BIOMEDICAL ENGINEERING & MECHANICS

Our Website (http://www.beam.vt.edu)

In September 2018, the State Council of Higher Education for Virginia approved a new undergraduate degree program in biomedical engineering at Virginia Tech. Unlike other programs of its kind, which tend to concentrate instruction in biology and pre-medicine, Virginia Tech's program requires six core courses in fundamental engineering principles. This approach means students will gain a more comprehensive understanding of broader engineering practice and cross-disciplinary teambuilding, which are both perceived as an advantage in industry. The goal is that graduating engineers can be fully integrated into diverse health care teams in order to better respond to industry needs. Graduates will be primed for placement in such fields as telemedicine, health care, data analytics, personalized medicine, medical robotics, and biomedical device design and regulatory practices, among others.

Biomedical Engineering is a multidisciplinary field, using engineering principles and design concepts to advance healthcare treatment and find innovative solutions. We strive to prepare our graduates to succeed in advanced graduate or professional study, industry, and government. Within a few years after graduation, we expect our graduates to productively contribute to improving the human condition. In these activities, our alumni will:

- Develop and advance in their professional careers within industry, academia, and/or healthcare.
- Communicate and collaborate effectively across professional and disciplinary boundaries while exhibiting self-awareness of their role within the profession.
- Continually build knowledge and skills to successfully navigate the changing technology and healthcare challenges.
- Embody Ut Prosim through application of their engineering knowledge and experience in ethical service to local, national, and global communities

These program educational objectives are supported by a curriculum that seeks to have its graduates achieve the following student outcomes:

- An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- An ability to communicate effectively with a range of audiences.
- An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
- An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
- An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
- An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The mechanics foundation and a total of 21 technical elective credits give students the flexibility to tailor their undergraduate degree within subdisciplines of the vast field of biomedical engineering. Our faculty expertise range from biomechanics, biomaterials, biomedical imaging, cardiovascular engineering, neuroengineering, tissue engineering, translational cancer research, and more. Additionally, our curriculum emphasizes active learning strategies and "hands-on" learning experiences to promote engaged learning and development of communication, teamwork, critical thinking, and problem-solving skills. Many students will pursue internship and co-operative (co-op) experiences. There are also numerous opportunities to participate in design experiences throughout the curriculum, culminating in the senior capstone sequence that includes consideration of design controls and regulatory processes. Our Industry Partners Program (IPP) actively engages with companies to enrich the experiential learning opportunities for our students.

The department also offers a BME minor for students enrolled in other VT engineering programs. The graduate program in BME is a joint program between the Virginia Tech College of Engineering and the Wake Forest School of Medicine to form the Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences (SBES) program. The SBES program is a unique multidisciplinary joint program that bridges the biomedical sciences and BME towards translational, real-world applications, offering MS, PhD and DVM/PhD at the VT campus. The BEAM department also participates in the Accelerated Undergraduate / Graduate Degree Program, in which students meeting the requirements for the program apply for admission to the Graduate School during their junior year. This program allows students to enroll and "double-count" 12 credit hours of graduate coursework taken during their senior year of their undergraduate program at VT.

Overview - Engineering Science and Mechanics

Mechanics is a fundamental area of science and engineering. It is an exciting, expanding field of learning with its roots grounded in the laws of motion formulated by Newton and the principles governing the behavior of solids and fluids, branching out in modern times into interdisciplinary fields such as new engineering materials (adhesives, composites, polymers, light metals), biomechanics, transportation, wind engineering, and vehicular structures. Although the problems to which they are applied may change, the basic principles of mechanics remain current and relevant.

Engineering Science and Mechanics has a rich tradition for providing an interdisciplinary engineering education. We strive to prepare our graduates to succeed in advanced graduate or professional study, industry, and government. In these activities, our alumni will:

- Apply fundamentals of engineering mechanics and related areas of applied science to define, model, and solve a wide range of engineering problems.
- Apply fundamental mathematical and scientific principles, as well as computational and experimental techniques, to the demands of engineering and scientific practice.
- Function on and lead teams that engage in new areas of research and development in engineering, particularly those that cross the boundaries of traditional disciplines.

- Maintain high productivity and high ethical standards.
- Continually enhance their knowledge throughout their careers.
- Communicate effectively to a broad range of audiences.

These educational objectives are supported by a curriculum that provides its graduates with:

- An ability to identify, formulate, and solve complex engineering problems by applying fundamental principles of engineering, science, mechanics, and mathematics.
- An ability to apply knowledge of mechanics and engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- An ability to communicate effectively orally, graphically, and in writing with a range of audiences.
- An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
- An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
- An ability to develop and conduct appropriate computational analysis and experimentation in mechanics of materials, fluid mechanics, and dynamics; analyze and interpret data; and use engineering judgment to draw conclusions.
- An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
- An ability to recognize the importance of safety in all phases of engineering design and practice.

