Biology and Biotechnology

BB 501. Seminar
1 credit per semester

BB 502. Techniques in Electron Microscopy
This course presents the theory of operation, applications and use of scanning and transmission electron microscopy in biology. Recent original articles from the biological literature illustrate the applications of these techniques to research. Students prepare specimens for both kinds of electron microscopes and employ the standard preparative techniques including fixation, dehydration, staining, critical point drying, vacuum evaporation, embedding and sectioning. Associated photographic methods are also introduced.

BB 505. Fermentation Biology
Material in this course focuses on biological (especially microbiological) systems by which materials and energy can be interconverted (e.g., waste products into useful chemicals or fuels). The processes are dealt with at the physiological and the system level, with emphasis on the means by which useful conversions can be harnessed in a biologically intelligent way. The laboratory focuses on measurements of microbial physiology and on bench-scale process design.

BB 507. Cell Culture
The use of cultured animal cell systems for research and production will be explored. Concepts including media design, the effects of extracellular matrices, scaling up of cell cultures, and biochemical and morphologic assessment of cell function will be discussed as a basis for reading from the literature.

BB 509. Scale Up of Bioprocessing
Strategies for optimization of bioprocesses for scale-up applications will be explored. In addition to the theory of scaling up unit operations in bioprocessing, students will scale up a bench-scale bioprocess (5 liters), including fermentation and downstream processing to 55 liters. Specific topics include the effects of scaling up on: mass transfer and bioreactor design, harvesting techniques including tangential flow filtration and centrifugation, and chromatography (open column and HPLC). (Prerequisites: BB 4050/505 and BB 4060/560 as a working knowledge of the bench-scale processes will be assumed. Otherwise, instructor permission is required.)

BB 510. Advanced Microbial Genetics
This course entails a study of modern molecular genetics as revealed by studies of microbial systems. This course covers detailed structure/function relationships in nucleic acids and proteins; molecular mechanisms of DNA replication and expression; mutagenesis, recombination, transposition, transformation, conjugation and repair; and molecular biology of plasmids and phages.

BB 542. Ecological Simulation Modeling
This course will cover computer simulation modeling of populations, bioenergetics, behavior of individuals and ecosystem dynamics. Modeling techniques covered will range from simple linear models of populations and interactions between ecosystem components to individual-based models of populations in complex environments. Students successfully completing the course should be capable of understanding models used in today’s study of populations and ecosystems, and of developing original models. Knowledge of a programming language is assumed.

BB 544. Bioinformatics
This course will focus on the field of bioinformatics. After providing an overview of biological data such as DNA and protein sequences and genetic markers, and providing a summary of population genetics concepts, the course will cover various methods of computational genetic analysis. Students will learn about DNA and protein sequence analysis, gene mapping, evolutionary analysis, molecular biology databases, analysis of expression data and microarray analysis.

BB 545. Advanced Cell Biology
Selected readings from the scientific literature are used to illustrate milestones of cell biology, state-of-the-art cellular lab techniques and experimental design. The course emphasizes the various approaches to study cell structure, function and the mechanisms by which cells reproduce, develop and interact.

BB 549. Molecular Biology
Course material focuses on the synthesis of biologically important macromolecules. Selected readings from the scientific literature are used to illustrate the milestones of molecular biology and the development of techniques and experiments. Studies of protein synthesis and ribosome structure lead into a discussion of RNA and finally DNA synthesis, with the chemistry of DNA molecules receiving significant attention.

BB 550. Recombinant DNA Biochemistry
This course presents the theory associated with recombinant DNA methodology. Topics covered include: enzymology of DNA manipulation, construction and isolation of recombinants, plasmid and bacteriophage vectors, and structural analysis of cloned DNA.

BB 560. Methods of Protein Purification and Downstream Processing
This course provides a detailed hands-on survey of state-of-the-art methods employed by the biotechnology industry for the purification of products, proteins in particular, from fermentation processes. Focus is on methods which offer the best potential for scale-up. Included are the theory of the design as well as the operation of these methods both at the laboratory scale as well as scaled up. It is intended for biology, biotechnology, chemical engineering and biochemistry students. (Prerequisite: A knowledge of basic biochemistry is assumed.)

BB 565. Virology
This advanced level course uses a seminar format based on research articles to discuss current topics related to the molecular/cell biology of viral structure, function, and evolution. Particular emphasis is placed on pathological mechanisms of various human disorders, especially emerging disease, and the use of viruses in research.

BB 570. Special Topics
Specially subject courses are offered based on the expertise of the department faculty. Content and format varies to suit the interest and needs of the faculty and students. This course may be repeated for different topics covered.

BE 598. Directed Research

BE 699. Ph.D. Dissertation

Biomedical Engineering

BE 523. Biomedical Instrumentation
Origins and characteristics of bioelectric signals, recording electrodes, amplifiers, chemical pressure and flow transducers, noninvasive monitoring techniques and electrical safety. (Prerequisites: Circuits and electronics, control engineering or equivalent.)

BE 525. Microprocessor-Based Biomedical Instrumentation
This course provides hands-on laboratory experience with common biomedical transducers and instrumentation used in physiological ...
BE/ME 550. Tissue Engineering
This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented. (Prerequisites: A first course in biomaterials equivalent to BE/ME 4814 and a basic understanding of cell biology and physiology. Admission of graduate students without the necessary biological science background requires the permission of the instructor. Admission of undergraduate students requires the permission of the instructor.)

BE/ME 551. Biological Signal Processing
Basic principles of digital processing of biological signals and its application on PC-compatible computers. The theoretical fundamentals and practical examples of signal processing. The major emphasis is on linking the theoretical knowledge with easy-to-comprehend, practical examples. (Prerequisite: Basic signal analysis.)

BE/ME 552. Tissue Mechanics
This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties, and design of medical devices and prostheses. (Prerequisite: A first course in biomechanics equivalent to BE/ME 4504.)

BE/ME 554. Composites with Biomedical and Materials Applications
Introduction to fiber/particulate-reinforced, engineered and biologic materials. This course focuses on the elastic description and application of materials that are made up of a combination of submaterials, i.e., composites. Emphasis will be placed on the development of constitutive equations that define the mechanical behavior of a number of applications, including: biomaterial, tissue and materials science. (Prerequisites: Understanding of stress analysis and basic continuum mechanics)

BE/ME 558. Biofluids and Biotransport
The emphasis of this course is on modeling fluid flow within the cardiovascular and pulmonary systems, and the transport processes that take place in these systems. Applications include artificial heart valves, atherosclerosis, arterial impedance matching, clinical diagnosis, respiration, aerosol and particle deposition. Depending upon class interest, additional topics may include reproductive fluids, animal propulsion in air and water, and viscoelastic testing. (Prerequisite: A first course in biofluids equivalent to BE/ME 4606.)

BE 560. Physiology for Engineers
An introduction to fundamental principles in cell biology and physiology designed to provide the necessary background for advanced work in biomedical engineering. Quantitative methods of engineering and the physical sciences are stressed. Topics include cell biology, DNA technology and the physiology of major organ systems.

BE 562. Laboratory Animal Surgery
A study of anesthesia, surgical techniques and postoperative care in small laboratory animals. Anatomy and physiology of species used included as needed. Class limited to 15 students. Approximately 15 surgical exercises are performed by each student. (Prerequisite: Graduate standing. Admission of undergraduate students requires the permission of the department head and the instructor.)

BE 570. Engineering in the Clinical Environment
Examines the responsibilities and functions of the biomedical engineer in the health care complex in the solution of the technical and engineering problems associated with patient care. Topics include equipment management, monitoring systems, electrical safety, prosthesis, technical education for medical personnel, hospital systems engineering and administrative functions.

BE 581. Medical Imaging Systems
Overview of the physics of medical image analysis. Topics covered include X-ray tubes, fluoroscopic screens, image intensifiers; nuclear medicine; ultrasound; computer tomography; nuclear magnetic resonance imaging. Image quality of each modality is described mathematically, using linear system theory (Fourier transforms, convolutions). (Prerequisite: Signal analysis course EE 3303 or equivalent.)

BE 582. Principles of In Vivo Nuclear Magnetic Resonance Imaging
This course emphasizes the applications of Fourier transform nuclear magnetic resonance (FTNMR) imaging and spectroscopy in medicine and biology. Course topics include review of the basic physical concepts of NMR (including the Bloch equations), theoretical and experimental aspects of FTNMR, theory of relaxation and relaxation mechanisms in FTNMR instrumentation for FTNMR, NMR imaging techniques (point, line, plane and volume methods) and in vivo NMR spectroscopy (including volume localization techniques). (Prerequisites: Differential and integral calculus, ordinary differential equations; organic chemistry recommended.)

BE 585. Principles of In Vivo Nuclear Magnetic Resonance Spectroscopy
This course emphasizes the applications of Fourier transform nuclear magnetic resonance imaging (FTNMR) spectroscopy in medicine and biology. Course topics include review of the basic physical concepts of NMR, review of covalent chemical binding and its relationship to the NMR chemical shift, factors in biological systems that influence the NMR chemical shift, data acquisition and processing techniques in vivo NMR spectroscopy, and the application of NMR spectroscopy to clinical studies. (Prerequisites: BE 582, organic chemistry and biochemistry are strongly recommended.)

BE 591. Graduate Seminar
Topics in biomedical engineering are presented by authorities in the field and full-time graduate students in the program. Provides a forum for the communication of
current research, and an opportunity for graduate students to prepare and deliver oral presentations. This is a required course (every semester) for all full-time graduate students (Prerequisite: Graduate standing.)

BE 595. Special Topics in Biomedical Engineering
Topics in biomedical engineering. Presentations and discussions of the current literature in one or more of the following areas: medical imaging, neurosensory systems, bio-statistics.

BE 595M. Medical Device Regulation
This course provides an overview of regulations that guide the medical devices industry. Primary focus is on the Food, Drug and Cosmetic Act (FD&C Act) and its associated regulations. The course covers the FD&C Act, including definitions, prohibited acts, penalties and general authority. The course also covers regulations, including establishment registration, premarket approval (PMA) and current good manufacturing practices. Requirements of other federal agencies (NRC, FCC, EPA) will also be discussed.

BE 596. Research Seminar
Presentations on current biomedical engineering research.

BE 598. Directed Research

BE 698. Laboratory Rotation in Biomedical Engineering
Offered fall, spring and summer for 3 or 4 credits (Prerequisite: Ph.D. student in biomedical engineering).

BE 699. Ph.D. Dissertation
The following graduate/undergraduate biomedical engineering courses are also available for graduate credit.

BE/ME 4504. Biomechanics
This course emphasizes the applications of mechanics to describe the material properties of living tissues. It is concerned with the description and measurements of these properties as related to their physiological functions. Emphasis on the interrelationship between biomechanics and physiology in medicine, surgery, body injury and prosthesis. Topics covered include review of basic mechanics, stress, strain, constitutive equations and the field equations encountered in fluids, viscoelastic behavior and models of material behavior. The measurement and characterization of properties of tendons, skin, muscles and bone. Biomechanics as related to body injury and the design of prosthetic devices. (Prerequisites: Ordinary differential and integral calculus, familiarity with the concepts of mechanics, including continuum mechanics [ME 3501].)

BE/ME 4606. Biofluids
This course emphasizes the applications of fluid mechanics to biological problems. The course concentrates primarily on the human circulatory and respiratory systems. Topics covered include: blood flow in the heart, arteries and veins, and microcirculation and air flow in the lungs and airways. Mass transfer across the walls of these systems is also presented. (Prerequisite: A background in continuum mechanics [ME 3501] and fluid mechanics equivalent to ME 3602 is assumed.)

BE/ME 4814. Biomedical Materials
This course discusses various aspects pertaining to the selection, processing, testing (in vitro and in vivo) and performance of biomedical materials. The biocompatibility and surgical applicability of metallic, polymeric and ceramic implants and prosthetic devices are discussed. The physico-chemical interactions between the implant material and the physiological environment will be described. The use of biomaterials in maxillofacial, orthopedic, dental, ophthalmic and neuromuscular applications is presented. (Prerequisite: Knowledge of introductory materials science [ES 2001] is assumed.)

The following courses in the Graduate School of Biomedical Sciences (GSBS) at the University of Massachusetts Medical School (UMMS) are appropriate for students in the biomedical engineering program and are available for graduate credit. While these are the most common courses taken by our students, many other GSBS courses not listed in this catalog may also be available for graduate credit.

Biomedical Science Core (I and II)
Provides students with an integral foundation in the sciences basic to medicine, emphasizing contemporary topics in biological chemistry, transfer of genetic information, cellular architecture and regulation, and multicellular systems and processes. Students may take all or part of the core, in either quarter or semester format.

Biomedical Sciences I (6 credits)
Quarter I: Biochemistry (3 credits)
Quarter II: Molecular Biology and Genetics
(3 credits)

Biomedical Sciences II (6 credits)
Quarter III: Cell Biology (3 credits)
Quarter IV: Systems (3 credits)

Responsible Conduct of Science
Ethics course on the responsible conduct of science (1 credit).

PY 700. “The Cell Works”:
Principles of Cell Physiology
4 credits
The objectives of “The Cell Works” are to provide a fundamental understanding of: (1) the basic biophysical principles of cell physiology, (2) the ability to relate cellular function to whole organ physiology, and (3) the cellular mechanisms underlying disease. By emphasizing the principles of cell physiology, the course will identify important physiological paradigms and the modern research methods used to resolve outstanding questions concerning cell function. (Prerequisites: Biochemistry and molecular biology.)

PY 740. “The Image Works”:
Optical Methods in Physiology
2 credits
This course studies basic optical techniques and their application to physiological problems, with special emphasis on digital image processing. (Prerequisites: Calculus.)

PY 750. “The Body Works”:
Cellular and Organ Physiology
3 credits
The objectives of “The Body Works” are to provide a fundamental understanding of: (1) the basic biophysical principles of physiology, (2) the relationship between cellular function and whole organ physiology, (3) the integration and regulation of the major organ systems of the human body, and (4) the mechanism of pathogenesis of disease. By correlating cellular processes with organ function, this course will identify important physiological paradigms and the modern research methods used to resolve outstanding questions. (Prerequisites: Biochemistry, molecular biology and cell physiology.)

Chemical Engineering
CM 501-502. Seminar
Reports on current advances in the various branches of chemical engineering or on graduate research in progress. Must be taken during every semester in residence.

CM 504. Mathematical Analysis in Chemical Engineering
Methods of mathematical analysis selected
from such topics as vector analysis, matrices, complex variables, eigenvalue problems, Fourier analysis, Fourier transforms, Laplace transformation, solution of ordinary and partial differential equations, integral equations, calculus of variation and numerical analysis. Emphasis on application to the solution of chemical engineering problems.

CM 506. Kinetics and Catalysis
Theories of reaction kinetics and heterogeneous catalysis for simple and complex reactions. Kinetics and mechanisms of catalyzed and uncatalyzed reactions, and effects of bulk and pore diffusion. Techniques for experimentation, reaction data treatment, and catalyst preparation and characterization.

CM 507. Chemical Reactor Design
Includes a review of batch, tubular and stirred tank reactor design. Kinetics review including advanced chemical kinetics and biochemical kinetics, and transport processes in heterogeneous reactions. In-depth reactor analysis includes fixed bed reactors, multiplicity and stability of steady states, reactor dynamics, optimal operation and control, biological reactors, nonideal flow patterns, and fluidized bed and multiphase reactors.

CM 508. Catalysis and Surface Science of Materials
Examines detailed structures and reactivities of solid catalysts: zeolites, solid state inorganics, supported metals and metal-support interactions, carbon catalysts, anchored catalysts and others. Important analytical techniques covered include X-ray photoelectron spectroscopy (ESCA), electron microprobe, AUGER, scanning electron microscopy, EXAFS, Mossbauer, Fourier-transform infrared, enhanced laser Raman spectroscopy and photoacoustics spectroscopy. Examines relationship between structures and reactivities of important catalysts in hydrocarbon oxidation and functionalization, syngas reactions and petroleum processing.

CM 510. Dynamics of Particulate Systems
Analyzes discrete particles which grow in size or in some other characteristic variable (e.g., age, molecular weight). Reaction engineering and population balance analyses for batch and continuous systems. Steady state and transient system dynamics. Topics may include crystallization, latex synthesis, polymer molecular weight distribution, fermentation/ecological systems and gas-solid systems.

CM 521. Biochemical Engineering
Ligand binding and membrane transport processes, growth kinetics of animal cells and microorganisms, kinetics of interacting multiple populations, biological reactor design and analysis, soluble immobilized enzyme kinetics, optimization and control of fermentation, biopolymer structure and function, properties of biological molecules, biological separation processes, scale-up of bioprocesses; laboratory work may be included when possible.

CM 543. Molecular Sieves
The structure, synthesis and properties of microporous crystals known as zeolites are examined. Major topics are systemization of crystal structures, zeolite syntheses and their mechanisms, spectroscopic characterization, physical properties and catalytic properties.

CM 561. Advanced Thermodynamics
Examination of the fundamental concepts of classical thermodynamics and presentation of existence theorems for thermodynamics properties. Inequality of Clausius as a criterion for equilibrium in both chemical and physical systems. Examination of thermodynamic equilibrium for a variety of restraining conditions. Applications to fluid mechanics, process systems and chemical systems. Computation of complex equilibria.

