immune response as a chemical and cellular Surveillance system; the consequences of activation of the immune system; and viruses, bacteria, fungi and protozoan and metazoan parasites as organisms and as agents of human disease. *Course is offered at the Terre Haute Center for Medical Education and may be taken for Rose-Hulman credit. To enroll in this course RHIT students need permission from the Chairman of the Department of Applied Biology and Biomedical Engineering.

**BE 623 Gross Anatomy 8C**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
An intensive study of the gross structure of the human body accomplished through maximum student participation in the dissection of the human cadaver. Lectures are interpretive and correlative. Audiovisual supplementation is provided. *Course is offered at the Terre Haute Center for Medical Education and may be taken for Rose-Hulman credit. To enroll in this course RHIT students need permission from the Chairman of the Department of Applied Biology and Biomedical Engineering.

**BE 624 Biochemistry 6C**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
The chemistry and reactions of constituents of living matter, including the carbohydrates, lipids, proteins, nucleic acids, vitamins, coenzymes and minerals; the chemistry and regulation of the reactions and processes of whole organisms; endocrinology; enzymology; nutrition; intermediary metabolism; and biochemical mechanisms in selected disease states. *Course is offered at the Terre Haute Center for Medical Education and may be taken for Rose-Hulman credit. To enroll in this course RHIT students need permission from the Chairman of the Department of Applied Biology and Biomedical Engineering

**BE 625 Physiology 8c**
**Prerequisites:** There are no prerequisites for this course.
**Corequisites:** There are no corequisites for this course.
The course in human physiology covers, in lectures and laboratories, such topics as circulation, respiration, digestion, endocrinology, heat metabolism, renal physiology, muscle physiology, and neurophysiology. *Course is offered at the Terre Haute Center for Medical Education and may be taken for Rose-Hulman credit. To enroll in this course RHIT students need permission from the Chairman of the Department of Applied Biology and Biomedical Engineering.

## BE CPT Curricular Practical Training 1R-0L-1C

**Prerequisites:** Consent of Department Head
**Corequisites:** There are no corequisites for this course.
Any international student with an F-1 Visa employed by any company in the form of an internship, co-op, or practicum must enroll in a CPT course. The CPT experience is to be complimentary training to the student's curriculum and should contribute substantially to his/her learning experience. Students must have an offer of employment from a company prior to registering for this course. The CPT must be approved by the Department Head, Director of International Student Services, and the student's adviser. Students are required to submit a report at the conclusion of the employment to his/her instructor to receive a grade for the CPT experience.

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