A total of 12 credit hours of technical electives and 6 credit hours of senior design give the student freedom to develop individually tailored programs of concentrated study. The department has emphasis areas in Biomechanics, Engineering physics, Fluid mechanics, Motions, or Solid mechanics. Exposure to the design process exists throughout the curriculum, culminating in a senior level capstone design course. The department offers official university degree options in Biomechanics and Engineering Physics.

The Cooperative Education Program is available to qualified candidates at undergraduate and graduate levels.

Undergraduate courses in engineering science and mechanics are taught on a service basis for all engineering curricula. A minor in engineering science & mechanics is available. The department offers graduate programs leading to M.S. (thesis and non-thesis option), M.Eng., and Ph.D. The department also participates in the Accelerated Undergraduate/Graduate Degree Program. Students with an interest in this program should contact the department for additional information.

The Engineering Science and Mechanics program at Virginia Tech is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (http://www.abet.org).

Degree Requirements

The graduation requirements in effect during the academic year of admission to Virginia Tech apply. Requirements for graduation are listed on checksheets. Students must satisfactorily complete all requirements and university obligations for degree completion. The university reserves the right to modify requirements in a degree program.

Please visit the University Registrar's website at https://www.registrar.vt.edu/graduation-multi-brief/checksheets.html for degree requirements.

- Biomedical Engineering Major (https://catalog.vt.edu/undergraduate/college-engineering/biomedical-engineering-mechanics/biomedical-engineering-bs/)

Department Head: Jennifer S. Wayne
Undergraduate BME Program Chair: Sara Arena
Undergraduate ESM Program Chair: James K. Lord
University Distinguished Professor: R.C. Batra
Adhesive and Sealant Science Professor: D.A. Dillard
Clifton C. Garvin Professor: R.C. Batra
Kevin P. Granata Faculty Fellow:
N. Waldo Harrison Professor: P. VandeVord
Samuel L. Herrick Professor:
Newport News-Tenneco Professor: T. Dingus
Reynolds Metal Professor: S. Case
L. Preston Wade Professor: R. Davalos
Harry C. Wyatt Professor: S.M. Duma
Professors: R.C. Batra, R. Davalos, R. De Vita, D.A. Dillard, T. Dingus, S.M. Duma, R. Gourdie, S.H. McKnight, A. Muelenaer, R.M. Queen, S.A. Ragab, T. Rikakis, J. Robertson, J.J. Socha, M.A. Stremler, P. VandeVord, and J.S. Wayne
Associate Professors: J. Chappell, Z. Doerzaph, A. Kemper, S. LaConte, Y.W. Lee, J. Munson, M. Perez, S. Poelzing, S. Rowson, A.E. Staples, C.D. Untaroiu, S. Verbridge, and V.M. Wang
Assistant Professors: C. Collins, J. Domann, and E. Vlaisavljevich
Collegiate Associate Professors: C. Arena and S. Arena
Collegiate Assistant Professors: J.K. Lord
Advanced Instructors: J. Gragg
Instructors: B. Aidi, C. Burgoyne, T.S. Chang, S. Davison, C. Galitz, N. Johnson, H. Pendar, and S. Tahmasian
Professors Emeritus: N.E. Dowling, J.C. Duke, J.W. Grant, M. Hajj, R.A. Heller, S.L. Hendricks, E. Henneke, R.M. Jones, L.G. Kraige, R. Kriz, D. Mook, D. Post, K.L. Reifsnider, M. Singh, and D.P. Telionis
Affiliate Faculty: Over 150 affiliate faculty (https://beam.vt.edu/people/faculty.html)
Academic and Career Advisor: A. Sandridge

Undergraduate Course Descriptions (BMES)

BMES 2004 - Concussion: Medical, Scientific and Societal Perspectives (3 credits)
Broad, multidisciplinary description of concussion as it relates to variety of fields including: medicine, psychology, biomedical research, technology, equipment design, ethics, and law. Concussion modeling, diagnosis and treatment. Testing and instrumentation. Research efforts, credibility and conflicts of interest. Ethical considerations in sports, medicine, and science. Legal implications.
Pathway Concept Area(s): 1A Discourse Advanced, 4 Reasoning in Natural Sci., 10 Ethical Reasoning
Instructional Contact Hours: (2 Lec, 3 Lab, 3 Crd)

BMES 2014 - Biomedical Engineering Professional Practice (1 credit)
Topics selected to foster professional development of the Biomedical Engineering (BME) student, including training for experiential learning opportunities, such as research, internships, co-ops, and design. Overview of BME specialization and research areas, career pathways, and preparation for interactions with industry, including the regulatory approval process associated with medical device development. Emphasis on teamwork, communication, employment opportunities, the development of a professional portfolio, ethical considerations, additive manufacturing, and engineering documentation using real-world examples and a design sprint/challenges.
Instructional Contact Hours: (1 Lec, 1 Crd)