CM 571. Intermediate Transport Phenomena
Mass, momentum and energy transport; analytical and approximate solutions of the equations of change. Special flow problems such as creeping, potential and laminar boundary-layer flows. Heat and mass transfer in multicomponent systems. Estimation of heat and mass transfer rates. Transport with chemical reaction.

CM 572. Mass and Energy Transfer
Advanced treatment of heat and mass transfer. Topics from: forced and natural convection; high-speed and rarefied gas flows; film and dropwise condensation, spray cooling, boiling and two-phase flow; packed and fluidized bed heat and mass transfer; the heat pipe; radiant transfer within enclosures, including radiation from gases and flames; ionic transport and electrochemical systems; combustion and mass transfer; drying and diffusion in porous materials, mass transfer in living systems; turbulent mass transfer; adsorption; design of heat and mass transfer equipment. Course may be offered by special arrangement.

CM 573. Separation Processes
Thermodynamics of equilibrium separation processes such as distillation, absorption, adsorption and extraction. Multistaged separations. Principles and processes of some of the less common separations.

CM 574. Fluid Mechanics
Advanced treatment of fluid kinematics and dynamics. Stress and strain rate analysis using vectors and tensors as tools. Incompressible and compressible one-dimensional flows in channels, ducts and nozzles. Nonviscous and viscous flow fields. Boundary layers and turbulence. Flow through porous media such as fixed and fluidized beds. Two-phase flows with drops, bubbles and/or boiling. Introduction to non-Newtonian flows.

CM 580. Transformation and Transport in the Environment
This course will focus on the transformation and transport of pollutant chemicals, nutrients and colloids in natural and engineered environmental systems. The first part of the course deals with the transfer of chemicals between different environments (water and air, water and solid phases). The second part of the course deals with processes by which a compound is chemically or biologically transformed into one or more products.

CM 594 (FPE 574). Process Safety Management
This course provides basic skills in state-of-the-art process safety management and hazard analysis techniques including hazard and operability studies (HAZOP), logic trees, failure modes and effects analysis (FMEA) and consequence analysis. Both qualitative and quantitative evaluation methods will be utilized. Following a case study format, these techniques, along with current regulatory requirements, will be applied through class projects addressing environmental health, industrial hygiene, hazardous materials, and fire or explosion hazard scenarios.

(Prerequisite: An undergraduate engineering or physical science background.)

Chemistry and Biochemistry
CH 501. Chemistry of the Main Group Elements
An advanced course in recent developments in selected areas of the chemistry of the elements other than transition metals. Topics covered

*Only one course for core credit.
**Core chemical engineering courses.
may include electron-deficient compounds and main group organometallics; and the preparation, reactions and physical properties of these compounds. Course may be offered by special arrangement.

CH 502. Bioinorganic Chemistry
The subject matter of this course is bioinorganic chemistry, with emphasis on the application of physical methods to the study of active sites in bioinorganic systems. The physical methods discussed include magnetic susceptibility measurements, electronic absorption spectroscopy, resonance Raman spectroscopy, electron spin resonance, EXAFS and electrochemical techniques. Applications of these to a variety of metalloproteins including oxygen carriers (myoglobin, hemoglobin, hemo-cyanin), blue copper proteins, iron sulfur proteins, and low molecular weight structural and functional model systems are covered in detail.

CH 516. Chemical Spectroscopy
The emphasis is on using a variety of spectroscopic data to arrive at molecular structures, particularly of organic molecules. Major emphasis is on H- and C-NMR, IR and MS. There is relatively little emphasis on theory or on sampling handling techniques.

CH 531. Electronic Interpretation of Organic Reactions
Organic reaction mechanisms are interpreted in terms of "electron-pushing” rationalizations and elementary molecular orbital theory. The course involves a series of problem-solving discussion sessions.

CH 533. Physical Organic Chemistry
Mechanisms of representative organic reactions and the methods used for their evaluation. Structural, electronic and stereochemical influences on reaction mechanisms.

CH 534. Organic Photochemistry
Introduction to the photophysical and photochemical consequences of light absorption by molecules. Experimental techniques, excited state description, photochemical kinetics and energy transfer are among the topics discussed in relation to the primary photochemical reactions in simple and complex molecules.

CH 536. Theory and Applications of NMR Spectroscopy
This course emphasizes the fundamental aspects of 1D and 2D nuclear magnetic resonance spectroscopy (NMR). The theory of pulsed Fourier transform NMR is presented through the use of vector diagrams. A conceptual nonmathematical approach is employed in discussion of NMR theory. The course is geared toward an audience which seeks an understanding of NMR theory and an appreciation of the practical applications of NMR in chemical analysis. Students are exposed to hands-on NMR operation. Detailed instructions are provided and each student is expected to carry out his or her own NMR experiments on a Bruker AC-200 instrument.

CH 537. Natural Products
The course will provide a review of the chemistry and synthesis of compounds from representative families of products such as terpenoids, steroids, polyketides, alkaloids and B-lactams. Prospective students should have a good foundation in organic chemistry.

CH 538. Medicinal Chemistry
This course will focus on the medicinal chemistry aspects of drug discovery from an industrial pharmaceutical research and development perspective. Topics will include chemotherapeutic agents (such as antibacterial, antiviral and antitumor agents) and pharmacodynamic agents (such as antihypertensive, antiallergic, antiulcer and CNS agents). (Prerequisite: A good foundation in organic chemistry, e.g., CH 2310 Organic Chemistry I and CH 2320 Organic Chemistry II.)

CH 539. Molecular Pharmacology
After a review of the pertinent aspects of human physiology, the course will focus on the variety of chemical messengers in the body, their storage release, action on target receptors and eventual fate. Discussion of endocrine receptors introduces the fundamental concepts of receptor-effector coupling, which are developed further in studies of the molecular structure and function of ion channels with application to the nerve impulse and of the acetylcholine receptors. Concepts of agonist and antagonist specificity, nonspecific blocking, drug addiction, etc. will be further developed in discussions of the catecholamines and the neuropeptides. Nonreceptor blocking will be further developed in a segment of ion cotransport systems in renal regulation. A knowledge of the material covered in one of the following is recommended: (1) CH 4110 and CH 4120, (2) BB 3100, or (3) CH 538, plus an understanding of protein and membrane structures.

CH 552. Statistical Mechanics
Application of the results of the quantum theory to achieve an atomistic physical understanding of the common thermodynamic variables. Maxwell-Boltzmann, Fermi-Dirac and Bose-Einstein distribution functions are defined using the concepts of phase space and the exclusion principle, and the thermodynamic functions are developed in terms of the distribution functions. Application of the partition function and the theory of fluctuations to common physical systems. Course may be offered by special arrangement.

CH 553. Quantum Mechanics of Molecules

CH 554. Molecular Modeling
This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical chemists who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a background at the introductory level in quantum mechanics is highly desirable. Methods to be explored include extended Hückel theory, molecular mechanics, semiempirical molecular orbital methods, ab initio methods, graphical display of molecules.

CH 555. Advanced Topics
1 to 3 credits as arranged
A course of advanced study in selected areas whose content and format varies to suit the interest and needs of faculty and students. This course may be repeated for different topics covered.

CH 556. Experimental Photochemistry
This course illustrates how modern spectroscopic techniques can be used to learn more about the photo-induced chemistry of organic materials. The principles of time-resolved and steady-state spectroscopic methods will be described in lectures and then applied in the laboratory to a variety of chemical systems. The aim will be to show how it is possible to fully describe the ground and excited state photochemical behavior of a chemical system using these techniques. Aspects of UV-visible
fluorescence emission, phosphorescence emission and laser-flash photolysis will be discussed. Students will gain hands-on experience with the use of UV-visible absorption and fluorescence emission spectrometers as well as the laser flash photolysis research facility. Also, as part of the course, students will submit a short research proposal based on one or more of the techniques used. Although there is no formal requirement for this course, some background and an interest in photochemistry would be an asset.

CH 560 Current Topics in Biochemistry
1 credit per semester

CH 571. Seminar
0.5 credit per semester

Reports on current advances in the various branches of chemistry.

The following graduate/undergraduate chemistry courses are also available for graduate credit.

CH 4110. Biochemistry I
Cell organization and the physical and chemical properties of biomolecules including amino acids, peptides, proteins, carbohydrates and lipids are discussed. Biochemical dynamics is introduced through a study of enzymes, coenzymes and enzyme kinetics. Bioenergetics, the role of ATP, its production through glycolysis, and the tricarboxylic acid cycle are discussed in detail.

CH 4120. Biochemistry II
Oriented around biological membranes, this term begins with a discussion of electron transport and the aerobic production of ATP, followed by a study of photosynthesis. The study of the biosynthesis of lipids and steroids leads to a discussion of the structure and function of biological membranes. Finally, the membrane processes in neurotransmission are discussed.

CH 4130/BB 4910. Biochemistry III
This course presents a thorough analysis of the biosynthesis of DNA (replication), RNA (transcription) and proteins (translation), and of their biochemical precursors. Proteins and RNAs have distinct lifetimes within the living cell; thus the destruction of these molecules is an important biochemical process that is also discussed. In addition to mechanistic studies, regulation of these processes is covered.

CH 4160. Membrane Biophysics
This course will focus on different areas of biophysics with special emphasis on membrane phenomena. The biomedical-biological importance of biophysical phenomena will be stressed. The course will begin with the introduction of the molecular forces relevant in biological media and subsequently develop the following topics: membrane structure and function; channels, carriers and pumps; nerve excitation and related topics; and molecular biophysics of motility.

CH 4190. Regulation of Gene Expression
This course will cover the biochemical mechanisms involved in regulation of gene expression: modifications of DNA structures that influence transcription rates, transcriptional regulation by protein binding, post-transcriptional modification of RNA including splicing and editing, regulation of translation including ribosome binding and initiation of translation, and factors that control the half-lives of both mRNA and protein. During the course, common experimental methods will be explored, including a discussion of the information available from each method. Recommended background: CH 4110, CH 4120, CH 4130, BB 4010.

CH 4330. Organic Synthesis
A discussion of selected modern synthetic methods including additions, condensations and cyclizations. Emphasis is placed on the logic and strategy of organic synthesis. (Prerequisite: Competence in elementary organic synthesis is assumed.)

CH 4420. Inorganic Chemistry II
This course deals with the stereochemistry of and the bonding in transition metal complexes of both the classical and organometallic types. The crystal field and molecular orbital theories of bonding in such complexes are treated in detail. Special attention is given to reactions and catalysts.

CH 4520. Chemical Statistical Mechanics
This course provides an introduction to the statistical methods of determining thermodynamic properties of substances from basic information about the atomic and molecular units from which they are formed. Through calculation of thermodynamic quantities and the evaluation of chemical equilibrium constants, broad insights into the kinetic molecular theory and the significance of the concepts of entropy and energy are developed.

CH 4550. Polymer Chemistry
Fundamentals of polymer science and technology based on organic polymers. The principal mechanisms of polymerization including radical, ionic and condensation are covered in detail. Characterization of polymers by physical means. Mechanical behavior including bulk and solution properties of polymers. Polymer syntheses and modifications including graft and copolymerization. Structure, property and end use applications of plastic materials. Plastics processing, testing and technology. Survey of commodity plastics as well as engineering resins, including their applications and economic considerations. Presentation of trade and technical literature in the field.

Civil and Environmental Engineering

CE 501. Professional Practice
Professional practices in engineering. Legal issues of business organizations, contracts and liability; business practice of staffing, fee structures, accounts receivable, negotiation and dispute resolution, and loss prevention; marketing and proposal development; project management involving organizing and staffing, budgeting, scheduling, performance and monitoring, and presentation of deliverables; professionalism, ethics and responsibilities.

CE 510. Structural Mechanics
Analysis of structural components: uniform and nonuniform torsion of structural shapes, analysis of determinate and indeterminate beams (including elastic foundation conditions) by classical methods, finite difference equations, numerical integrations, series approximation, elastic stability of beams and frames, lateral stability of beams, beams-columns, analysis of frames including the effect of axial compression. Course may be offered by special arrangement.

CE 511. Structural Dynamics
Analysis and design of beams and frames under dynamic loads; dynamics of continuous beams, multistory building frames, floor systems and bridges; dynamic analysis and design of structures subjected to wind and earthquake loads; approximate methods of analysis and practical design applications.

CE 512. Structural Stability Theory
Theory of elastic and inelastic buckling of beam columns and frames; lateral and torsional buckling of beams; buckling rings, arches and thin plates; buckling of shells; design equations and finite element methods in stability; bending of thin plates and shells. Use of Microcomputers in stability problems. Course
may be offered by special arrangement. (Prerequisite: Differential equations, structural mechanics and matrix structural analysis will be assumed.)

CE 519. Advanced Structural Analysis
Energy methods in structural analysis, concepts of force method and displacement methods, methods of relaxation and numerical techniques for the solution of problems in buildings, and longspan structures and aircraft structural systems. Effects of secondary stress in structures. Course may be offered by special arrangement. (Prerequisites: Structural mechanics and undergraduate courses in structural analysis, differential equations.)

CE 523. Advanced Matrix Analysis
Review of matrix computer methods of structural analysis including the stiffness and flexibility methods, energy formulation, Eigenvalue problems, the finite element method, elements suitable for analysis, structural dynamic problems, computer solutions of numerous examples using time-sharing programs and STRUDL.

CE 524. Stress Analysis by Finite Elements
(Same as ME 533.) See course description under ME 533 on page 103.

CE 525. Analysis and Design of Shell Structures
Analysis and design of thin shell concrete structures such as domes, cylindrical shells, hyperbolic paraboloids, shells of double curvature and folded plate roof systems; membrane theory of thin shells and the methods of analysis for displacements and stress-resultants; methods of analysis of shells including finite element formulations; design of cylindrical, spherical and hyper shell structures; applications to long-span roof systems, arch dams and liquid-containment structures. An understanding of the undergraduate topics in structural mechanics, reinforced concrete design and differential equations is assumed.

CE 526. Advanced Finite Element Methods
(Same as ME 633.) See course description under ME 633 on page 103.

CE 527. Impact Analysis and Structural Crashworthiness
This course provides the student with a basic understanding of the mechanics of impact and contact as well as the behavior of materials subjected to dynamic loadings. Analytical, computational and experimental methods are used to investigate impact phenomena. Students will explore impact phenomena in a semester-long investigation of a particular impact problem of interest to the student, involving analytical methods, physical experiments and computation modeling. Topics include one-dimensional wave mechanics, impulsively loaded beams, explicit time integration, computational contact methods and element formulation for impact problems. While a good general background in mechanics is required, no special preparation in finite element methods or continuum mechanics is presumed. This course is normally offered every fall semester.

CE 531. Advanced Design of Steel Structures
Advanced design of steel members and connections; ultimate strength design in structural steel; codes and specifications; loads and working stresses; economic proportions; and buckling of slender elements and built-up sections, torsion, lateral-torsional buckling, beam-columns, design for lateral forces, and connections for building frames.

CE 532. Advanced Design of Reinforced Concrete Structures
Advanced design of reinforced concrete members and structural systems; effect of continuity; codes and specifications; ultimate strength theory of design; economic proportions and constructibility considerations; and deep beams, torsion, beam-columns, two-way slabs, design for lateral forces, and beam-to-column joints.

CE 533. Prestressed Concrete Structures
Analysis and design of prestressed concrete structures. Linear prestressing, materials used in prestressed concrete, determinate and statically indeterminate prestressed concrete structures, connections, and shear and torsion. Design of tension and compression members and flat plates. (Prerequisite: A knowledge of undergraduate course in concrete design is necessary.)

CE 534. Structural Design for Fire Conditions
The development of structural analysis and design methods for steel and reinforced concrete members subjected to elevated temperatures caused by building fires. Beams, columns and rigid frames will be covered. The course is based on research conducted during the past three decades in Europe, Canada and the United States. Course may be offered by special arrangement. (Prerequisites: Knowledge of statically indeterminate structural analysis, structural steel design and reinforced concrete design.)

CE 535. Integration of Design and Construction
As an interactive case study of the project development process, student groups design a facility and prepare a construction plan, including cost and schedule, to build the project. The students present their design-build proposal to participating industrial clients. Emphasis is on developing skills to generate, evaluate and select design alternatives that satisfy the needs of the owner and the constraints imposed by codes and regulations, as well as by the availability of construction resources. Emphasis is also in developing team-building skills and efficient communication. Computer-based methods for design, construction cost estimating and scheduling, and personal communications are extensively used. The interactive case study is specifically chosen to balance the content between design, construction engineering and management. Students taking this course are expected to have a background in at least two of these disciplines.

CE 536. Construction Failures: Analysis and Lessons
This course develops an understanding of the integration process of technical, human, capital, social and institutional aspects that drive the life cycle of a construction project. The study of failures provides an excellent vehicle to find ways for the improvement of planning, design and construction of facilities. Students are required to complete a term project on the investigation of a failure and present their findings and recommendations. This investigation includes not only the technical analysis of the failure but also requires a comprehensive analysis of the organizational, contractual and regulatory aspects of the process that lead to the failure. The course uses case studies to illustrate different types of failure in the planning, design, construction and operation of constructed facilities. Students taking this course are expected to have some background in the disciplines mentioned above.

CE 537. Advanced Properties and Production of Structural Materials
This course is particularly designed for civil engineers and will cover structure, properties and performance of construction materials. Topics include the structure of solids, phase equilibrium and reaction kinetics. A detailed
analysis of mechanical properties and deterioration of solids will be presented. Theories and mathematical models based on these concepts will be applied to construction materials such as cementitious materials, bituminous materials, metals and alloys, timber, ceramics and composites. (Prerequisites: Structural mechanics, materials of construction, differential equations and computer literacy.)