BMES 2104 - Introduction to Biomedical Engineering (3 credits)
Identification, exploration, and evaluation of real-world, complex biomedical engineering problems including safety and ethical considerations. Emphasis on critical thinking, problem solving, group skills, and communication related to the field of biomedical engineering. Literature review and experimental design in biomedical engineering research.
Prerequisite(s): (ENGE 1216 or ENGE 1414) and (MATH 2214 or MATH 2214H)
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 2974 - Independent Study (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 2984 - Special Study (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 2994 - Undergraduate Research (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 3004 - Helmet Design: Biomechanics to Health & Social Disparities in Sports (3 credits)
Provides a multidisciplinary description of helmet design with applications to all sports. The biomechanical design parameters for helmets are presented in the broader context of health and social disparities. Through reasoning in the social sciences the class investigates how sex and gender roles have shaped sports and their individual helmet design disparities. A critical analysis of equity relative to race and healthcare is analyzed as it pertains to helmets and concussion treatments and outcomes. Demonstrate the interdisciplinary nature of helmet design and how ethical reasoning and social constructs have shaped the industry.
Pathway Concept Area(s): 3 Reasoning in Social Sciences, 7 Identity & Equity in U.S., 10 Ethical Reasoning
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3024 - BME Cell Engineering Laboratory and Design (2 credits)
Principles of cell engineering, experiment design, quantitative alyses. Laboratory notebook keeping, report writing and oral presentation in a team setting. Measurement of biological molecules such as DNA, RNA, and proteins. Assessment of animal cell viability, migration, mechanics and interactions with biomaterials. Identification of cell phenotypes.
Corequisite(s): BIOL 1105, BMES 2104
Instructional Contact Hours: (1 Lec, 3 Lab, 2 Crd)

BMES 3034 - Bioinstrumentation Laboratory and Design for Living Systems (2 credits)
Principles of biomedical sensors and their usage for experimental design. Collection of biological signals using analog signal amplifiication and filters, biopotentials, digital acquisition, digital filtering and processing. Analysis of physiological signals on living systems with focus on neural, cadiovascular, respiratory, and muscular systems using a group problem solving approach. Instrumental regulation and safety considerations.
Prerequisite(s): BMES 2104 and ECE 3054
Instructional Contact Hours: (1 Lec, 3 Lab, 2 Crd)

BMES 3114 - Needs Identification in Healthcare (3 credits)
Define open-ended problem statements related to healthcare. Immersive clinical observation and transdisciplinary medical technology innovation. Needs exploration and screening, disease state fundamentals, and evaluation of existing solutions. User-centered research planning, contextual inquiry, data documentation, stakeholder and market analysis, and regulatory and reimbursement basics.
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3124 - Introduction to Biomechanics (3 credits)
Basic principles of biomechanics. Basic musculoskeletal anatomy. Application of classical mechanics to biological systems. Emphasis placed on mechanical behavior (stress and strain), structural behavior, motion, and injury tolerance of the human body. Biomechanics of medical devices and implants. Advances in safety equipment used in automotive, military, and sports applications.
Prerequisite(s): BMES 2104 and ESM 2204 and ESM 2304
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3134 - Introduction to Biomedical Imaging (3 credits)
Introduction to major biomedical imaging modalities. Emphasis on X-rays, computerized tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), ultrasound, and optical imaging. Essential physics and imaging equations of the imaging system. Sources of noise and primary artifacts. Patient safety and clinical application.
Prerequisite(s): BMES 2104 and (MATH 2204 or MATH 2204H) and PHYS 2306
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3144 - Biomedical Devices (3 credits)
Design and uses of biomedical devices for diagnosis and therapy of human and animal diseases. Disease eiologies, progression, risk factors, and epidemiology. Tissue, organ, and systems dysfunction and failure and relevance to life stages (pediatric, adolescent, adult, aged). Useful characteristics of engineered materials for device fabrication, including biocompatibility. Gaps between medical needs and current medical devices.
Prerequisite(s): BMES 2104
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3154 - Biosignal Processing and Classification (3 credits)
Introduction to the concepts and applications of digital signal processing and machine learning on bioinstrumentation signals from physiologic systems. Emphasis on processing techniques for electrocardiogram (ECG), electromyography (EMG), and speech signals. Apply basic machine learning algorithms for diagnostic classification of biosignals.
Prerequisite(s): BMES 2104 and (CS 1044 or CS 1054 or CS 1064 or CS 1114 or ME 2004 or AOE 2074 or ESM 2074 or BSE 3144)
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3184 - Problem Solving in BME (3 credits)
Computational and analytical approaches to analyzing biological systems and solving biomedical engineering problems. Problem formulation and exploration of problem-solving techniques to validate computational solutions. Self-directed inquiry and team-based approaches that use reverse engineering, user-in-mind design, and engineering software tools.
Prerequisite(s): BMES 2104 and ESM 2074
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 3844 - Computational Neuroscience and Neural Engineering (3 credits)
Introduction to computational and systems neuroscience. Data analysis and signal processing techniques for neural data. Neural modeling to include mean field models, Hodgkin-Huxley models, integrate and fire models. Neural engineering and brain machine interface (BMI) applications.
Prerequisite(s): MATH 1226
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: NEUR 3844

BMES 3900 - Bridge Experience (0 credits)
Application of academic knowledge and skills to in a work-based experience aligned with post-graduation goals using research-based learning processes. Satisfactory completion of work-based experience often in the form of internship, undergraduate research, co-op, or study abroad; self-evaluation; reflection; and showcase of learning. Pre: Departmental approval of 3900 plan.
Instructional Contact Hours: (0 Crd)

BMES 3984 - Special Study (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 4015 - BME Senior Design and Project (3 credits)
4015: Apply biomedical engineering principles to the design of an approved project using the team approach. Develop design and communication skills. Integrate ethical, global and social issues in engineering. 4016: Apply biomedical engineering principles to develop solutions for an approved design project using a team approach. Complete a project resulting in prototype medical device, circuit, or system. Refine design and communication. Integrate ethical, global, environmental and social issues in engineering. Pre: Senior standing for 4015.
Prerequisite(s): BMES 3034 and BMES 3184
Pathway Concept Area(s): 1A Discourse Advanced, 10 Ethical Reasoning
Instructional Contact Hours: (2 Lec, 3 Lab, 3 Crd)

BMES 4016 - BME Senior Design and Project (3 credits)
4015: Apply biomedical engineering principles to the design of an approved project using the team approach. Develop design and communication skills. Integrate ethical, global and social issues in engineering. 4016: Apply biomedical engineering principles to develop solutions for an approved design project using a team approach. Complete a project resulting in prototype medical device, circuit, or system. Refine design and communication. Integrate ethical, global, environmental and social issues in engineering. Pre: Senior standing for 4015.
Prerequisite(s): BMES 4015
Pathway Concept Area(s): 1A Discourse Advanced, 10 Ethical Reasoning
Instructional Contact Hours: (2 Lec, 3 Lab, 3 Crd)

BMES 4034 - Wearable Bioinstrumentation (3 credits)
Exploration of science, engineering, and data analytics principles behind wearable technology. Non-invasive measurement and assessment of human physiology and behavior. Data processing and analysis of non-invasive biosignals. Data privacy, protection, and ethical considerations of wearable devices.
Prerequisite(s): BMES 2104 and (CS 1044 or CS 1054 or CS 1064 or CS 1114 or ME 2004 or AOE 2074 or ESM 2074 or BSE 3144) and (STAT 3615 or STAT 3704 or STAT 4604) and (ECE 2054 or ECE 3054)
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 4064 - Introduction to Medical Physiology (3 credits)
An introductory to the principles of medical physiology. Designed primarily for (but not limited to), undergraduate students minoring in biomedical engineering, and other related engineering and physical sciences majors with little or no formal background in biological sciences. Basic principles and concepts of human physiology. Special emphasis on the interactions of human systems biology in their entirety rather than individual genes and pathways. Pre: Junior standing or permission of instructor.
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 4134 - Global, Societal, and Ethical Considerations in Biomedical Engineering (3 credits)
Overview of contemporary technological advances to improving human health. Comparison of healthcare systems, problems, and existing solutions throughout the developed and developing world. Consideration of legal and ethical issues associated with developing and implementing new medical technologies. Recognition and definition of gaps between medical needs and current methods and therapies between developed and developing countries. Conceptually design a novel technology.
Prerequisite(s): BMES 2104
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 4154 - Commercialization of BME Res (3 credits)
Commercialization process applied to translational research. Regulatory aspects of biomedical engineering products and technologies (e.g. devices, diagnostics, drugs, biologics). Intellectual property, technology transfer processes, clinical trial design, commercialization of university research, modeling of development costs (e.g. cash flow and revenue projections). Small business startup approaches.
Prerequisite(s): BMES 2104
Instructional Contact Hours: (3 Lec, 3 Crd)

BMES 4234 - Mechanics of Biological Systems (3 credits)
Anatomy and physiology of biological systems such as cells, tissues, and organs. Experimental techniques for determining the mechanical behavior of biological systems. Simplified mechanics-based mathematical models of biological systems. Specific biological systems include cells, tissues, and organs of the musculoskeletal, cardiovascular, integumentary system, and reproductive systems.
Prerequisite(s): ESM 2204 and MATH 2214 and MATH 2114
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: ESM 4234

BMES 4614 - Probability-Based Modeling, Analysis, and Assessment (3 credits)
Uncertainty analysis of engineering data, parameters estimation, probability concepts, random variables, functions of random variables, probability-based performance functions and failure modes, risk and reliability functions, probability of failure and safety index, random sequences and stochastic processes, correlation functions and spectral densities, return period and extreme values, failure rates, performance monitoring and service life prediction.
Prerequisite(s): ESM 2204
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: ESM 4614