CE 538. Pavement Analysis and Design for Highways and Airports
This course is designed for civil engineers and will provide a detailed survey of analysis and design concepts for flexible and rigid pavements for highways and airports. The materials will cover elastic and inelastic theories of stress pavement components and currently used design methods, i.e., Corps of Engineers, AASHTO, etc. The use of finite element methods for pavement stress and deformation analysis will be presented. A review of pavement rehabilitation methods and processes will be presented. (Prerequisites: Differential equations, construction materials, soil mechanics, computer literacy.)

CE 542. Geohydrology
This course addresses engineering problems associated with the migration and use of subsurface water. An emphasis is placed on the geology of water-bearing formations including the study of pertinent physical and chemical characteristics of soil and rock aquifers. Topics include principles of groundwater movement, geology of groundwater occurrence, regional groundwater flow, water well technologies, construction dewatering, groundwater chemistry and unsaturated flow. (Prerequisite: A knowledge of the material in GE 2341 is recommended.)

CE 543. Highway Design and Traffic Safety
This course is an in-depth study of highway safety as it affects the geometric design of highways. Topics include the classification and purposes of roadway systems, developing safety design criteria, the design of safe vertical and horizontal alignments, proper selection of cross-sectional elements, providing adequate sight distance, selection of appropriate speed limits, control of speeds, and other highway design issues. While there is no formal prerequisite, the course presumes a basic knowledge of undergraduate highway design as taught in CE 3050. This course is usually offered in alternate spring semesters.

CE 544. Highway Safety Audits

CE 552. Earth Structures
This course provides an in-depth study of the geotechnical principles applied to design of earth structures including earth dams, waste containment facilities, soil slopes, highway cuts, embankments and slurry trenches. It includes fundamentals of analysis of flow through porous media by graphical and digital techniques, slope stability, use of geosynthetics, soil stabilization, and the design of preloads and drain installations. Course may be offered by special arrangement.

CE 553. Advanced Foundation Engineering
This course covers advanced methods of sub-surface exploration and recent developments in prediction of bearing capacity and settlement of shallow foundations. It includes design of mat foundations, analysis and design of pile and drilled shaft foundations, and discussion of case studies. The course content is determined in part by the student’s interests and often also includes design of lateral support systems, reinforced earth, dewatering systems and buried structures.

CE 550. Theoretical Soil Mechanics
This course provides an advanced level study of theories of soil behavior and mechanics. The topics reviewed are physico-chemical factors affecting soil behavior, the effective stress principle, moisture migration, application of the theory of elasticity to compute stresses in soil masses, settlement analysis, consolidation theory and geothermics. Appropriate laboratory and field testing procedures are discussed. Course may be offered by special arrangement.

CE 551. Theoretical Soil Mechanics II
A continuation of CE 550. It addresses the nature of the strength-deformation characteristics of both rapidly and slowly draining soils. Stress path methods of analysis and critical state behavior models are emphasized. Elastic and plastic material failure theories are reviewed, and modern laboratory and field testing devices are described. Course may be offered by special arrangement.

CE 560. Advanced Principles of Water Treatment
Theory and practice of water treatment. Aeration, water softening, coagulation sedimentation, water infiltration, disinfection, taste and odor control, desalination, and corrosion control.

CE 561. Advanced Principles of Wastewater Treatment
Theory and practice of wastewater treatment. Natural purification of streams; screening; sedimentation; flotation, thickening; aerobic treatment methods; theory of aeration; anaerobic digestion; disposal methods of sludge including vacuum filtration, centrifugation and drying beds; wet oxidation; removal of phosphate and nitrogen compounds; and tertiary treatment methods.

CE 562. Biosystems in Environmental Engineering
Application of microbial and biochemical understanding to river and lake pollution; natural purification processes; biological conversion of important elements such as C, N, S, O and P; biological aspects of wastewater treatment; disease-producing organisms with emphasis on waterborne diseases; and quantitative methods used in indicator organism counts and disinfection.

CE 563. Industrial Waste Treatment
Legislation; the magnitude of industrial wastes; effects on streams, sewers and treat-
ment units; physical, chemical and biological characteristics; pretreatment methods; physical treatment methods; chemical treatment methods; biological treatment methods; and wastes from specific industries. Lab includes characterization and treatment of typical industrial wastes.

CE 564. Solid Waste Management
Sources and types of solid wastes; generation rates; environmental, public health and aesthetic aspects; on-site handling, storage and processing; collection systems; transfer and transport of solid wastes; processing techniques and equipment; recovery of resources and energy; composting; disposal methods of solid wastes and residual matter; hazardous wastes handling; solid waste legislation and governmental agencies; solid waste management issues and options; and case studies.

CE 565. Stream, Lake and Estuarine Analysis
This course provides a quantitative base for determining the fate of effluent discharged into natural waters. Models are developed to describe the transport, dispersal, and chemical/biological reaction of substances introduced in rivers, estuaries, lakes and coastal areas. The concept of conservation of mass is used to derive the general transport equation. This equation is applied to analyze BOD, DO, temperature, nutrients and plankton population dynamics. Other topics include salinity intrusion in estuaries, thermal stratification of reservoirs and physio-biological predictions as a tool for water quality management.

CE 566. Groundwater Flow and Pollution
This course provides a review of the basic principles governing ground water flow and solute transport, and examines the models available for prediction and analysis including computer models. Topics covered include mechanics of flow in porous media; development of the equations of motion and of conservation of solute mass; analytical solutions; and computer-based numerical approaches and application to seepage, well analysis, artificial recharge, groundwater pollution, salinity intrusion and regional groundwater analyses.

CE 567. Hazardous Waste: Containment, Treatment and Prevention
This course provides a survey of the areas associated with hazardous waste management. The course materials deal with identification of hazardous waste legislation, containment, storage, transport, treatment and other hazardous wastes management issues. Topics include hazardous movement and containment strategies, barrier design considerations, hazardous waste risk assessment, spill response and clean-up technologies, centralized treatment facilities, on-site treatment, in situ treatment, and industrial management and control measures. Design of selected containment and treatment systems, and a number of industrial case studies are also covered. This course is offered to students with varying backgrounds. Students interested in taking this course must identify a specific problem that deals with either regulation, containment of hazardous waste, treatment of hazardous waste or industrial source reduction of hazardous waste. This problem becomes the focal point for in-depth study. The arrangement of topics between the students and the instructor must be established by the third week. A knowledge of basic chemistry is assumed.

CE 568. Design of Water Distribution Piping Systems
This course covers both hydraulic and water quality modeling of water distribution systems. Emphasis is placed on potable water distribution systems for municipal use, but high purity water networks for industrial use are also covered. Popular software models currently used for this type of analysis, such as the KYPIPE, CYBERNET and EPANET models, are used.

CE 569. Environmental Engineering Treatability Laboratory
Addresses an aspect of environmental engineering that has been unavailable to civil engineering students in the past. As demand increases for modern methods of dealing with complex facilities to remediate pollution, this course will become an increasingly important component of environmental education.

CE 570. Multiphase Contaminant Transport
Introduces concepts of physical transport processes in the environment with emphasis on exchanges across phase boundaries. Topics include equilibrium conditions of environmental interfaces; partitioning and distribution of contaminants in the environment; transport across sediment-water interfaces; dispersion, sorption and the movement of nonaqueous phase liquids in groundwater; gas exchanges across air-water interfaces; effects of turbulence and particles on transport in surface water flow; and the effects of reactions on the transport in the environment. (Prerequisite: A knowledge of the material covered in ES 3004 and CE 3069 is expected.)

CE 580. Advanced Project Management
This course develops an understanding of the managerial principles and techniques used throughout a construction project as they are applied to its planning, preconstruction and construction phases. The course emphasizes the integrative challenges of the human, physical and capital resources as experienced from the owner’s point of view in the preconstruction phase of a project. Through assignments and case studies, the course reviews the complex environment of the construction industry and processes, project costing and economic evaluation, project organization, value engineering, time scheduling, contracting and risk allocation alternatives, contract administration, and cost and time control techniques.

CE 581. Real Estate Development
Principles of real estate development, emphasizing the system approach to the process of conception, design, construction and operation; organization and control systems for real estate development, value and decision analysis.

CE 582. Engineering and Construction Information Systems
This course provides an understanding of the various subjects involved in the use, design, development, implementation and maintenance of computer-based information systems in the construction industry. Theoretical and hands-on review of basic building blocks of information and decision support systems including user interfaces, database management systems, object-oriented approaches and multimedia. Applications include project scheduling and cost control, budgeting, project risk analysis, construction accounting, materials management and procurement systems, project document tracking and resource management. Commercial software—such as PRI-MAVERA Project Planner, TIMBERLINE, and spreadsheets and databases—is extensively used. Students are required to complete a term project reviewing an existing information system and presenting recommendations for improvement. (Prerequisites: A knowledge of the material covered in CE 580, CE 584 and CE 585 is expected). Course may be offered by special arrangement.

CE 583. Contracts and Law for Civil Engineers
An introduction to the legal aspects of construction project management, emphasis on legal problems directly applied to the practice of project management, contracts and specifi-
COURSE DESCRIPTIONS

CE 584. Advanced Cost Estimating Procedures
This course examines cost estimating as a key process in planning, designing and constructing buildings. Topics include the analysis of the elements of cost estimating; database development and management, productivity, unit costs, quantity surveys and pricing, and the application of these tools in business situations; marketing, sales, bidding, negotiating, value engineering, cost control, claims management and cost history. Computerization is evaluated as an enhancement to the process.

CE 585. Information Technology in the Integration of Civil Engineering
This course provides an understanding and hands-on experience of state-of-the-art information technology and its application to the planning, design, construction and management of civil engineering projects. These technologies include integrated database management systems, electronic data interchange (EDI), electronic media for date input/output (bar coding, voice recognition, image processing), networks and knowledge-based systems. The course format includes formal lectures, computer laboratory sessions and a class project developed collaboratively by the students throughout the term. Using information technology, the class develops a package that includes drawings, specifications, cost estimate and schedule of a civil engineering project. (Prerequisites: Basic knowledge of computers and construction project management.)

CE 586. Building Systems
This course introduces design concepts, components, materials and processes for major building projects. The topics analyze the choice of foundations, structures, building enclosures and other major building subsystems as affected by environmental and legal conditions, and market and project constraints. Consideration is given to the functional and physical interfaces among building subsystems. Emphasis is given to the processes through which design decisions are made in the evolution of a building project.

CE 590. Special Problems
2 to 4 credits
Individual investigations or studies of any phase of civil engineering as may be selected by the student and approved by the faculty member who supervises the work.

CE 591 Environmental Engineering Seminar
Participation of students in discussing topics of interest to environmental engineers.

CE 592. Constructed Facilities Seminar
Participation of students, faculty and recognized experts outside of WPI in developing modern and advanced topics of interest in the constructed facilities area.

CE 593. Advanced Project
This capstone project is intended for students completing the M.E. degree. The student is expected to identify all aspects of the M.E. curriculum and an integrative, descriptive systems approach. The project activity requires the student to describe the development, design construction, maintenance and operation process for an actual facility; to evaluate the performance of the facility with respect to functional and operational objectives; and to examine alternative solutions. Specific areas of study are selected by the student and approved by the faculty member. The work may be accomplished by individuals or small groups of students working on the same project. (Prerequisite: Consent of instructor.)

CE 599. M.S. Thesis
Research study at the M.S. level.

Research study at the Ph.D. level.

Computer Science

CS 501. Discrete Structures
Topics from discrete mathematics relevant to computer science are presented in a way that helps the student develop a facility for dealing with abstractions and formal proofs. These topics include sets, relations, posets, graphs, digraphs, monoids, groups, discrete probability theory and propositional calculus. (Prerequisites: College math at least through calculus and some experience with recursive programming.) NOTE: This course is intended only for students with a limited formal computer science background and should only be taken with advisor or instructor approval.

CS 502. Operating Systems
The design and theory of multiprogrammed operating systems, concurrent processes, process communication, input/output supervi-
implement them are covered in some detail. The data structures covered include lists, stacks, queues, priority queues, trees, balanced trees, graphs and dictionaries. Projects and assignments will treat the development of theoretical results, the writing of programs to obtain practical results and techniques to integrate different data structures in complex algorithms that place a variety of demands upon them. (Prerequisites: The student is expected to know a recursive programming language, to have taken two years of college math and an undergraduate course in data structures, and to have exposure to formal mathematics as might be found in CS 501.) NOTE: This course is intended only for students with a limited formal computer science background and should only be taken with advisor or instructor approval.

CS 509. Design of Software Systems
This course focuses on the high-level design aspects of software engineering. Included are architectural and interface design. Within architectural design, the topics covered are Yourdan structured design, Jackson structured design and object-oriented design. When possible, real-time extensions are discussed. Sufficient coverage of the areas of requirements specification and testing is given to support the above topics. (Prerequisites: Knowledge of a recursive high-level language and data structures. An undergraduate course in software engineering is desirable.)

CS 513/EE 506. Introduction to Local and Wide Area Networks
This course provides an introduction to the theory and practice of the design of computer and communications networks, including the ISO seven-layer reference model. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types including local area and wide area networks are introduced, as are evolving network technologies. The theory, design and performance of local area networks are emphasized. The course includes an introduction to queuing analysis and network programming. (Prerequisites: A knowledge of the C programming language is assumed. CS 504 or EE 502 or equivalent background in probability may be taken concurrently.)

CS 514. Advanced Systems Architecture
(Same as EE 572) See EE 572 course description on page 88.

CS 515. Multiple Processor and Distributed Systems
This course covers the principles of the design and implementation of multiple processor computer systems, case studies of tightly and loosely coupled systems, interprocessor communications software and operating systems, performance and reliability calculations, concurrent programming languages and data flow architectures. (Prerequisites: A good working knowledge of single-processor computer systems [EE 572] and single-processor operating systems [CS 502]. The ability to program in a high-level block-structured language [Pascal or C] is required for the project and a prior course in networks such as EE 506 is recommended.)

CS 525. Topics in Computer Science
A topic of current interest is covered in detail. (Prerequisites: Vary with topic.) Please consult the department for a current listing of selected topics in this area.

CS 530/EE 530. High-Performance Networks
This course is an in-depth study of the theory, design and performance of high-speed networks. Topics include specific high-performance network implementations and emerging technologies, including multimedia networks and quality of service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queuing models. (Prerequisite: CS 513/EE 506.)

CS 531. System Simulation
The theory and design of discrete simulations are discussed. Other topics are random number generations, analysis of output and optimization. (Prerequisites: CS 504 or equivalent background in probability, and some background in statistics.)

CS 533/EE 581. Modeling and Performance Evaluation of Network and Computer Systems
Methods and concepts of computer and communication network modeling and system performance evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queuing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service and priority systems; workload characterization; performance evaluation problems. (Prerequisites: CS 504 or EE 502 or equivalent background in probability.)

CS 534. Artificial Intelligence
This course gives a broad survey of artificial intelligence. Several basic techniques such as search methods, formal proofs and knowledge representation are covered. Selected topics involving the applications of these tools are investigated. Such topics might include natural language understanding, scene understanding, game playing, learning and planning. (Prerequisites: A familiarity with data structures and a recursive high-level language. Knowledge of LISP is an advantage.)

CS 535. Advanced Topics in Operating Systems
This course discusses advanced topics in the theory, design and implementation of operating systems. Topics will be selected from such areas as performance of operating systems, distributed operating systems, operating systems for multiprocessor systems and operating systems research. (Prerequisites: CS 502 and CS 504, or equivalent background in probability.)

CS 536. Programming Language Design
This course discusses the fundamental concepts and general principles underlying current programming languages and models. Topics include control and data abstractions, language processing and binding, indeterminacy and delayed evaluation, and languages and models for parallel and distributed processing. A variety of computational paradigms are discussed: functional programming, logic programming, object-oriented programming and data flow programming. (Prerequisites: Student is expected to know a recursive programming language and to have an undergraduate course in data structures.)

CS 537. Advanced Compiler Design
A study of modern compiler techniques with emphasis on compiler generators. Formal, theoretical issues underlying compilers are investigated, concentrating on those topics which are at the forefront of current compiler technology. Focus is on the “back end” of compilers. (Prerequisites: Basic knowledge of compiler construction, automata and formal language theory, and a thorough understanding of the constructs in modern programming languages.)

CS 538. Expert Systems
The course will review expert knowledge-
CS 539. Machine Learning
The focus of this course is machine learning for knowledge-based systems. It will include reviews of work on similarity-based learning (induction), explanation-based learning, analogical and case-based reasoning and learning, and knowledge compilation. It will also consider other approaches to automated knowledge acquisition as well as connectionist learning. (Prerequisite: CS 534 or equivalent, or permission of the instructor.)

CS 540. Artificial Intelligence in Design
The main goal of this course is to obtain a deeper understanding of what “design” is, and how AI might be used to support and study it. Students will examine some of the recent AI-based work on design problem-solving. The course will be run in seminar style, with readings from the current literature and with student presentations. The domains will include electrical engineering design, mechanical engineering design, civil engineering design and software design (i.e., automatic programming). This course will be of interest to those wanting to prepare for research in design, or those wishing to increase their understanding of expert systems. Graduate students from departments other than computer science are welcome. (Prerequisite: Knowledge of artificial intelligence is required. This can only be waived with permission of the instructor).

CS 542. Database Management Systems
An introduction to the theory and design of database management systems. Topics covered include internals of database management systems, fundamental concepts in database theory, and database application design and development. In particular, logical design and conceptual modeling, physical database design strategies, relational data model and query languages, query optimization, transaction management and distributed databases. Typically there are hands-on assignments and/or a course project. Selected topics from the current database research literature may be touched upon as well. (Prerequisite: CS 504 or permission of the instructor.)

CS 543. Computer Graphics
This course examines typical graphics systems, both hardware and software; design of low-level software support for raster displays; 3-D surface and solids modeling; hidden line and hidden surface algorithms; and realistic image rendering including shading, shadowing, reflection, refraction and surface texturing. (Prerequisites: A familiarity with data structures, a recursive high-level language and linear algebra. CS 509 would be helpful.)

CS 544. Compiler Construction
A general approach to the design of language processors is presented without regard for either the source language or target machine. All phases of compilation and interpretation are investigated in order to give the student an appreciation for the overall construction of a compiler. Typical projects may include implementation of a small compiler for a recursive or special-purpose language. (Prerequisites: A knowledge of several higher-level languages and at least one assembly language. The material in CS 503 is helpful.)

CS 545. Digital Image Processing
(Same as EE 545) This course presents fundamental concepts of digital image processing and an introduction to machine vision. Image processing topics will include visual perception, image formation, imaging geometries, image transform theory and applications, enhancement, restoration, encoding and compression. Machine vision topics will include feature extraction and representation, stereo vision, model-based recognition, motion and image flow, and pattern recognition. Students will be required to complete programming assignments in a high-level language. (Prerequisites: A working knowledge of undergraduate level signal analysis and linear algebra; familiarity with probability theory is helpful but not necessary.)

CS 546. Human-Computer Interaction
This course prepares graduate students for research in human-computer interaction. Topics include the design and evaluation of interactive computer systems, basic psychological considerations of interaction, interactive language design, interactive hardware design and special input/output techniques. Students are expected to present and review recent research results from the literature, and to complete several projects. (Prerequisites: Students are expected to have mature programming skills. Knowledge of software engineering would be an advantage.)

CS 549. Computer Vision
This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images. (Prerequisites: CS 534, CS 543, CS 545, or the equivalent of one of these courses.)

CS 552. Numerical Methods
(Same as MA 510) See MA 510 course description on page 97.

CS 553. Theory of Computability
This course investigates the principal concerns of computability theory and presents several alternate formulations of the Church-Turing Thesis. Starting where the computability portion of CS 503 leaves off, the interrelationships between mathematics and computation are explored using several different approaches. (Prerequisite: CS 503.)

CS 559. Advanced Topics in Theoretical Computer Science
This version of CS 559 will cover randomized algorithms. It will also cover the design and analysis of probabilistic algorithms, which are often simpler or faster than deterministic algorithms. Problem areas will include data structures, graph algorithms and computational geometry. (Prerequisites: A knowledge of probability such as may be acquired in CS 504, and data structures such as may be acquired in CS 507. This course will satisfy the CS 504 distribution requirement.)

CS 561. Advanced Topics in Database Systems
This course covers modern database and information systems as well as research issues in the field. Topics and systems covered may include object-oriented, workflow, active, deductive, spatial, temporal and multimedia databases. Also discussed will be recent advances in database systems such as data mining, on-line analytical processing, data
warehousing, declarative and visual query languages, multimedia database tools, web and unstructured data sources, and client-server and heterogeneous systems. The specific subset of topics for a given course offering is selected by the instructor. Research papers from recent journals and conferences are used. Group project required. (Prerequisites: CS 542 or equivalent. Expected background includes a knowledge of relational database systems.)

CS 562. Advanced Topics in Software Engineering
This course focuses on the non-design aspects of software engineering. Topics may include requirements specification, software quality assurance, software project management and software maintenance. (Prerequisite: CS 509.)

CS 563. Advanced Topics in Computer Graphics
This course examines one or more selected current issues in the area of image synthesis. Specific topics covered are dependent on the instructor. Potential topics include: scientific visualization, computational geometry, photorealistic image rendering and computer animation. (Prerequisite: CS 543 or equivalent.)

CS 577. Advanced Computer and Communications Networks
This course covers advanced topics in the theory, design and performance of computer and communications networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queuing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies. (Prerequisite: CS 513/EE 506 and CS 533/EE 581.)

CS 578. Cryptography and Data Security
(Same as EE 578) See EE 578 course description on page 88.

CS 595. Computer and Communications Networks Internship
6 credits
(Same as EE 595) This project will provide an opportunity to put into practice the principles which have been studied in previous courses. It will generally be conducted off campus and will involve a real-world networking situation. Overall conduct of the internship will be supervised by a WPI faculty member, and an on-site liaison will direct day-to-day activity. The project must include substantial analysis and/or design related to computer or communications networking, and will conclude with a substantial written report. A public oral presentation must also be made, to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison and one additional WPI faculty member. Successful completion of the internship will be verified by this committee. For a student from industry, an internship may be sponsored by his or her employer. (Prerequisite: Completion of 12 credits of the CCN program.)

Electrical and Computer Engineering

EE 502. Analysis of Probabilistic Signals and Systems
Applications of probability theory and its engineering applications. Random variables, distribution and density functions. Functions of random variables, moments and characteristic functions. Sequences of random variables, stochastic convergence and the central limit theorem. Concept of a stochastic process, stationary processes and ergodicity. Correlation functions, spectral analysis and their application to linear systems. Mean square estimation. (Prerequisite: Undergraduate course in signals and systems.)

EE 503. Digital Signal Processing
Discrete-time signals and systems, frequency analysis, sampling of continuous time signals, the z-transform, implementation of discrete time systems, the discrete Fourier transform, fast Fourier transform algorithms, filter design techniques. (Prerequisites: Courses in complex variables, basic signals and systems.)

EE 504. Analysis of Deterministic Signals and Systems

EE 505. Computer Architecture
This course introduces the fundamentals of computer system architecture and organization. Topics include CPU structure and function, addressing modes, instruction formats, memory system organization, memory mapping and hierarchies, concepts of cache and virtual memories, storage systems, standard local buses, high-performance I/O, computer communication, basic principles of operating systems, multiprogramming, multiprocessing, pipelining and memory management. The architecture principles underlying RISC and CISC processors are presented in detail. The course also includes a number of design projects, including simulating a target machine, architecture using a high-level language (HLL). (Prerequisites: Undergraduate course in logic circuits and microprocessor system design, as well as proficiency in assembly language and a structured high-level language such as C or Pascal.)

EE 506. Introduction to Local and Wide Area Networks
(Same as CS 513) This course provides an introduction to the theory and practice of the design of computer and communications networks, including the ISO seven-layer reference model. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types and evolving network technologies are introduced, including local, metropolitan and wide area networks. The theory, design and performance of local area networks are emphasized. The course includes an introduction to queueing analysis and network programming. (Prerequisites: A knowledge of the C programming language is assumed. CS 504 or EE 502 or equivalent background in probability; may be taken concurrently. NOTE: Students who receive credit for EE 573 may not receive credit for EE 506.)

EE 508. Telecommunications Policy
This course provides an understanding of some of the major trends and issues involved in the development of U.S. telecommunications and information technology policies. The course highlights the interaction between technology and policy; it will help engineers to accept the reality that, in the introduction of new technologies, policy considerations often play a more important role than do technological advances. The course traces the historical development of U.S. telecommunications policy from supporting a regulated monopoly to the creation of the current increasingly more competitive and less regulated information marketplace. Topics explored include: the difficulties involved in assessing newly emerging technologies; regulation and deregulation of the telecommunications and information industries; the past, present and future concept of universal service; the
convergence of telecommunications, computer and television technologies to create the information network of the future; current competition in local, long-distance, wireless and multimedia services; issues related to standards, interoperability and intellectual property.

EE 511. Electromagnetic Theory
Introduction to analytical and numerical solution techniques in electromagnetics. Investigations of classical approaches to electrostatic, magnetostatic, quasistatic and dynamic field problems. Review of boundary-value problems and their practical limitations. Introduction of the principles and applications of methods of finite differences and finite elements. (Prerequisite: Undergraduate course in E/M field theory.)

EE 512. Acoustic and Ultrasound Engineering
Fundamentals of vibration. The acoustic wave equation, transmission phenomena, absorption and attenuation. Radiation from acoustic sources, dipole and line source radiation, planar piston source, radiation patterns, beam width, directivity, fields from pulsed transducers, Green’s function, diffraction, reciprocity. Techniques for ultrasound modeling. Acoustic waveguides. Ultrasound transducer types and transducer modeling. Transducer characterization and calibration. Acoustic measurement techniques. (Prerequisites: EE 502 and EE 504 or equivalent, undergraduate course in modern signal theory, undergraduate course in E/M field theory, or permission of the instructor.)

EE 514 Fundamentals of RF and MW Engineering
This introductory course develops a comprehensive understanding of Maxwell’s field theory as applied to high-frequency radiation, propagation and circuit phenomena. Topics include radio-frequency (RF) and microwave (MW) propagation modes, transmission line aspects, Smith Chart, scattering parameter analysis, microwave filters, matching networks, power flow relations, unilateral and bilateral amplifier designs, stability analysis, oscillators circuits, mixers and microwave antennas for wireless communication systems. (Prerequisites: EE 501 Modern Signal Analysis, undergraduate course in electromagnetic field analysis.)

EE519G. Introduction to Neural Networks: Theory and Applications
In this course graduate students are given comprehensive coverage of the theoretical concepts and practical aspects of neurocomputing. Specific topics to be addressed in this course are principles of distributed computing, learning processes, learning strategies, self-organized neural networks, stability and convergence of neural systems, and software as well as hardware implementation strategies. In addition, software engineering aspects of neural networks are analyzed, ranging from simple pattern recognition algorithms to multilayer backpropagation and self-organization networks along with their applications to practical problems. (Prerequisite: EE502 or equivalent.)

EE 523. Power Electronics
The application of electronics to energy conversion and control. Electrical and thermal characteristics of power semiconductor devices—diodes, bipolar transistors and thyristors. Magnetic components. State-space averaging and sampled-data models. Emphasis is placed on circuit techniques. Application examples include dc-dc conversion, controlled rectifiers, high-frequency inverters, resonant converters and excitation of electric machines. (Prerequisites: EE 3204 and undergraduate courses in modern signal theory and control theory; EE 504 is recommended.)

EE 524. Advanced Analog Integrated Circuit Design
This course is an introduction to the design of analog and mixed analog-digital CMOS integrated circuits for communication and instrumentation applications. An overview of the CMOS fabrication process shows the differences between discrete and integrated circuit design. The MOS transistor is reviewed with basic device physics and the development of circuit models in various operating regions. The use of SPICE simulation in the design process will be covered. Integrated MOS amplifier circuits are developed with an emphasis on understanding performance advantages and limitation in such areas as speed, noise and power dissipation. Simple circuits are combined to form the basic functional building blocks such as the op-amp, comparator, voltage reference, etc. These circuit principles will be explored in an IC design project, which may be fabricated in a commercial analog CMOS process. Examples of possible topics include sample-and-hold (S/H) amplifier, analog-to-digital (A/D) and digital-to-analog (D/A) converters, phase-locked loop (PLL), voltage-controlled oscillator, phase detector, switched capacitor and continuous-time filters, and sampled current techniques. (Prerequisite: Background in analog circuits both at the transistor and functional block (op-amp, comparator, etc.) level. Also familiarity with techniques such as small-signal modeling and analysis in the s-plane using Laplace transforms. Undergraduate course equivalent background EE 3204; EE 4902 helpful but not essential). EE 529. Selected Topics in Electronic System Design
Courses in this group are devoted to the study of advanced topics in electronic system design.

EE 530. High Performance Networks
(Same as CS 530) This course is an in-depth study of the theory, design and performance of high-speed networks. Topics include specific high-performance network architectures and protocols and emerging technologies including multimedia networks and quality-of-service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queuing models. (Prerequisite: EE 506/CS 513.)

EE 531. Principles of Detection and Estimation Theory
Detection of signals in noise, optimum receiver principles, M-ary detection, matched filters, orthogonal signals and representations of random processes. MAP and maximum likelihood estimation. Wiener filtering and Kalman filtering. Channel considerations: pre-whitening, fading and diversity combining. (Prerequisites: EE 502 and EE 504 or equivalent.)

EE 532. Digital Communications: Modulation and Coding
Studies various modulation techniques and coding schemes for digital communications over additive white Gaussian noise channels. Overview of communication networks, and relation to link design and modem design technology. Representation of bandpass signals. Binary and M-ary signaling, basic modulation techniques: PSK, FSK, PAM, QAM and MSK. Timing and phase recovery. Introduction to information theory, source coding and channel coding. Signaling with coded waveforms, soft decision and hard decision block codes, convolutional codes and Trellis Code Modulation. Characterization of time-dispersive band-limited channels and intersymbol interference (ISI). (Prerequisite: EE 502.)

EE 533. Advances in
Digital Communication
Methods for ISI reduction: linear, decision feedback, pass band and fractionally spaced equalizers; maximum likelihood sequence estimation (MLSE). Fast start-up equalization, blind equalization and echo-cancellation. Characterization of fading multipath channels such as troposcatter, HF, microwave line-of-sight, urban and indoor radio. Digital signaling over fading multipath channels. Methods to improve performance in fading multipath channels: diversity combining, coding and equalization. Introduction to spread spectrum communication; code division multiple access, performance in fading channels. Multiple access techniques in radio networks. (Prerequisite: EE 502 or equivalent).

EE 534. Adaptive Space-Time Filtering and Spectral Estimation
This course presents adaptive algorithms used in spatial beamforming and temporal filtering. It also includes algorithms used in spectral estimation. Topics covered include: single-channel (single-sensor) temporal processing and multi-sensor/multichannel spatial-temporal processing; FFT-based, nonparametric algorithms; channel estimation, Welch’s method, parametric spectral estimation, autoregressive modeling, Levinson-Durbin algorithms, Burg algorithm and maximum entropy method; lattice structures; and adaptive transversal filters. It also covers the LMS and RLS algorithms, algorithms based on parameter estimation using ML techniques, direction finding, conjugate gradient descent algorithms, Matrix decompositions, QR and SVD, and subspace tracking algorithms will also be covered. (Prerequisite: EE 502 and EE 503; 531 is recommended).

EE 535. Telecommunications Transmission Technologies
This course introduces the principal technologies used to implement the physical networking layer. These include high-speed electronic pulse shapers and receivers, optical sources, detectors, fiber media, active optical elements, RF devices and systems, and the related protocols and modulation schemes for reliable and multiuser communications (time, frequency, space and code-division multiplexing, error correction coding, spectral re-use, and so on). The course includes laboratory experiments. (Prerequisites: EE 502 or CS 504; undergraduate-level understanding of signal and circuit theory.)

EE 537. Advanced Computer and Communications Networks
(Same as CS 577) This course covers advanced topics in the theory, design and performance of computer and communication networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queuing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies. (Prerequisite: EE 506/CS 513 and EE 581/CS 533.)

EE 538. Wireless Information Networks
Overview of wireless information networks and personal communications systems: digital cellular, wireless PBX, cordless phone, wireless LAN, and mobile data, multimedia wireless and directions of the future. Radio propagation modeling for urban and indoor radio channels, coverage interface and cell size. Modulation techniques for efficient use of bandwidth resources. Methods to increase the data rate: antenna diversity and sectorization, adaptive equalization, multirate transmission and multiantipulse phase modulation. Spread spectrum for digital cellular, personal communications and wireless LAN applications. TDMA, CDMA, ALOHA, and CSMA, DECT, GSM, USDC, JDC, IEEE 802.11, WINForum, and HIPERLAN. (Prerequisite: Background in networks. Familiarity with probability, statistics and signal processing).

EE 539. Selected Topics in Communication Theory and Signal Processing
Topics from the following: sensitivity and error analysis in linear systems; band-limited signals; the uncertainty principle; bandwidth compression, nonstationary processes; radio and inter-symbol interference. Current problems in digital and analog communications; two-dimensional Fourier analysis; pattern recognition; Fourier optics. Time-series analysis, radar signals, graph theory and information theory. The content of this course will change from year to year.

EE 539A. Real-Time Digital Signal Processing
This course develops the ability to implement digital signal processing algorithms in real time. Topics: architectures of digital signal processors, with an emphasis on TMS320C6x (C6x); fixed- and floating-point processors; the VLIW architecture. Real-time implementation of algorithms including waveform generation, digital and adaptive filters, FFT, multirate processing. Input and output considerations. DSP tools and techniques. Programming using C/C++, with some assembly code. Final project required with real-time application using C6x. Laboratory exercises. (Prerequisite: EE 503 or permission of instructor.)

EE 539S. Mobile Data Networking
This course presents the principles of wireless data communications by introducing the state-of-the-art network architectures, standards and products, and explaining the key factors in evolution of this industry. Overview of wireless networks. Architecture of existing mobile data networks: ARDIS, Mobitex, TETRA, Merticom, CDPD and GPRS. Wireless LAN technologies: 802.11, HIPERLAN and wireless ATM. Effects of mobility on different ISO layers. Physical layer options. MAC layer in mobile environments. Issues in mobile computing. Mobile IP, IPv6, and DHCP. Mobility gateway technologies: MASE and eNetwork. InterTech roaming and handover for wireless data networks. (Prerequisite: Familiarity with communication networks [EE 506 or similar] is desirable.)