BMES 4974 - Independent Study (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 4984 - Special Study (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 4984A - Special Study (1-19 credits)
Pathway Concept Area(s): 1A Discourse Advanced
Instructional Contact Hours: Variable credit course

BMES 4994 - Undergraduate Research (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 4994H - Undergraduate Research (1-19 credits)
Instructional Contact Hours: Variable credit course

BMES 29844 - Special Study (1-19 credits)
Instructional Contact Hours: Variable credit course

Undergraduate Course Descriptions (ESM)

ESM 2014 - Professnl Dvlpmnt Seminar ESM (1 credit)
Topics designed to foster the professional development of the ESM student. ESM program objectives and outcomes. Professional careers, employment opportunities, expectations to the profession. Technical concentration within the ESM major. Ethical decision-making, safe and life-long learning.
Instructional Contact Hours: (1 Lec, 1 Crd)

ESM 2074 - Computational Methods (2 credits)
Solving engineering problems using numerical methods and software, truncation and round-off error, root finding, linear and polynomial regression, interpolation, splines, numerical integration, numerical differentiation, solution of linear simultaneous equations. A grade of C- or better required in the prerequisite.
Prerequisite(s): ENGE 1216 or ENGE 1434 or ENGE 1414
Instructional Contact Hours: (1.5 Lec, 1.5 Lab, 2 Crd)
Course Crosslist: AOE 2074

ESM 2104 - Statics (3 credits)
Vector mechanics of forces and moments, free-body diagrams, couples, resultants, equilibrium of particles and rigid bodies in two and three dimensions, forces in trusses, frames, and machines, centroids, centers of mass, distributed forces, internal shear forces and bending moments in beams, shear and moment diagrams, friction, belt friction, area of moments of inertia, parallel axis theorem. Course requirements may be satisfied by taking MATH prerequisite prior to or concurrent with course.
Prerequisite(s): MATH 1226
Corequisite(s): MATH 2204 or MATH 2204H or MATH 2406H
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 2114 - Statics & Structures (3 credits)
Vector algebra of forces, movements, couples and resultants. Free-body diagrams. Equilibrium of particles and rigid bodies in two and three dimensions. Friction. Forces in trusses and frames. Centroids, centers of mass, area moments of inertia. Internal axial forces, shear forces, and bending moments in bars in beams. Shear and moment diagrams. Stress and strain in bars in beams.
Corequisite(s): MATH 2204 or MATH 2204H or MATH 2406H.
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 2204 - Mechanics of Deformable Bodies (3 credits)
Concepts of stress, strain, and deformation. Factor of safety. Stress-strain relationships and material properties. Stress concentrations. Area moments of inertia. Axially loaded members, torsionally loaded members, bending of beams. Shear and moment diagrams. Stresses due to combined loading. Thin-walled pressure vessels. Transformation of stress including Mohrs circle. Beam deflections and buckling stability.
Prerequisite(s): (ESM 2104 or ESM 2114) and (MATH 2204 or MATH 2204H or MATH 2406H)
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 2214 - Statics and Mechanics of Materials (3 credits)
Forces, moment, resultants, and equilibrium. Stress, strain, and stress-strain relations. Centroids and distributed loads. Analysis of axially loaded bars and beams. Principal stresses and Mohrs circle, combined loading. Pressure vessels and buckling of columns. Partially duplicates 2104 and 2204. Must be CHE major.
Corequisite(s): MATH 2224
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 2304 - Dynamics (3 credits)
Vector treatment of the kinematics and kinetics of particles and rigid bodies, Newtons laws, work and energy, impulse and momentum, impact, mass moments of inertia, rotating axes.
Prerequisite(s): (ESM 2104 or ESM 2114) and (MATH 2204 or MATH 2204H or MATH 2406H)
Corequisite(s): MATH 2214
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 2974 - Independent Study (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 2984 - Special Study (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 2994 - Undergraduate Research (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 2994H - Undergraduate Research (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 3024 - Introduction to Fluid Mechanics (3 credits)
Fluid properties. Hydrostatics. Derivation and application of the mass, momentum, and energy conservation equations. Dimensional analysis and similitude. Introduction to analyses of pipe flows and piping systems, open channel flows, and fluid forces on solid bodies.
Prerequisite(s): PHYS 2305 and ESM 2104
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 3034 - Fluid Mechanics Laboratory (1 credit)
Introduction to experimental fluid mechanics. Dimensional analysis. Experiments on fluid properties, flow measurements, and flow visualization, including manometry, determining hydrostatic forces on submerged surfaces, applications of the impulse-momentum principle, velocity measurements, measuring drag forces, quantifying flow in channels. Modern data acquisition techniques.
Prerequisite(s): ESM 2304 and ECE 3054
Corequisite(s): ESM 3234
Instructional Contact Hours: (3 Lab, 1 Crd)