EE 541. Modern Control Theory
Theory of modern deterministic linear optimal control strategies for continuous and discrete-time systems are studied. Emphasis is on the state-space system description and multiple-input, multiple-output systems. Topics include: linearization of nonlinear systems, model reduction, pole assignment using state feedback, design and noninteracting (decoupled) systems, performance indices and specifications, deterministic linear optimal regulators, the Riccati equation and computational considerations, state reconstruction (full and reduced order observers), optimal linear output feedback control systems, and comparison of optimal and classical controllers. Where possible, examples from the current literature are used. (Prerequisites: Undergraduate courses in control theory and modern signal theory; EE 504 is recommended.)

EE 545. Digital Image Processing
(Same as CS 545) See CS 545 course description on page 84.

EE 549. Selected Topics in Control
Courses in this group are devoted to the study of advanced topics in the formulation and solution of theoretical or practical problems in modern control.

EE 559. Selected Topics in Energy Systems
Courses in this group are devoted to the study
of advanced topics in energy systems. Typical topics include optimal power flow, probability methods in power systems analysis, surge phenomena, design of electrical apparatus, transient behavior of electric machines and advanced electromechanical energy conversion.

EE 565. Physics and Technology of Integrated Semiconductor Devices
This course introduces a student to the physics of planar devices and develops an understanding of the limitations of device performance that result from the current planar technology. The course primarily considers silicon-based devices and technology, although the extensions to other systems is included. Solid-state technology: vapor phase growth, thermal oxidation, ion implantation, solid-state diffusion; theory of pn-junctions, bipolar transistors, field-effect transistors, metal insulator-semiconductor devices. (Prerequisite: Undergraduate background in semiconductor devices.)

EE 566. VLSI Design
VLSI Design introduces computer engineers and computer scientists to the techniques, methodologies and issues involved in conceptual and physical design of complex, digital integrated circuits. The course presupposes knowledge of computer systems and hardware design such as found in EE 505, but does not assume detailed knowledge of transistor circuits and physical electronics. (Prerequisite: EE 505 or equivalent.)

EE 569. Selected Topics in Solid State Courses
Courses in this group are devoted to the study of advanced topics in solid state, for example: degenerate semiconductors, many-body theory, elastic effects and phonon conduction, and solar cells. To reflect changes in faculty research interests, these courses may be modified or new courses may be added.

EE 572. Advanced Systems Architecture
(Same as CS 514) This course covers techniques such as caching, hierarchical memory, pipelining and parallelism, that are used to enhance the performance of computer systems. It compares and contrasts different approaches to achieving high performance in machines ranging from advanced microprocessors to vector supercomputers (CRAY, CYBER). It also illustrates how these techniques are applied in massively parallel SIMD machines (DAP, Connection Machine). In each case the focus is on the combined hardware/software performance achieved and the interaction between application demands and hardware/software capabilities. (Prerequisites: This course assumes the material covered in EE 505. The student should also have a background in computer programming and operating systems (CS 502). Familiarity with basic probability and statistics such as EE 502 or MA 541 is recommended.)

EE 574. VHDL Modeling and Synthesis
This is an introductory course on the VHDL (VHSCIC Hardware Description Language) for students with no background in VHDL or hardware modeling. In this course we will examine some of the important features of VHDL. The course will enable students to design, simulate, model and synthesize digital designs. The data flow, structural and behavioral modeling techniques will be discussed and related to how they are used to design combinational and sequential circuits. The use of test benches to exercise and verify the correctness of hardware models will also be described. Course projects will involve the modeling and synthesis of systems using the ECE department VHDL design tools. (Prerequisites: Logic circuits, programming in a high-level language such as C or Pascal, and a computer architecture course such as EE 505.)

EE 578. Cryptography and Data Security
(Same as CS 578) This course gives a comprehensive introduction into the field of cryptography and data security. The course begins with the introduction of the concepts of data security, where classical algorithms serve as an example. Different attacks on cryptographic systems are classified. Some pseudo-random generators are introduced. The concepts of public and private key cryptography are developed. As important representatives for secret key schemes, DES and IDEA are described. The public key schemes RSA and ElGamal, and systems based on elliptic curves are then developed. Signature algorithms, hash functions, key distribution and identification schemes are treated as advanced topics. Some advanced mathematical algorithms for attacking cryptographic schemes are discussed. Application examples will include a protocol for security in a LAN and a secure smart card system for electronic banking. Special consideration will be given to schemes which are relevant for network environments. For all schemes, implementation aspects and up-to-date security estimations will be discussed. (Prerequisites: Working knowledge of C; an interest in discrete mathematics and algorithms is highly desirable. Students interested in a further study of the underlying mathematics may register for MA 4891 [B term], where topics in modern algebra relevant to cryptography will be treated.)

EE 579. Selected Topics in Computer Engineering
Courses in this group are devoted to the study of advanced topics in computer engineering such as real-time intelligent systems, VLSI design and high-level languages.

EE 579R. Advanced Cryptography
This course provides deeper insight into areas of cryptography which are of great practical and theoretical importance. The three areas treated are detailed analysis and the implementation of crypto-algorithms, advanced protocols, and modern attacks against cryptographic schemes. The first part of the lecture focuses on public key algorithms, in particular ElGamal, elliptic curves and Diffie-Hellman key exchange. The underlying theory of Galois fields will be introduced. Implementation of performance security aspects of the algorithms will be looked at. The second part of the course deals with advanced protocols. New schemes for authentication, identification and zero-knowledge proof will be introduced. Some complex protocols for real-world application—such as key distribution in networks and for smart cards—will be introduced and analyzed. The third part will look into state-of-the-art cryptoanalysis (i.e., ways to break cryptosystems). Brute force attacks based on special purpose machines, the baby-step giant-step and the Pohlig-Hellman algorithms will be discussed. (Prerequisites: EE 578/CS 578 or equivalent background.)

EE 579S. Computer Security
This course provides a comprehensive introduction to the field of computer security. Security architectures and their impact on computers are examined. Critical computer security aspects are identified and examined from the standpoints of both the user and the attacker: physical security, communications security, system security and operational security. Computer system vulnerabilities are examined, and mitigating approaches are identified and evaluated. Concepts and procedures for computer and computer network risk analysis are introduced. An overview of computer security statutes and case law is presented. The course emphasizes a timely approach, maintained by using recent examples of computer attacks and the resources available to deal with the rapidly changing framework of computer security. (Prerequisites: Working knowledge of computers, basic computer net-
works and a programming language.)

EE 579T. Network Security
This course provides a comprehensive introduction to the field of network security. Network architectures and protocols and their impact on security are examined. Critical network security aspects are identified and examined from standpoints of both the user and the attacker. Network vulnerabilities are examined, and mitigating approaches are identified and evaluated. Concepts and procedures for network risk analysis are introduced. Integration of network and computer security is introduced. An overview of statutes and case law affecting network security is presented. The course emphasizes a timely approach, maintained by using recent examples of network vulnerability. (Prerequisites: Working knowledge of computers, basic computer networks, computer security, and a programming language.)

EE 581. Modeling and Performance Evaluation of Network and Computer Systems
(3) Methods and concepts of computer and communication network modeling and system performance evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service and priority systems; work load characterization; performance evaluation problems. (Prerequisites: CS 504 or EE 502, or equivalent background in probability.)

EE 595. Computer and Communications Networks Internship
6 credits
(3) This project will provide an opportunity to put into practice the principles which have been studied in previous courses. It will generally be conducted off campus and will involve a real-world networking situation. Overall conduct of the internship will be supervised by a WPI faculty member, and an on-site liaison will direct day-to-day activity. The project must include substantial analysis and/or design related to computer or communications networking, and will conclude with a substantial written report. A public oral presentation must also be made to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison, and one additional WPI faculty member. Successful completion of the internship will be verified by this committee. For a student from industry, an internship may be sponsored by his or her employer. (Prerequisite: Completion of 12 credits in the program.)

EE 596A and EE 596B. Graduate Seminars
The presentations in the graduate seminar series will be of tutorial nature and will be presented by recognized experts in various fields of electrical and computer engineering. All full-time graduate students will be required to take both seminar courses, EE 596A and EE 596B, once during their graduate studies in the Electrical and Computer Engineering Department. The course will be given Pass/Fail. (Prerequisite: Graduate standing.)

EE 597. Independent Study
Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. Can be technical in nature, or a review of electrical and computer engineering history and literature of importance and permanent value. (Prerequisite: B.S. in EE or equivalent.)

EE 598. Directed Research
Each student will work under the direct supervision of a member of the department staff on an experimental or theoretical problem which may involve an extensive literature search, experimental procedures and analysis. A comprehensive report in the style of a technical report or paper and an oral presentation are required. (A maximum of two registrations in EE 598 is permitted.) (Prerequisite: Graduate standing.)

EE599 Thesis
EE 630. Advanced Topics in Signal Processing
The course will cover a set of important topics in signal and image analysis: orthogonal signal decomposition, wavelet transforms, analytic signals, time-frequency estimation, 2D FT, Hankel transform and tomographic reconstruction. The presentation will be given at a level appropriate for fire protection engineers, and will generally be conducted off campus and will involve a real-world networking situation.

EE 650. Advanced Topics in Network and Computer Systems
This course will provide an opportunity to put into practice the principles which have been studied in previous courses. It will generally be conducted off campus and will involve a real-world networking situation. Overall conduct of the internship will be supervised by a WPI faculty member, and an on-site liaison will direct day-to-day activity. The project must include substantial analysis and/or design related to computer or communications networking, and will conclude with a substantial written report. A public oral presentation must also be made to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison, and one additional WPI faculty member. Successful completion of the internship will be verified by this committee. For a student from industry, an internship may be sponsored by his or her employer. (Prerequisite: Completion of 12 credits in the program.)

EE 504 Analysis of Deterministic Signals and Systems, undergraduate course in linear systems theory and vector calculus.)

EE699 Ph.D. Dissertations

Fire Protection Engineering
FPE 510. Flammability Tests, Codes and Standards
Code-related fire tests standards will be presented at a level appropriate for fire protection engineers in a format which includes background on perceived need to regulate, analysis of the value and limitation of test methodology, and effectiveness of code requirements to control combustible materials and mitigate particular fire hazards. Fire test standards selected for discussion provide data and results which relate to surface flame spread, fire penetration, smoke obscuration, toxic potency of combustion products, and rate of heat release for products and systems including interior finish, wall and floor assemblies, thermal insulation, furniture, bedding and draperies.

FPE 520. Fire Modeling
Advanced topics in fire dynamics, combustion and compartment fire behavior will be discussed within a framework of modeling fire and its effects. Topics include computer modeling of pre-flashover and post-flashover compartment fires, burning characteristics of polymers and other fuels, the effect of fire retardants, products of combustion generation, flame spread models, plume and ceiling jet models, and overall toxicity assessment. Some familiarity with computer programming is recommended. (Prerequisite: EE 521 or permission of the instructor.)

FPE 521. Fire Dynamics I
This course introduces students to fundamentals of fire and combustion and is intended to serve as the first exposure to fire dynamics phenomena. The course includes fundamental topics in fire and combustion such as thermodynamics of combustion, fire chemistry, premixed and diffusion flames, solid and liquid burning, ignition, plumes and ceiling jets. These topics are then used to develop the basis for introducing compartment fire behavior, pre- and post-flashover conditions and smoke movement. (Prerequisites: Undergraduate chemistry, thermodynamics or physical
COURSE DESCRIPTIONS

FPE 553. Fire Protection Systems
This course provides an introduction to automatically activated fire suppression and detection systems. A general overview is presented of relevant physical and chemical phenomena, and commonly used hardware in automatic sprinkler, gaseous agent, foam and dry chemical systems. Typical contemporary installations and current installation and approval standards are reviewed. (Prerequisites: Undergraduate courses in chemistry, fluid mechanics and either thermodynamics or physical chemistry.)

FPE 554. Advanced Fire Suppression
Advanced topics in suppression systems analysis and design are discussed with an aim toward developing a performance-based understanding of suppression technology. Automatic sprinkler systems are covered from the standpoint of predicting actuation times, reviewing numerical methods for hydraulic analyses of pipe flow networks and understanding the phenomenology involved in water spray suppression. Special suppression systems are covered from the standpoint of two-phase and non-Newtonian pipe flow and simulations of suppression agent discharge and mixing in an enclosure. (Prerequisite: FPE 553 or special permission of instructor.)

FPE 555. Detection, Alarm and Smoke Control
Principles of fire detection using flame, heat and smoke detector technology are described. Fire alarm technology and the electrical interface with fire/smoke detectors are reviewed in the context of contemporary equipment and installation standards. Smoke control systems based on buoyancy and HVAC principles are studied in the context of building smoke control for survivability and safe egress. (Prerequisites: FPE 553. Also FPE 521, which can be taken concurrently.)

FPE 563. Risk Management
(Same as MG 541 Operations Risk Management) See MG 541 course description on page 92.

FPE 565. Firesafety Engineering Evaluation
This course develops techniques to evaluate the firesafety performance of a variety of facilities of the built environment and to produce management plans for decision making. The framework for this course is a firesafety engineering method which decomposes the firesafety system into discrete elements suitable for quantitative evaluation using a variety of fire protection engineering and fire science materials. (Prerequisites: FPE 521, FPE 553 and FPE 570.)

FPE 570. Building Firesafety I
This course focuses on the presentation of qualitative and quantitative means for firesafety analysis in buildings. Fire test methods, fire and building codes and standards of practice are reviewed in the context of a systematic review of firesafety in proposed and existing structures.

FPE 571. Performance-Based Design
This course covers practical applications of fire protection engineering principles to the design of buildings. Both compartmented and non-compartmented buildings will be designed for criteria of life safety, property protection, continuity of operations, operational management and cost. Modern analytical tools as well as traditional codes and standards are utilized. Interaction with architects and code officials, and an awareness of other factors in the building design process are incorporated through design exercises and a design studio. (Prerequisites: FPE 553, FPE 521 and FPE 570, or special permission of the instructor.)

FPE 572. Failure Analysis
Development of fire investigation and reconstruction as a basis for evaluating and improving firesafety design. Accident investigation theory and failure analysis techniques such as fault trees and event sequences are presented. Fire dynamics and computer modeling are applied to assess possible fire scenarios and the effectiveness of fire protection measures. The product liability aspects of failure analysis are presented. Topics include products liability law, use of standard test methods, warnings and safe product design. Application of course materials is developed through projects involving actual case studies. (Prerequisite: FPE 521 or special permission of the instructor.)

FPE 573. Industrial Fire Protection
Principles of fire dynamics, heat transfer and thermodynamics are combined with a general knowledge of automatic detection and suppression systems to analyze fire protection requirements for generic industrial hazards. Topics covered include safe separation distances, plant layout, hazard isolation, smoke control, warehouse storage, and flammable liquid processing and storage. Historic industrial fires influencing current practice on these topics are also discussed. (Prerequisites: FPE 553, FPE 521 or special permission of the instructor.)

FPE 574 (CM 594). Process Safety Management
This course provides basic skills in state-of-the-art process safety management and hazard analysis techniques including hazard and operability studies (HAZOP), logic trees, failure modes and effects analysis (FMEA), and consequence analysis. Both qualitative and quantitative evaluation methods will be utilized. Following a case study format, these techniques along with current regulatory requirements will be applied through class projects addressing environmental health, industrial hygiene, hazardous materials, and fire or explosion hazard scenarios. (Prerequisite: An undergraduate engineering or physical science background.)

FPE 575. Explosion Protection
Principles of combustion explosions are taught along with explosion hazard and protection applications. Topics include a review of flammability limit concentrations for flammable gases and dusts; thermochemical equilibrium calculations of adiabatic closed-vessel deflagration pressures, and detonation pressures and velocities; pressure development as a function of time for closed vessels and vented enclosures; the current status of explosion suppression technology; and vapor cloud explosion hazards.

FPE 580. Special Problems
Individual or group studies on any topic relating to fire protection may be selected by the student and approved by the faculty member who supervises the work.

FPE 581. Seminar
0 credits
Reports on current advances in the various branches of fire protection.

FPE 587. Fire Science Laboratory
This course provides overall instruction and hands-on experience with fire-science-related experimental measurement techniques. The objective is to expose students to laboratory-scale fire experiments, standard fire tests and state-of-the-art measurement techniques. The lateral ignition and flame transport (LIFT) apparatus, state-of-the-art smoke detection
systems, closed-cup flashpoint tests and gas analyzers are among the existing laboratory apparatus. Fire-related measurement techniques for temperature, pressure, flow and velocity, gas species and heat fluxes, infrared thermometry, laser doppler velocimetry (LDV) and laser-induced fluorescence (LIF) will be reviewed. (Prerequisite: FPE 521.)

FPE 590. Thesis
Research study at the M.S. level.

FPE 592. Graduate Project
This activity requires the student to demonstrate the capability to integrate advanced fire-safety science and engineering concepts into the professional practice environment. The work may be accomplished by individuals or small groups of students working on the same project. This practicum requires the student to prepare detailed, written technical reports and make oral presentations to communicate the results of their work.

FPE 690. Ph.D. Dissertation

Interdisciplinary

IDG 501. Seminar in College Teaching
2 credits
This seminar is designed to acquaint graduate students with some of the basic principles and theories of education and with instructional practices associated with effective college teaching. This information applies without regard to the particular nature of the subject matter being taught; the emphasis is on the educational process, not the disciplinary content. Course activities include readings, lectures, discussion, and individual and group projects. Topics covered include an introduction to learning theories, cognitive development and motivation for learning; effective teaching skills such as lecturing, class discussion, active and cooperative learning, and use of instructional technology; evaluating student performance; and life as a college professor. Students who have completed IDG 501 will be prepared for IDG 502 Practicum in College Teaching, which is offered as an independent study on demand.

Management

MG501. Financial Accounting
2 credits
This course is an introduction to the accounting process, its underlying concepts, and the techniques of preparing and analyzing financial statements. Students are introduced to issues in accounting for assets, liabilities and stockholders’ equity, and issues in revenue and expense recognition. The course demonstrates the role of accounting information for users outside the firm, and the application of accounting numbers in financial analyses and market decisions. Where appropriate, emphasis is given to technology-oriented firms.

MG 502. Finance
2 credits
This course introduces students to the foundations of modern finance. The student is expected to gain an understanding of the time value of money, basic security valuation, investment criteria, capital market history, portfolio theory, and exchange rate risk. These topics are taught using a problem-oriented approach with an emphasis on conceptual understanding and the acquisition of the appropriate analytical and quantitative skills. (Prerequisites: MG 501 or equivalent content, and a knowledge of college algebra and basic statistics.)

MG 503. Organizational Behavior
2 credits
This course introduces concepts, theories and current research in the effective management of organizations. Topics include the basics of systems thinking, as well as team and group dynamics. The role of perception and motivation in the behavior of the individual is addressed. Cases, workshops and readings are integrated in a cohesive approach to management problems.

MG 504. Operations Management
2 credits
This course provides students with a broad conceptual framework for evaluating operations management practices, and for developing useful intuition into the strategies and tactics that companies are employing to become world-class firms. Major topics are divided into two categories: (1) decisions on the design issues, including operations strategy, management of technology, process management, statistical process control, total quality management, capacity planning, facility location and facility layout; and (2) decisions on planning and controlling, such as supply chain management, forecasting, aggregate planning, inventory control, material requirements planning, just-in-time, lean manufacturing principle, scheduling, project management and others.

MG 505. Quantitative Methods
2 credits
This course provides the background by which a modern manager may understand and apply quantitative methods. Topics covered include descriptive state, probability theory, measures of dispersion and hypothesis testing, and confidence descriptions. Additional discussion focuses on correlation and regression analysis, as well as analysis of variance and time series mathematics as applied to business analysis.

MG 506. Principles of Marketing
2 credits
This course provides the background by which managers may understand consumer and industrial decision making. Topics covered include segmentation and target marketing, market research, competitor analysis and marketing information systems. Additional discussion focuses on the development of a marketing plan and positioning of the product. Attention is also paid to product management, new product development, promotion, price and distribution. Both national and global aspects of these issues are discussed.

MG 507. Management Information Systems
2 credits
This course focuses on information technology and management. Topics covered are information technology and organizations, information technology and individuals (privacy, ethics, job security, job changes), information technology within the organization (technology introduction and implementation), business process engineering and information technology between organizations (electronic data interchange and electronic commerce).

MG 508. Economics of the Firm
2 credits
This course covers the basic concepts of supply and demand. Various forms of business organization (e.g., corporations, partnerships) are discussed. Attention is paid to both consumer behavior (e.g., utility theory) and firm behavior (including production theory and cost analysis). Alternative market structures, including output markets (e.g., competition, monopoly) and inputs (e.g., labor, capital) are addressed. Additional topics include the government regulation of markets (e.g., antitrust laws), international trade, and public and merit goods.

MG 509. Domestic and Global Economic Environment of Business
2 credits
This course addresses the role of government in the economy, including concepts of income redistribution, taxation and stabilization. The fundamentals of aggregate demand and supply are also discussed. Topics include the concept and measurement of aggregate output and input (e.g., Gross Domestic Product [GDP]); Keynesian and post-Keynesian income determination analysis; fiscal policy (including government deficits and the public debt); monetary policy, the role of the Federal Reserve, and the banking system; economic growth; international trade and exchange rate determination.

MG 511. Interpersonal and Leadership Skills for Technological Managers
This course provides a background on the new technological organization, including new employment relationships and organizational forms. Attention is focused on cultural dynamics and diversity, including national, global and ethical issues. The importance of teams and leadership in the networked organization are addressed. Assignments include case analyses, individual and group projects and presentations. (Prerequisite: MG 503 or equivalent content, or consent of instructor.)

MG 512. Creating and Implementing Strategy in Technological Organizations
This course focuses on understanding the market and the importance of market research, customer needs, competitor analysis, business environment and forecasting. The development of ethical and effective strategy is discussed, including exploiting and developing the core competencies of the organization. Promoting and developing interfunctional and international communication and cooperation are addressed. Special attention is paid to the integration of emerging technologies. Other areas covered include assessment analysis, including controlling quality and tracking customer response. (Prerequisite: MG 506 or equivalent content, or consent of the instructor.)

MG 513. Creating Processes in Technological Organizations
This course introduces students to the critical role of processes in modern technological organizations. This course addresses organizational, technical and ethical issues related to designing, analyzing and reengineering business process. Techniques and tools for process design are covered. Key global processes such as customer service, order fulfillment, and goods/services creation and distribution processes and their enabling information technology are studied in detail. (Prerequisites: MG503, MG 504 and MG 507 or equivalent content, or consent of instructor.)

MG 514. Business Analysis for Technological Managers
4 credits
This course provides an understanding of the concepts and tools of business analysis. One major focus emphasizes how accounting information aids the planning, control, decision making and evaluation of the firm’s operations, through cost accounting techniques, budgetary analysis, control and evaluation of operations using accounting information, and analysis of how accounting information can advance a firm’s goals and strategies. This course also provides an introduction to the strategic role of financial management, analysis of company performance, the impact of major corporate decisions, the relationship among major stakeholders of the firm and cash management. (Prerequisites: MG 501, MG 502, MG 505, MG 506 and MG 508 or equivalent content, or consent of instructor).

MG 515. Legal and Ethical Context of Technological Organizations
2 credits
This course introduces students to U.S. and International law, examining the structure, function and development of the areas of law most important to the conduct of business. Heavy emphasis is given to approaches to ethical analysis for decision making. Students will gain a sound understanding both of the basic areas of law (torts, contracts, property and constitutional law) and of the analytical principles that govern the application of law generally. The course will also touch on the areas of intellectual property law, business formation and organization, international business law, securities regulation, cyber law and e-commerce, antitrust law, employment law and environmental law. The course focuses on practical considerations and makes extensive use of case studies. In addition to analyzing the legal mandates that restrict and guide the conduct of business, the course discusses and debates ethical considerations that often confront managers.

MG 516. Graduate Qualifying Project in Management (GQP)
4 credits
This course integrates management theory and practice, and incorporates a number of skills and tools acquired in the M.B.A. curriculum. The medium is a major project, often for an external sponsor, that is completed individually or in teams. In addition to a written report, the project will be formally presented to members of the department, outside sponsors and other interested parties. (Prerequisites: All foundation and core courses or equivalent content, or consent of instructor.)

MG 531. Managing Organizational Change
This course focuses on the design and implementation of organizational change. The course is developed around important theories of change using technology-based organizations as case studies. The course also emphasizes the roles and responsibilities of change management with particular reference to the strategists, implementers and recipients of change.

MG 533. Negotiations
This course focuses on improving the student’s understanding of the negotiation process and effectiveness as a negotiator. Emphasizes issues related to negotiating within and on behalf of organizations, the role of third parties, the sources of power within negotiation, and the impact of gender, culture and other differences. Conducted in workshop format, combining theory and practice.

MG 53X. Virtual Teams
This course focuses primarily on helping students understand the challenges of working on virtual teams, and identify and practice more effective ways to manage those challenges. It is totally Web-based and relies on the Blackboard course management and communication tool to serve as the venue where each virtual team will meet, work and learn about the opportunities and pitfalls of virtual team participation.

MG 541. Operations Risk Management
(Same as FPE 563) Operations risk management deals with decision making under uncertainty. It is interdisciplinary, drawing upon management science, engineering economy and managerial decision making, along with material from cognitive psychology and sociology. Classic methods from risk assessment and risk evaluation are first covered and then applied, from the perspective of business process improvement, across a broad set of operations management problems. A course
This course focuses on planning, implementing, measuring and evaluating productivity improvement efforts in both manufacturing and service organizations, including overall strategies as well as specific techniques for improving productivity. Both the technological and behavioral aspects of productivity improvement are covered.

MG 549. Strategies for Manufacturing and Service Firms

This course focuses on developing and implementing strategies for product design that will best support the overall strategy of the firm. Topics include: positioning the product and production system in the industry, location and capacity decisions, selecting and implementing manufacturing or service technologies, planning, vertical integration, and developing organizations, cultures and policies for implementation. Case studies of manufacturing and service firms are utilized extensively. (Prerequisite: MG 504 or equivalent content, or consent of instructor.)

MG 54X. Global Operations Strategy

This course focuses on operations strategy from a global perspective. Topics such as strategy of logistics and decisions to outsource are examined. These topics will include the strategic issues concerned with firms, for example, that are doing R&D in the United States, circuit board assembly in Ireland and final assembly in Singapore. Cases are used, as well as textbooks and recent articles relating to this topic. A term paper based on actual cases is required.

MG 561. Marketing Research

A survey of market research techniques and information management. Effective technology marketing requires timely and accurate market information, analysis and dissemination. This course will prepare the student to work effectively with secondary data sources, design market research studies, interpret market research results, work effectively with research providers, and understand the dynamics of information use. Topics include: secondary data sources, experimental design, sampling, questionnaire design, the management of field work, qualitative analysis, forecasting, univariate and multivariate data analysis, report dissemination, development of market information systems, factors affecting research use, and ethical issues associated with collecting and using data. (Prerequisites: MG 505 and MG 506, or equivalent content, or consent of instructor.)

MG 563. Marketing of Emerging Technologies

This course focuses on the new product development process in high-tech corporations, from idea generation through launch. Topics include: understanding customer responses to innovation, engaging customers in the innovation process, developing the marketing mix for new products (product features and benefits, pricing, channel selection, communications), new product introduction timing and competitive positioning. Particular emphasis is placed on how new products can be used to generate firm growth and renewal in a dynamic environment, and on the challenges of incorporating emerging technologies in new products. Basic knowledge of marketing management is assumed.

MG 564. Global Technology Marketing

Extending technology to global markets requires an understanding of consumer behavior in different cultures, and effective management of risk and overseas infrastructures. This course addresses the issues associated with technology application in new markets and includes the following topics: consumer behavior differences in international markets and the implications for the marketing mix, cultural differences that affect business practices in new markets, managing exchange rate fluctuation, factors that affect manufacturing and research location, the impact of local government on marketing decision making, and the use of strategic alliances to acquire expertise and manage risk in global market development. Knowledge of marketing management is assumed.

MG 566. Marketing and Electronic Commerce

This course discusses the tools and techniques being used today to harness the vast marketing potential of the Internet. It examines various Web-based business models for effectively and efficiently using the net as a strategic market-
ing tool for new products, market research, direct and indirect distribution channels, and marketing communications. The course considers both business-to-consumer and business-to-business applications, and explores the major opportunities, limitations and issues of profiting from the Internet.

MG 571. Database Applications Development Business applications are increasingly centered on databases and the delivery of high-quality data throughout the organization. This course introduces students to the theory and practice of computer-based data management. It focuses on the design of database applications that will meet the needs of an organization and its managers. The course also covers data security, data integrity and data distribution. Students will be exposed to commercially available database management systems, such as MS/Access and SQL Server. As a project during the course, students will design and implement a small database that meets the needs of some real-world business data application.

MG 572. Telecommunications Management and Electronic Commerce Telecommunications is an integral part of the way work is done in today’s business organizations. This course provides students with the technical and managerial background of telecommunications and its applications in electronic commerce. It covers the technical fundamentals of data transmission, local area networks, local Internetworking and enterprise Internetworking. The issues involved in developing and managing an organization’s telecommunications infrastructure will be discussed. This course also examines the role of telecommunications technology, especially the Internet, in electronic commerce, and surveys current topics in electronic commerce. As a course project, students will learn to use commercially available Web development tools to design and implement a small Web-based business application.

MG 573. System Design and Development This course introduces students to the concepts and principles of systems analysis and design. It covers all aspects of the systems development life cycle, from project planning and management through requirements identification, process and data modeling, system design and implementation. Object-oriented analysis techniques will be introduced. Students will learn to use an upper level CASE (computer-aided software engineering) tool, which they will employ in completing a real-world systems analysis and design project. (Prerequisite: MG 571 or consent of the instructor.)

MG 575. Information and Decision Support Systems This course analyzes how managers make decisions and the information they need to make these decisions. It focuses on the planning, deployment and use of information systems and technologies for delivering high-quality information to managers and for supporting their decision making. This is primarily a case-based course. The cases include examples of the design and implementation of a variety of information technologies to support organizational operations as well as managerial decision making. The information technologies covered in the cases include enterprise systems, decision support systems, expert systems, group support systems and executive information systems. Students will analyze case studies, write short papers and investigate new information technologies for ensuring that high-quality information is accessible to an organization and its managers as needed. (Prerequisite: MG 571 or consent of the instructor.)

MG 576. Project Management This course presents the specific concepts, techniques and tools for managing projects effectively. The role of the project manager as team leader is examined, together with important techniques for controlling cost, schedules and performance parameters. Lectures, case studies and projects are combined to develop skills needed by project managers in today’s environment.

MG 592. New Venture Management and Entrepreneurship Entrepreneurship has been defined as the “pursuit of opportunity without regard to resources currently held.” This course is intended to introduce students to a new way of thinking (the pursuit of opportunity) and a new set of economic relationships (without regard to resources currently held) through its requirement that they plan and launch a new e-commerce venture. Topics will include opportunity recognition and evaluation, new venture teams, the business plan, venture finance and resource requirements, and harvesting the venture.

MG 597. Internship The internship is an elective-credit option designed to provide an opportunity to put into practice the principles which have been studied in previous courses. Internships will be tailored to the specific interests of the student. Each internship must be carried out in cooperation with a sponsoring organization, generally from off campus, and must be approved and advised by a WPI faculty member in the Department of Management. Internships may be proposed by the student or by an off-campus sponsor. The internship must include proposal, design and documentation phases. Following the internship, the student will prepare a report describing his or her internship activities and will make a presentation before a committee including the Faculty Advisor and a representative from the sponsoring organization. Students are limited to one 3-credit, semester-length internship experience. The internship may not be completed at the student’s place of employment. (Prerequisite: Completion of the required component of the individual student’s graduate management degree program.)

MG 598. Data Mining This course will introduce a variety of data mining tools and techniques through the consideration of business problems for which these tools have proven to be successful. By focusing on such business situations as credit scoring, churn management and customer segmentation, we will motivate, describe and use the techniques of decision trees, logistic regression, artificial neural nets and cluster analysis, among others. The use of data mining tools and the business interpretation of their output will be central to this course. Roughly half the class time will be given to lectures on the techniques and their associated general applications, while the remaining time will be an applications laboratory in which these tools are used to analyze data and solve realistic business problems. Some experience in basic data analysis is required, and familiarity with basic statistical tools (e.g., contingency tables and regression) is advised.

MG 598. Independent Study Directed in-depth independent study or seminar program following one or more of the core areas of management. Independent study can
focus on a major problem in manufacturing, information systems, health systems, energy, government, etc. Each student must have a designated Faculty Advisor who must approve the subject and methodology in advance. Before registering for independent study, students should contact the director of graduate management programs.

MG 599. Thesis
6 to 9 credits
Research study at the master’s level.

Manufacturing Engineering

MFE 500. Current Topics in Manufacturing Seminar
0 credits
This seminar identifies the typical problems involved in a variety of manufacturing operations, and generic approaches for applying advanced technologies to implement operations. Topical areas of application and development such as intelligent materials processing, automated assembly, MRPII and JIT scheduling, vision recognition systems, high-speed computer networks, distributed computer control of manufacturing processes and flexible manufacturing systems may be covered. This seminar is coordinated with the undergraduate program in manufacturing engineering.

MFE 510. Control and Monitoring of Manufacturing Processes
Covers a broad range of topics centered on control and monitoring functions for manufacturing, including process control, feedback systems, data collection and analysis, scheduling, machine-computer interfacing and distributed control. Typical applications are considered with lab work.

MFE 511. Application of Industrial Robotics
(Concurrent with ME 4815) This course introduces the student to the field of industrial automation. Topics covered include robot specification and selection, control and drive methods, part presentation, economic justification, safety, implementation, product design and programming languages. The course combines the use of lecture, project work and laboratories that utilize industrial robots. Theory and application of robotic systems will be emphasized.

MFE 520. Design and Analysis of Manufacturing
The first half of the course covers the axiomatic design method, applied to simultaneous product and process design for concurrent engineering, with the emphasis on process and manufacturing tool design. Basic design principles as well as qualitative and quantitative methods of analysis of designs are developed. The second half of the course addresses methods of engineering analysis of manufacturing processes, to support machine tool and process design. Basic types of engineering analysis are applied to manufacturing situations, including elasticity, plasticity, heat transfer, mechanics and cost analysis. Special attention will be given to the mechanics of machining (traditional, nontraditional and grinding) and the production of surfaces. Students, with the advice and consent of the professor, select the topic for their term project.

MFE 530. Computer-Integrated Manufacturing
(Same as MG 543) An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. (Prerequisites: Recommended background courses—MG 504, MG545.)