ESM 3054 - Mechanical Behavior of Materials (3 credits)
Mechanical properties and behavior of solid materials subjected to static, cyclic, and sustained loads resulting from stress states, environments, and stress histories typical of service conditions; multiaxial failure criteria; behavior of cracked bodies; fatigue of materials; creep of materials; microstructure-property relationships; design methodologies.
Prerequisite(s): ESM 2204 and (MSE 2034 or MSE 2044 or MSE 3094 or AOE 3094 or CEE 3684)
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: MSE 3054

ESM 3064 - Mechanical Behavior of Materials Laboratory (1 credit)
Laboratory experiments on behavior and mechanical properties of solid materials. Tension, compression, bending, hardness, nano-indentation, and impact tests; behavior of cracked bodies; fatigue and crack growth tests; creep deformation; microstructure-property relationships; laboratory equipment, instrumentation, and computers.
Prerequisite(s): ESM 2204
Corequisite(s): ESM 3054
Instructional Contact Hours: (3 Lab, 1 Crd)
Course Crosslist: MSE 3064

ESM 3114 - Problem Definition and Scoping in Engineering Design (1 credit)
Define open-ended engineering design projects, identify relevant broad social, global, economic, cultural and technical needs and constraints, determine ways in which technical skills contribute to addressing complex engineering design challenges. Identify a capstone project for ESM 4015-4016. Pre-requisite: Junior standing in ESM.
Prerequisite(s): ESM 2014
Instructional Contact Hours: (2 Lab, 1 Crd)

ESM 3124 - Dynamics II- Analytical and 3-D Motion (3 credits)
Review of Newtons Laws, introduction to Lagranges equations, rotating coordinate systems, particle dynamics, systems of particles, rigid-body dynamics, small amplitude oscillations, holonomic and nonholonomic constraints, phase space and energy methods.
Prerequisite(s): ESM 2304 and (MATH 2214 or MATH 2214H or MATH 2406H) and (MATH 2204 or MATH 2204H or MATH 2406H)
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 3134 - Dynamics III - Vibration and Control (3 credits)
Single-degree-of-freedom vibration, n-degree-of-freedom systems, continuous systems, nonlinear systems, system stability, introduction to the feedback control of dynamic systems.
Prerequisite(s): ESM 3124 and MATH 4564
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 3154 - Solid Mechanics (3 credits)
Introduction to tensors, mathematical description of deformations and internal forces in solids, equations of equilibrium, principle of virtual work, linear elastic material behavior, solution for linear elastic problems including axially and spherically symmetric solutions, stress function solutions to plane stress and strain problems, solutions to 3-D problems, energy methods.
Prerequisite(s): ESM 2204 and (MATH 2214 or MATH 2214H)
Corequisite(s): MATH 4574
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 3234 - Fluid Mechanics I-Control Volume Analysis (3 credits)
Fluid statics. Control volume approach to flow analysis: conservation laws, pipe flows, compressible flow, open channel flow.
Prerequisite(s): ESM 2304 and PHYS 2306
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 3334 - Fluid Mechanics II-Differential Analysis (3 credits)
Introduction to continuum mechanics for fluid systems. Fluid kinematics. Differential approach to flow analysis: conservation equations, exact solutions, potential flows, viscous flows.
Prerequisite(s): ESM 3234 or ME 3404
Corequisite(s): MATH 4574
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 3444 - Mechanics Laboratory (2 credits)
Concepts in instrumentation, data acquisition, and signal analysis. Measurements of mechanics quantities and phenomena associated with solid, fluid, and dynamical systems. Open-ended problem definition and approach formulation. Application and synthesis of engineering mechanics fundamentals to the modeling and solution of open-ended problems. Group-working skills and effective written and oral communication.
Prerequisite(s): ESM 3234 and ESM 3034 and ESM 3054 and ESM 3064 and ESM 3124 and ECE 3054
Corequisite(s): ESM 3134, ESM 3154, ESM 3334
Instructional Contact Hours: (1 Lec, 3 Lab, 2 Crd)