MFE 540. Design for Manufacturability
The problems of cost determination and evaluation of processing alternatives in the design-manufacturing interface. Approaches for introducing manufacturing capability knowledge into the product design process are covered, with emphasis on part and process simplification, analysis of alternative manufacturing methods based on anticipated volumes and design for automated assembly.

MFE 594. Special Topics
Theoretical and experimental studies in subjects of interest to graduate students in manufacturing engineering. (Prerequisite: Consent of instructor.)

MFE 594T. Surface Metrology: Measurement and Analysis of Surface Textures
This course examines the methods for measuring and analyzing surface texture (roughness) in order to make functional correlations between the texture and performance, and to improve the understanding of texture-dependent surface phenomena like adhesion, scattering, fracture, friction and wear. Selection of surface measurement instruments and analysis methods, including fractal-based analysis, for finding functional correlations, quality control and the design of surface textures will be discussed. Examples from a broad range of applications will be discussed, including skin, runways, thermal spray adhesion, hard disks, machining and grinding.

MFE 598. Directed Research
3 to 6 credits
MFE 599. Thesis Research
Maximum 3 credits

Materials Science and Engineering

Research—As arranged.
Additional acceptable courses, 4000 series, may be found in the Undergraduate Catalog.

MTE 580. Materials Science and Engineering Seminar
Reports on the state-of-the-art in various areas of research and development in materials science and engineering will be presented by the faculty and outside experts. Reports on graduate student research in progress will also be required.

MTE 581. Phase Transformations
Applications of thermodynamics, kinetics and diffusion to phase transformations. Modeling of materials systems, phase diagrams and invariant reactions are presented. (Prerequisites: ME 4840 and ME 4850 or equivalent.)

MTE 5810. X-Ray and Electron Microscopy
Diffraction theory studied as a basis for understanding and for determining crystal structures of polycrystalline solids. Quantitative phase analysis. Experimental methods applied to materials engineering. (Prerequisite: ME 4840 or equivalent.)

MTE 5811. Physical Ceramics
Examination of the interrelationships among crystal structure, microstructure, processing and properties. Fundamentals of microstructure development; nucleation, grain growth, precipitation, sintering, vitrification. Mechanical, optical, electrical, magnetic properties in various ceramic systems and their relationship to microstructure will be discussed. (Prerequisite: ME 4813.)

MTE 5812. Advanced
Microstructural Analysis
Quantitative optical microscopy. Electron microscopy; replica and transmission techniques. Selected topics. Course may be offered by special arrangement. (Prerequisites: ME 3811 and ME 4840 or equivalent.)

MTE 582. Mechanical Behavior of Materials
Topics including plastic deformation, creep, fatigue, fracture and metal forming are presented and discussed. (Prerequisite: ME 3023 or equivalent.)

MTE 5822/MFE 5822. Solidification Processes
A course designed for in-depth study of industrial processes based on liquid-solid transformations. Fundamentals are developed and applied to commercial processes. The topics covered include qualitative treatment of casting processes, sand casting, die casting, investment casting, semisolid forming, various welding processes, laser welding, rapid solidification, spray forming, compocasting and other emerging technologies which utilize liquid-solid transformations. Library and laboratory work will be included. (Suggested preparation: an understanding of heat transfer, fluid flow, solid state diffusion and microscopy [ES 2001, ES 3003, ES 3004, ME 3811, ME 4840] or equivalent.) Offered in the 2000/2001 academic year and in alternate years thereafter.

MTE 5823/MFE 5823. Particulate Processing of Materials
Particulate processing is used to manufacture net-shaped components from particulate materials as in powder metallurgy (PM), metal injection molding (MIM) and the processing of ceramic and refractory materials. Processing of particulate materials is covered in detail, including atomization to produce powders, compaction, sintering and postsintering operations. Interfacial issues to control flow and final density are studied, as are the fundamentals of phase flow, compaction and densification. Industrial applications and plant trips will augment classroom experience. (Suggested background: [ES 2001, ME 2820, ME 3811, ME 4840] or equivalent.) Offered in the 1999/2000 academic year and alternate years thereafter.

MTE 583. Analytical Methods in Materials Engineering
Heat transfer and diffusion kinetics are applied to the solution of materials engineering problems. Mathematical and numerical methods are developed for solutions to Fourier’s and Fick’s laws for a variety of boundary conditions. Primary emphasis is given to heat treatment and surface modification processes. (Prerequisites: ME 3811 and ME 4840 or equivalent.)

MTE 584. Polymer Engineering
Structure-property relationships are developed for polymeric materials. Characterization techniques are discussed. Special emphasis is given to the mechanical, corrosion, fracture properties and processing of polymers. Course may be offered by special arrangement.

MTE 5841. Surface Metrology and Tribology
This course examines the methods for measuring and analyzing surface texture (roughness) in order to make functional correlations between the texture and performance, and to improve the understanding of texture-dependent surface phenomena like adhesion, scattering, friction, friction and wear. Tribology, the study of friction, lubrication and wear, will be reviewed in the context of surface texture. Selection or surface measurement instruments and analysis methods, including fractal-based analysis, for finding functional correlations, for quality control and for the design of surface textures will be discussed. Examples from a broad range of applications will be discussed, including skin, runways, thermal spray adhesion, hard disks, machining and grinding.

MTE 5842. Corrosion and Corrosion Control
Advanced topics in corrosion. Stress corrosion cracking and hydrogen effects on metals. High-temperature oxidation, carburization and sulfidation. Discussions focus on current corrosion engineering problems and research. Course may be offered by special arrangement.

MTE 585. Thermodynamics of Materials
The thermodynamics of surfaces, interfaces and defects in solids is presented. The applications to metals and ceramics are discussed. The application of thermodynamics to electrochemical reactions and reactions between gases and alloys also will be developed. Course may be offered by special arrangement. (Prerequisites: ME 3811, ME 4840 and ME 4850 or equivalent.)

MTE 520. Design and Analysis of Manufacturing Processes
The first half of the course covers the axiomatic design method applied to simultaneous product and process design for concurrent engineering, with emphasis on process and manufacturing tool design. Basic design principles as well as qualitative and quantitative methods of analysis of designs are developed. The second half of the course addresses methods of engineering analysis of manufacturing processes, to support machine tool and process design. Basic types of engineering analysis are applied to manufacturing situations including elasticity, plasticity, heat transfer, mechanics and cost analysis. Special attention will be given to the mechanics of machining (traditional, nontraditional and grinding) and the production of surfaces. Students, with the advice and consent of the professor, select the topic for their term project.

MTE 554. Composites with Biomedical and Materials Applications
Introduction to fiber/particulate reinforced, engineered and biologic materials. This course focuses on the elastic description and application of materials that are made up of a combination of submaterials, i.e., composites. Emphasis will be placed on the development of constitutive equations that define the mechanical behavior of a number of applications including biomaterial, tissue and materials science. (Prerequisites: Understanding of stress analysis and basic continuum mechanics.)

MTE 570. Electronic, Magnetic and Optical Materials Science and Processing
This course discusses the fundamentals of materials science and processing for information technology devices. Optical, electrical and magnetic properties of materials will be studied. The theory and technology of integrated circuit fabrication will be presented. The focus will be on understanding the underlying physical principles of the unit processes which are the basis for most fabrication steps, such as bulk crystal growth, thin film deposition, lithography, metallization, ion implantation, etching, reliability, electrical behavior and materials device characterization. The emphasis of this course will be on materials-processing principles and the relationship with structure, properties and performance.

MTE 594. Special Topics—As arranged.
Theoretical or experimental studies in subjects of interest to graduate students in materials science and engineering.

Mathematical Sciences
MA 4451. Boundary Value Problems
Science and engineering majors often encounter partial differential equations in the study of...
the flow, vibrations, electric circuits and similar areas. Solution techniques for these types of problems will be emphasized in this course. Topics covered include derivation of partial differential equations as models of prototype problems in the areas mentioned above, solution of linear partial differential equations by separation of variables, Fourier integrals and a study of Bessel functions. (Prerequisite: A knowledge of ordinary differential equations is assumed.)

MA 501. Engineering Mathematics
This course develops mathematical techniques used in the engineering disciplines. Preliminary concepts will be reviewed as necessary, including vector spaces, matrices and eigenvalues. The principle topics covered will include vector calculus, Fourier transforms, fast Fourier transforms and Laplace transformations. Applications of these techniques for the solution of boundary value and initial value problems will be given. The problems treated and solved in this course are typical of those seen in the applications and include the problems of heat conduction, mechanical vibrations and wave propagation. (Prerequisite: A knowledge of ordinary differential equations, linear algebra and multivariable calculus is assumed.)

MA 503-504. Analysis I and II
Topics covered include open and closed sets, compactness, continuity, upper and lower semicontinuity, Lebesque measure, integration, functions of bounded variation, absolute continuity, the fundamental theorem of calculus for Lebesque integrals, Banach spaces, classical $L^p$ spaces, the Holder and Minkowski inequalities, the Riesz-Fischer theorem, and the Riesz representation theorem. (Prerequisite: Basic knowledge of undergraduate analysis is assumed.)

MA 505. Complex Analysis
This course will provide a rigorous and thorough treatment of the theory of functions of one complex variable. The topics to be covered include, complex numbers, complex differentiation, the Cauchy Riemann equations, analytic functions, Cauchy’s theorem, complex integration, the Cauchy integral formula, Liouville’s theorem, Gauss mean value theorem, maximum modulus theorem, Rouche’s theorem, Poisson integral formula, Taylor-Laurent expansions, singularity theory, conformal mapping with applications, analytic continuation, Schwarz’s reflection principle and elliptic functions. (Prerequisite: A knowledge of advanced calculus.)

MA 508. Mathematical Modeling
This course introduces mathematical model building using dimensional analysis, perturbation theory and variational principles. Models are selected from the natural and social sciences according to the interests of instructor and students. Examples are: planetary orbit, spring-mass systems, fluid flow, isomers in organic chemistry, biological competition, biochemical kinetics and physiological flow. Computer simulation of these models will also be considered. (Prerequisite: A knowledge of ordinary differential equations and of analysis at the level of MA 501 is assumed.)

MA 509. Stochastic Modeling
This course gives students a background in the theory and methods of probability, stochastic processes and statistics for applications. The course begins with a brief review of basic probability, discrete and continuous random variables, expectations, conditional probability and basic statistical inference. Topics covered in greater depth include generating functions, limit theorems, basic stochastic processes, discrete and continuous time Markov chains, and basic queueing theory including M/M/1 and M/G/1 queues. (Prerequisite: A knowledge of basic probability at the level of MA 3613 and statistics at the level of MA 2612 is assumed.)

MA 510. Numerical Methods
(Same as CS 552) This course is an introduction to modern numerical techniques. It is suitable for both mathematics majors and students from other departments. It covers material not treated in either MA 512 or MA 514, and it introduces the main ideas of those two courses. Topics covered include interpolation by polynomials, roots of nonlinear equations, approximation by various types of polynomials, orthogonal polynomials, least-squares approximation, trigonometric polynomials and fast Fourier transforms, piecewise polynomials and splines, numerical differentiation and integration, unconstrained optimization including Newton’s method and the conjugate direction method, and an introduction to the solution of systems of linear equations and initial value problems for ordinary differential equations. Both theory and practice are examined. Error estimates, rates of convergence and the consequences of finite precision arithmetic are also discussed. Other topics may include integral equations or an introduction to boundary value problems. In the course of analyzing some of the methods, topics from elementary functional analysis will be introduced. These include the concept of a function space, norms and inner products, operators and projections. (Prerequisite: Knowledge of undergraduate linear algebra and differential equations, and a higher-level programming language is assumed.)

MA 512. Numerical Differential Equations
This course begins where MA 510 ends in the study of the theory and practice of the numerical solution of differential equations. Central topics include a review of initial value problems, including Euler’s method, Runge-Kutta methods, multistep methods, implicit methods and predictor-corrector methods; the solution of two-point boundary value problems by shooting methods and by the discretization of the original problem to form systems of nonlinear equations; numerical stability; existence and uniqueness of solutions; and an introduction to the solution of partial differential equations by finite differences. Other topics might include finite element or boundary element methods, Galerkin methods, collocation, or variational methods. (Prerequisites: Graduate or undergraduate numerical analysis. Knowledge of a higher-level programming language is assumed.)

MA 514. Numerical Linear Algebra
This course provides students with the skills necessary to develop, analyze and implement computational methods in linear algebra. The central topics include vector and matrix algebra, vector and matrix norms, the singular value decomposition, the LU and QR decompositions, Householder transformations and given rotations, and iterative methods for solving linear systems including Jacobi, Gauss-Seidel, SOR and conjugate gradient methods; and eigenvalue problems. Applications to such problem areas as least squares and optimization will be discussed. Other topics might include: special linear systems, such as symmetric, positive definite, banded or sparse systems; preconditioning; the Cholesky decomposition; sparse tableau and other least-square methods; or algorithms for parallel architectures. (Prerequisite: Basic knowledge of linear algebra or equivalent background. Knowledge of a higher-level programming language is assumed.)

MA 519. Optimization
This course provides a basic foundation for students interested in mathematical programming. This course introduces the concepts of convex analysis, optimality conditions, Lagrangian duality, algorithms for uncon-
strained and constrained optimization, convergence properties and computational complexity of algorithms. Topics covered include search methods, Newton’s method and steepest descent method, trust region methods, penalty/barrier functions, interior point methods, finite element techniques and applications to special nonlinear programming problems arising in such areas as structural optimization using finite element formulations. May be taught by special arrangement. (Prerequisite: Knowledge of graduate or undergraduate numerical analysis, basic linear algebra and a higher-level programming language are assumed.)

MA 525. Optimal Control and Design with Composite Materials I

Modern technology involves a wide application of materials with internal structure adapted to environmental demands. This, the first course in a two-semester sequence, will establish a theoretical basis for identifying structures that provide optimal response to prescribed external factors. Material covered will include basics of the calculus of variations: Euler equations; transversality conditions; Weierstrass-Erdmann conditions for corner points; Legendre, Jacobi and Weierstrass conditions; Hamiltonian form of the necessary conditions; and Noether’s theorem. Pontryagin’s maximum principle in its original lumped parameter form will be put forth as well as its distributed parameter extension. Chattering regimes of control and relaxation through composites will be introduced at this point. May be offered by special arrangement.

MA 526. Optimal Control and Design with Composite Materials II

Topics presented will include basics of homogenization theory. Bounds on the effective properties of composites will be established using the translation method and Hashin-Shtrikman variational principles. The course concludes with a number of examples demonstrating the use of the theory in producing optimal structural designs. The methodology given in this course turns the problem of optimal design into a problem of rigorous mathematics. This course can be taken independently or as the sequel to MA 525.


This course provides the student of mathematics or computer science with an overview of discrete structures and their applications, as well as the basic methods and proof techniques in combinatorics. Topics covered include sets, relations, posets, enumeration, graphs, digraphs, monoids, groups, discrete probability theory and propositional calculus. (Prerequisites: College math at least through calculus. Experience with recursive programming is helpful, but not required.)

MA 533. Discrete Mathematics II

This course is designed to provide an in-depth study of some topics in combinatorial mathematics and discrete optimization. Topics may vary from year to year. Topics covered include, as time permits, partially ordered sets, lattices, matroids, matching theory, Ramsey theory, discrete programming problems, computational complexity of algorithms, branch and bound methods.

MA 540/4631. Probability and Mathematical Statistics I

This course is designed to provide background in principles of statistics. Topics covered include point and interval estimation; sufficiency, completeness, efficiency, consistency; the Rao-Blackwell theorem and the Cramer-Rao bound; minimum variance unbiased estimators, maximum likelihood estimators and Bayes estimators; tests of hypotheses including uniformly most powerful, likelihood ratio, minimax and Bayesian tests. (Prerequisite: A knowledge of MA 3613 and MA 3831/3832 is assumed.)

MA 541/4632. Probability and Mathematical Statistics II

This course is designed to provide background in principles of statistics. Topics covered include point and interval estimation; sufficiency, completeness, efficiency, consistency; the Rao-Blackwell theorem and the Cramer-Rao bound; minimum variance unbiased estimators, maximum likelihood estimators and Bayes estimators; tests of hypotheses including uniformly most powerful, likelihood ratio, minimax and Bayesian tests. (Prerequisite: A knowledge of MA 540 is assumed.)

MA 542. Applied Regression Analysis

Regression analysis is a statistical tool that utilizes the relation between a response variable and one or more predictor variables for the purposes of description, prediction and/or control. Successful use of regression analysis requires an appreciation of both the theory and the practical problems that often arise when the technique is employed with real-world data.

The widespread availability of computers and software has contributed greatly to the expanding use of regression in scientific and industrial work. Topics will be selected from: simple linear regression and correlation, measures of model adequacy, simultaneous inferences, multiple regression, polynomial regression, indicator variables, variable selection and model building, multicollinearity and influential observations, generalized and weighted least squares and robust regression, nonlinear regression, and validation of regression models. Application of theory to real-world problems will be emphasized using statistical computer packages. (Prerequisite: A knowledge of statistics at the level of MA 2611 is assumed.)

MA 544. Statistical Response Surface Analysis

Response surface methodology is a collection of statistical techniques for analyzing the relationship between a set of independent variables or operating conditions and a response variable. It is commonly used in scientific and industrial work to (1) describe and explain this relationship, (2) choose operating conditions to achieve desired specification, and (3) search for optimal operating conditions. Topics covered include review of basic probability and statistics, least squares, response surface designs, steepest ascent, and the fitting and analysis of second order models. As time permits, additional topics will be chosen from transformations, ridge systems and variance-optimal designs. Emphasis will be on the application of the theory to real data using statistical computer packages. (Prerequisite: A knowledge of statistics at the level of MA 2611 is assumed.)