ESM 3704 - Basic Principles of Structures (3 credits)
Static equilibrium of forces and moments, concurrent and nonconcurrent force systems, center of gravity, concentrated and distributed loads. Solution of trusses. Stress and strain, elastic behavior of materials, cables and arches, shear, bending, and deformation in beams, indeterminate structures. Not available to students in engineering.
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4014 - Applied Fluid Mechanics (3 credits)
Analysis of flow over practical configurations, panel methods, Reynolds-averaged Navier-Stokes equations, turbulent boundary layers, flow separation and three-dimensional effects. Unsteady flows, fluid-structure interactions.
Prerequisite(s): ESM 2074 and ESM 3016
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4015 - Creative Design and Project (3 credits)
Capstone senior design project. Synthesis and application of fundamental principles of engineering science and mechanics to an open-ended problem. 4015: Project proposal, including objectives, goals and plans for project. Identification of needs, constraints, and engineering standards with consideration of public health, safety, and welfare, including ethical, global, cultural, societal, environmental, and economic contexts. Proof-of-concept prototyping. Teamwork and communication of design and project progress. 4016: Design specifications with consideration of public health, safety, and welfare, as well as ethical, global, cultural, social, environmental, and economic factors where applicable. Design, test, and analysis of functional prototype. Teamwork and communication of design and project progress. Pre: Senior standing.
Prerequisite(s): ESM 3114
Pathway Concept Area(s): 1A Discourse Advanced, 10 Ethical Reasoning
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4016 - Creative Design and Project (3 credits)
Capstone senior design project. Synthesis and application of fundamental principles of engineering science and mechanics to an open-ended problem. 4015: Project proposal, including objectives, goals and plans for project. Identification of needs, constraints, and engineering standards with consideration of public health, safety, and welfare, including ethical, global, cultural, societal, environmental, and economic contexts. Proof-of-concept prototyping. Teamwork and communication of design and project progress. 4016: Design specifications with consideration of public health, safety, and welfare, as well as ethical, global, cultural, social, environmental, and economic factors where applicable. Design, test, and analysis of functional prototype. Teamwork and communication of design and project progress. Pre: Senior standing.
Prerequisite(s): ESM 4015
Pathway Concept Area(s): 1A Discourse Advanced, 10 Ethical Reasoning
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4024 - Advanced Mechanical Behavior of Materials (3 credits)
Mechanical behavior of materials, emphasizing solid mechanics aspects and methods for predicting strength and life of engineering components. Plasticity, failure criteria, fracture mechanics, crack growth, strain-based fatigue, and creep. Microstructure-property relationships, and laboratory demonstrations.
Prerequisite(s): ESM 3054 or MSE 3054
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4044 - Mechanics of Composite Materials (3 credits)
Introduction to the deformation, stress, and strength analysis of continuous-fiber-polymer-matrix laminated composites. Fabrication, micromechanics of stiffness and expansional coefficients, classical lamination theory (CLT). Environmentally induced stresses. Computerized implementation and design.
Prerequisite(s): ESM 2204 or AOE 2024
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: CEE 4610

ESM 4084 - Engineering Design Optimization (3 credits)
Use of mathematical programming methods for engineering design optimization including linear programming, penalty function methods, and gradient projection methods. Applications to minimum weight design, open-loop optimum control, machine design, and appropriate design problems from other engineering disciplines.
Prerequisite(s): MATH 2224 or MATH 2204 or MATH 2204H
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: AOE 4084

ESM 4105 - Engineering Analysis of Physiologic Systems (3 credits)
Engineering analysis of human physiology. Physiologic systems are treated as engineering systems with emphasis input-output considerations, system interrelationships and engineering analogs. 4105 - Mass and electrolyte transfer, nerves, muscles, renal system. 4106 - cardiovascular mechanics, respiratory system, digestive systems, senses.
Prerequisite(s): ESM 2304 and MATH 2214
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4106 - Engineering Analysis of Physiologic Systems (3 credits)
Engineering analysis of human physiology. Physiologic systems are treated as engineering systems with emphasis input-output considerations, system interrelationships and engineering analogs. 4105 - Mass and electrolyte transfer, nerves, muscles, renal system. 4106 - cardiovascular mechanics, respiratory system, digestive systems, senses.
Corequisite(s): ME 3105
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4114 - Nonlinear Dynamics and Chaos (3 credits)
Motion of systems governed by differential equations: stability, geometry, phase planes, bifurcations, Poincare sections, point attractors, limit cycles, chaos and strange attractors, Lyapunov exponents. Forced, nonlinear oscillations: jump phenomena, harmonic resonances, Hopf bifurcations, averaging and multiple-scales analysis. Systems governed by discrete maps: return maps, cobweb plots, period-multiplying bifurcations, intermittency, delay coordinates, fractal dimensions.
Prerequisite(s): (ESM 2304 or PHYS 2504) and (MATH 2214 or MATH 2214H)
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: AOE 4514

ESM 4154 - Nondestructive Evaluation of Materials (3 credits)
Concepts and methods of nondestructive evaluation of materials. Discussion of techniques and mathematical bases for methods involving mechanical, optical, thermal, and electromagnetic phenomena; design for inspectability; technique selection criteria; information processing and handling; materials response measurement and modeling; signal analysis.
Prerequisite(s): ESM 3054 and (PHYS 2206 or PHYS 2306)
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4194 - Sustainable Energy Solutions for a Global Society (3 credits)
Addresses energy metrics, global and US energy supply and demand, transitional energy sources (natural gas, petroleum, coal, nuclear), sustainable/renewable source (solar, geothermal, hydro, tidal, wind, biofuels), and methods for increasing efficiencies (energy storage, batteries, green building, conservation). Options for transportation, electricity, lighting and heating needs of industry, agriculture, community, and citizens. Production, transmission, storage, and disposal issues considered in the context of global political, economic, and environmental impacts. Senior Standing in major may be substituted for pre-requisite ENGL 3764.
Prerequisite(s): (CHEM 1035 or CHEM 1055) and PHYS 2306
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: ME 4194

ESM 4204 - Musculoskeletal Biomechanics (3 credits)
Skeletal anatomy and mechanics. Muscle anatomy and mechanics. Theory and application of electromyography. Motion and force measuring equipment and techniques. Inverse dynamics modeling of the human body. Current topics in musculoskeletal biomechanics research.
Prerequisite(s): ESM 2304 and (CS 1044 or CS 1064 or CS 1114 or AOE 2074 or ESM 2074 or ME 2004)
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4224 - Biodynamics and Control (3 credits)
Study of human movement dynamics and neuromuscular control of multi-degree-of-freedom systems. Computational simulation of forward-dynamics and state-space linear control of human movement to investigate functional performance and neuromuscular pathology.
Prerequisite(s): ESM 2304
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4234 - Mechanics of Biological Systems (3 credits)
Anatomy and physiology of biological systems such as cells, tissues, and organs. Experimental techniques for determining the mechanical behavior of biological systems. Simplified mechanics-based mathematical models of biological systems. Specific biological systems include cells, tissues, and organs of the musculoskeletal, cardiovascular, integumentary system, and reproductive systems.
Prerequisite(s): ESM 2204 and MATH 2214 and MATH 2114
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: BMES 4234

ESM 4245 - Mechanics of Animal Locomotion (3 credits)
4245: Mechanical and biological principles of terrestrial animal locomotion, including walking, running, jumping, climbing, burrowing, and crawling. Terrestrial locomotion- based bio-inspired design. 4246: Mechanical and biological principles of animal locomotion in fluids, including active and gliding flight, swimming, jetting, and running on water. Engineering design inspired by fluid based biological locomotion.
Prerequisite(s): ESM 3054
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4246 - Mechanics of Animal Locomotion (3 credits)
Mechanical and biological principles of of animal locomotion in fluids, including active and gliding flight, swimming, jetting, and running on water. Enginneering desgn inspired by fluid-based biological locomotion.
Prerequisite(s): ESM 3234 or ME 3414
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4304 - Hemodynamics (3 credits)
Study of the human cardiovascular system and blood flow. Anatomy and physiology of the human heart, vascular system, and its organization. Blood physiology and rheology. Non-Newtonian blood flow models. Steady and pulsatile blood flow in rigid and elastic arteries. Pressure waves in elastic arteries. Three-dimensional blood flow in the aortic arch and flow around heart valves.
Prerequisite(s): ESM 3334 or ME 3404 or ME 3414
Instructional Contact Hours: (3 Lec, 3 Crd)

ESM 4404 - Fundamentals of Professional Engineering (2 credits)
A refresher of basic principles and problem solving techniques involving twelve subject areas most common to all engineering curricula. The topics include those tested by the National Council of Engineering Examiners on the EIT (Engineer in Training) examination, the first requirement, in all fifty states, toward P.E. (Professional Engineer) licensing. Duplicates material of other engineering courses and impracticable for non-engineers, hence not usable for credit toward any degree. Pre: Junior and senior standing in Engineering or in Building Construction or Graduate students in Engineering.
Instructional Contact Hours: (2 Lec, 2 Crd)

ESM 4444 - Stability of Structures (3 credits)
Introduction to the methods of static structural stability analysis and their applications. Buckling of columns and frames. Energy method and approximate solutions. Elastic and inelastic behavior. Torsional and lateral buckling. Use of stability as a structural design criterion.
Prerequisite(s): AOE 3024 or CEE 3404
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: AOE 4054

ESM 4614 - Probability-Based Modeling, Analysis, and Assessment (3 credits)
Uncertainty analysis of engineering data, parameters estimation, probability concepts, random variables, functions of random variables, probability-based performance functions and failure modes, risk and reliability functions, probability of failure and safety index, random sequences and stochastic processes, correlation functions and spectral densities, return period and extreme values, failure rates, performance monitoring and service life prediction.
Prerequisite(s): ESM 2204
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: BMES 4614

ESM 4734 - An Introduction to the Finite Element Method (3 credits)
The finite element method is introduced as a numerical method of solving the ordinary and partial differential equations arising in fluid flow, heat transfer, and solid and structural mechanics. The classes of problems considered include those described by the second-order and fourth-order ordinary differential equations and second-order partial differential equations. Both theory and applications of the method to problems in various fields of engineering and applied sciences will be studied.
Prerequisite(s): (CS 3414 or MATH 3414 or AOE 2074 or ESM 2074) and (MATH 2224 or MATH 2224H or MATH 2204 or MATH 2204H)
Instructional Contact Hours: (3 Lec, 3 Crd)
Course Crosslist: AOE 4024

ESM 4904 - Project and Report (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 4974 - Independent Study (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 4974H - Independent Study (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 4984 - Special Study (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 4994 - Undergraduate Research (1-19 credits)
Instructional Contact Hours: Variable credit course

ESM 4994H - Undergraduate Research (1-19 credits)
Honors
Instructional Contact Hours: Variable credit course