MA 546. The Statistical Design and Analysis of Scientific and Industrial Experiments

The goal of the statistical design and analysis of experiments is to (1) identify the factors which most affect a given process or phenomenon; (2) identify the ways in which these factors affect the process or phenomenon, both individually and in combination; (3) accomplish goals 1 and 2 with minimum cost and maximum efficiency while maintaining the validity of the results. Topics covered include, as time permits, the implementation and analysis of completely randomized, randomized complete block, nested and nested factorial, split plot type, Latin square type and other incomplete block designs; factorial designs and fractional factorial designs, and their relation to the Taguchi methodology. Emphasis will be on the application of the theory to real data using statistical computer packages. (Prerequisite: A knowledge
of basic statistics at the level of MA 2611 is assumed.)

MA 548. Reliability and Quality Control
This course provides the student with the basic statistical tools needed to (1) evaluate the quality and reliability of manufactured products, and (2) design products and production processes to insure a desired level of quality and reliability. Topics covered include the philosophy and implementation of continuous quality improvement methods, acceptance sampling, control charts, cumulative sum charts, reliability models, censoring, the identification and fitting of reliability models to data, inference from reliability models. Special emphasis will be placed on realistic applications of the theory using statistical computer packages available. (Prerequisite: A knowledge of basic probability and statistics, at the level of MA 2611 is assumed.)

MA 550. Time Series
Analysis and Forecasting
Time series are collections of observations made sequentially in time. Examples occur in a variety of fields, ranging from economics to engineering, and methods of analyzing time series constitute an important area of statistics. There are several objectives in analyzing a time series which can be classified as description, explanation, prediction, and control. This course provides students with the basic knowledge of time series both in the frequency domain and in the time domain. Topics covered include, as time permits, autocorrelation, elements of spectral analysis, ARMA models, Box-Jenkins methodology, fitting, forecasting, seasonal adjustment. Additional topics will be chosen from: Kalman filter, exponential smoothing, Holt-Winters procedures. Applications of the theory to real data using statistical computer packages will be emphasized. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 552. Nonparametric and Robust Statistical Methods
Nonparametric statistical methods do not require modeling a population in terms of a specific parametric family of distributions. Robust statistical methods are methods which retain much of the sensitivity of parametric methods when model assumptions are satisfied, but which are relatively insensitive to departures from these assumptions. Topics covered include, as time permits, order statistics and ranks; distribution free tests and associated interval and point estimators including the sign test, rank sum tests, Mann-Whitney-Wilcoxon tests and Kruskal-Wallis tests; the Kolmogorov-Smirnov test; permutation methods; M, L and R estimation and applications; computer techniques and programs; discussion and comparison with standard parametric methods. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 554. Multivariate Analysis
This course is an introduction to statistical methods for analyzing multivariate data. Topics covered are multivariate sampling distributions, tests and estimation of multivariate normal parameters, multivariate ANOVA, correlation and regression, discriminant analysis, factor analysis and principal components. Additional topics covered as time permits include multivariate discrete analysis: loglinear and logit regression models. Students will be required to analyze real data using one of the standard packages available. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 556. Decision Theory and Applied Bayesian Statistics
This course is an introduction to Decision Theory and Applied Bayesian Statistics. Decision theory is concerned with the ways that data can be used to make decisions. The Bayesian approach allows the synthesis of current data with past information to aid decision making. Topics covered include decision theory, Bayes estimation and hypothesis-testing, standard normal-theory inference problems such as K-sample problems, regression and one-way ANOVA are emphasized. Numerical computation of posterior densities, e.g., Hermite, Laplace approximation and Monte Carlo integration, is also covered. Applications of decision-theoretic and Bayesian methods to such areas as survey sampling theory, reliability theory, time series analysis and categorical data analysis will be discussed. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 558. Statistical Consulting
After suitable preparation through readings and practice consulting sessions, the student will serve as a statistical consultant, under the supervision of statistics faculty, to clients from academia, business and industry. There are no formal prerequisites, but knowledge of a range of statistical methodology will be required for admission.

MA 571. Financial Mathematics I
Introduction to arbitrage-based pricing of derivative securities, and their uses for hedging and risk management. Topics include securities markets, futures, options, swaps and other derivatives; arbitrage and risk-neutral pricing; binomial trees, martingales, stochastic difference equations; Black-Scholes formula and partial differential equation via limit transition; pricing of American options, convertible bonds, options on dividend-paying stock and on futures; sensitivity measures (“greeks”), implied and estimated volatilities; use of derivatives for hedging and risk management.

MA 572. Financial Mathematics II
This course introduces the advanced mathematical concepts and terminology used at the professional quantitative financial workplace and in the literature, and provides students with the background necessary to work in the rapidly expanding fixed income securities sector. The first part of the course is devoted to the concepts, terminology and methods of continuous-time mathematical finance. Topics include Brownian motion, continuous-time martingales. Stochastic differential equations, Ito calculus; risk-neutral valuation in terms of equivalent martingale measures. The power of the new tools is demonstrated on the derivation of the Black-Scholes and foreign exchange option pricing formulas. The second part of the course is devoted to fixed income securities and the term-structure of interest rates. Topics covered in this part include fixed income markets, instruments, risks and the term structure of interest rates; yield curve models, calibration and fitting; pricing of interest rate derivatives using models based on short rates (Vasicek, Cox-Ingersoll-Ross), and on the static and dynamic term-structure of interest rates (Ho-Lee, Black-Derman-Toy, Hull-White and Heath-Jarrow-Morton); pricing of corporate bonds, mortgage-backed securities and insurance-linked bonds; implementation of pricing models; derivative strategies for hedging and risk management in the fixed income sector. (Prerequisites: MA 503, MA 540 and MA 571.)

MA 573. Computational Methods of Financial Mathematics
Most realistic financial derivatives models are too complex to allow explicit analytic solutions. The computational techniques used to implement those models fall into two broad categories: finite difference methods for the solution of partial differential equations (PDEs) and Monte Carlo simulation.
Accordingly, the course consists of two 7-week blocks covering the following topics.

Part I: parabolic PDEs, Black-Scholes PDE for European and American options; binomial and trinomial trees; explicit, implicit and Crank-Nicholson finite difference methods; far boundary conditions, convergence, stability, variance bias; early exercise and free boundary conditions; parabolic PDEs arising from fixed income derivatives; implied trees for exotic derivatives, adapted trees for interest rate derivatives.

Part II: Random number generation and testing; evaluation of expected payoff by Monte Carlo simulation; variance reduction techniques—antithetic variables, importance sampling, martingale control variables; stratification, low-discrepancy sequences and quasi-Monte Carlo methods; efficient evaluation of sensitivity measures; methods suitable for multifactor and term-structure dependent models. (Prerequisites: MA 571, undergraduate level familiarity with numerical programming skills.)

MA 574. Portfolio Valuation and Risk Management
Balancing returns vs. risks is one of the fundamental tasks of quantitative financial management. This course presents the most important mathematical concepts, methods and models used to value assets; select, maintain and optimize portfolios; and to manage risks. Topics covered include the following: returns, risks and utilities; quantification of risk—variance, shortfall risk, value at risk; portfolio analysis, diversification, correlations, principal components, sensitivity measures (“greeks”); asset valuation and pricing methods as capital markets theory, capital asset pricing model, efficient frontiers, arbitrage pricing theory; consumption/accumulation and equilibrium models; risk management techniques—diversification, immunization, insurance/reinsurance, hedging; optimal asset allocation, portfolio optimization and dynamic delta hedging. The quantitative techniques covered in this course are used to support decisions by trading desk managers, corporate investment strategists, mutual companies, utilities, and of companies with commodities or foreign exchange risk exposures. (Prerequisite: MA 571.)

MA 562 A and B.
Professional Master’s Seminar

This seminar will introduce professional master’s students to topics related to general writing, presentation, group communication and interviewing skills, and will provide the foundations to successful cooperation within interdisciplinary team environments. All full-time students will be required to take both components A and B of the seminar during their professional master’s studies.

MA 598. Professional Master’s Project

1 or more credits

This project will provide the opportunity to apply and extend the material studied in the course to the study of a real-world problem originating in the industry. The project will be a capstone integrating industrial experience with the previously acquired academic knowledge and skills. The topic of the project will come from a problem generated in industry, and could originate from prior internship or industry experience of the student. The student will prepare a written project report and make a presentation before a committee including the faculty advisor, at least one additional WPI faculty member and representatives of a possible industrial sponsor. The Advisor of Record must be a faculty member of the WPI Mathematical Sciences Department. The student must submit a written project proposal for approval by the Graduate Committee prior to registering for the project.

MA 590. Special Topics

Courses on special topics are offered under this number. Contact the Mathematical Sciences Department for current offerings.

MA 595. Independent Study

1 to 3 credits

Supervised independent study of a topic of mutual interest to the instructor and the student.

MA 599. Thesis

1 or more credits

Research study at the master’s level.

Mathematics for Educators

MME 518. Geometrical Concepts

This course focuses primarily on the foundations and applications of Euclidean and non-Euclidean geometries. The rich and diverse nature of the subject also implies the need to explore other topics, for example, chaos and fractals. The course incorporates collaborative learning and the investigation of ideas through group projects. Possible topics include geometrical software and computer graphics, tiling and tessellations, two- and three-dimensional geometry, inversive geometry, graphical representations of functions, model construction, fundamental relationship between algebra and geometry, applications of geometry, geometry transformations and projective geometry, and convexity.

MME 522. Applications of Calculus

2 credits

There are three major goals for this course: to establish the underlying principles of calculus, to reinforce students’ calculus skills through investigation of applications involving those skills, and to give students the opportunity to develop projects and laboratory assignments for use by first-year calculus students. The course will focus heavily on the use of technology to solve problems involving applications of calculus concepts. In addition, MME students will be expected to master the mathematical rigor of these calculus concepts so that they will be better prepared to develop their own projects and laboratory assignments. For example, if a MME student chose to develop a lab on convergence of sequence, he/she would be expected to understand the rigorous definition of convergence and how to apply it to gain sufficient and/or necessary conditions for convergence. The process of developing these first-year calculus assignments will enable the MME students to increase their own mathematical understanding of concepts while learning to handle mathematical and computer issues which will be encountered by their own calculus students. Their understanding of the concepts and applications of calculus will be further reinforced through computer laboratory assignments and group projects. Applications might include exponential decay of drugs in the body, optimal crankshaft design, population growth, or development of cruise control systems.

MME 523. Analysis with Applications

2 credits

This course introduces students to mathematical analysis and its use in modeling. It will emphasize topics of calculus (including multidimensional) in a rigorous way. These topics will be motivated by their usefulness for understanding concepts of the calculus and for facilitating the solutions of engineering and science problems. Projects involving applications and appropriate use of technology will be an essential part of the course. Topics covered may include dynamical systems and differential equations; growth and decay; equilibrium; probabilistic dynamics; optimal decisions and reward; applying, building and validating
models; functions on R^n vectors; properties of functions; parametric equations; series; applications such as pendulum problems; electromagnetism; vibrations; electronics; transportation; gravitational fields; and heat loss.

MME 524-25. Probability, Statistics and Data Analysis I, II
4 credits
This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills:

- Probability models—mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena.
- Data analysis—the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized.
- Statistical inference and modeling—the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data.
- Design of experiments and sampling studies—The proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation.

Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

MME 526-27. Linear Models I, II
4 credits
This two-course sequence imparts computational skills, particularly those involving matrices; to deepen understanding of mathematical structure and methods of proof; and includes discussion on a variety of applications of the material developed, including linear optimization. Topics in this sequence may include systems of linear equations, vector spaces, linear independence, bases, linear transformations, determinants, eigenvalues and eigenvectors, systems of linear inequalities, linear programming problems, basic solutions, duality and game theory. Applications may include economic models, computer graphics, least squares approximation, systems of differential equations, graphs and networks, and Markov processes.

MME 528. Mathematical Modeling and Problem Solving
2 credits
This course introduces students to the process of developing mathematical models as a means for solving real problems. The course will encompass several different modeling situations that utilize a variety of mathematical topics. The mathematical fundamentals of these topics will be discussed, but with continued reference to their use in finding the solutions to problems. Problems to be covered include balance in small group behavior, traffic flow, air pollution flow, group decision making, transportation, assignment, project planning and the critical path method, genetics, inventory control and queueing.

MME 529. Numbers, Polynomials and Algebraic Structures
2 credits
This course enables secondary mathematics teachers to see how commonly taught topics such as number systems and polynomials fit into the broader context of algebra. The course will begin with treatment of arithmetic, working through Euclid’s algorithm and its applications, the fundamental theorem of arithmetic and its applications, multiplicative functions, the Chinese remainder theorem and the arithmetic of Z/n. This information will be carried over to polynomials in one variable over the rational and real numbers, culminating in the construction of root fields for polynomials via quotients of polynomial rings. Arithmetic in the Gaussian integers and the integers in various other quadratic fields (especially the field of cube roots of unity) will be explored through applications such as the generation of Pythagorean triples and solutions to other Diophantine equations (like finding integer-sided triangles with a 60 degree angle). The course will then explore cyclotomy, and the arithmetic in rings of cyclotomic integers. This will culminate in Gauss’ construction of the regular 5-gon and 17-gon and the impossibility of constructing a 9-gon or trisecting a 60-degree angle. Finally, solutions of cubics and quartics by radicals will be studied. All topics will be based on the analysis of explicit calculations with (generalized) numbers. The proposed curriculum covers topics that are part of the folklore for high school mathematics (the impossibility of certain ruler and compass constructions), but that many teachers know only as facts. There are also many applications of the ideas that will allow the teachers to use results and ideas from abstract algebra to construct for their students problems that have manageable solutions.

MME 531. Discrete Mathematics
This course deals with concepts and methods which emphasize the discrete nature in many problems and structures. The rapid growth of this branch of mathematics has been inspired by its wide range of application to diverse fields such as computer science, management, and biology. The essential ingredients of the course are:

- Combinatorics —
  The Art of Counting. Topics include basic counting principles and methods such as recurrence relations, generating functions, the inclusion-exclusion principle and the pigeonhole principle. Applications may include block designs, Latin squares, finite projective planes, coding theory, optimization and algorithmic analysis.

- Graph Theory. This includes direct graphs and networks. Among the parameters to be examined are traversibility, connectivity, planarity, duality and colorability.

MME 562. Seminar: Issues in Mathematics
2 credits
This course gives students an opportunity to participate in focused discussions on various topics in mathematics and mathematics education. Students will research current literature in mathematics and mathematics education. Invited speakers will address issues relevant to a broad understanding of mathematics and its applications in our society. Students will be required to synthesize and critique course materials through written papers and formal presentations. The course will emphasize teachers as professionals and educational innovators. The content of the course will vary depending on the interests of the participants. However, topics may include careers in mathematics; mathematics in industry; historical perspectives and the motivation of mathematical development; critical thinking skills; impact of the NCTM curriculum and evaluation standards; mathematics on the national
scene, including the roles of MSEB, NSF, NCTM,AMS, MAA,AMATYC; mathematics reform; then and now; mathematics anxiety; issues in the teaching of developmental mathematics; women and minorities in mathematics; technical writing in mathematics; funding sources for mathematics reform; and assessment in mathematics, including the AP Calculus Exam and ideas on alternative forms of assessment; textbooks and other resources in mathematics. MME 592. Project Preparation
(Prerequisites: Part of a 3-course sequence with MME 594 and MME 596) 2 credits
Students will research and develop a mathematical topic or pedagogical technique. The project will typically lead to classroom implementation; however, a project involving mathematical research at an appropriate level of rigor will also be acceptable. Preparation will be completed in conjunction with at least one faculty member from the Mathematical Sciences Department and will include exhaustive research on the proposed topic. The course will result in a detailed proposal that will be presented to the MME Project Committee for approval; continuation with the project is contingent upon this approval. MME 594. Project Implementation 2 credits
Students will implement and carry out the project developed during the project preparation course. Periodic contact and/or observations will be made by the project advisor (see MME 592 Project Preparation) in order to provide feedback and to ensure completion of the proposed task. Data for the purpose of evaluation will be collected by the students throughout the term, when appropriate. If the project includes classroom implementation, the experiment will last for the duration of a semester.

Mechanical Engineering
Fluids Engineering
ME 511. Incompressible Fluid Dynamics
An introduction to graduate level fluid dynamics including dimensional analysis, Eulerian and Lagrangian descriptions, flowlines, conservation equations, governing equations of viscous fluid motion, exact solutions of Navier-Stokes and Euler equations, unsteady flows, laminar boundary layer theory, turbulence, separation, Stokes flow, vorticity dynamics, potential flow and surface flows. (Prerequisites: Fundamentals of thermodynamics and mechanics, knowledge of advanced mathematics, undergraduate courses in fluid mechanics.)

ME 512. Gas Dynamics and Real Gas Effects
Kinetic theory of gases including equilibrium and nonequilibrium gas properties, macroscopic equations, binary and inelastic collisions, chemical reactions. Equilibrium flows including steady and unsteady shock waves, nozzle flow, Prandtl-Meyer flow, theory of characteristics, effects of head addition and friction, linearized compressible flow and acoustics. Compressible flows with vibrational, chemical or translational nonequilibrium including variable transport properties, nozzle flow and shock waves. (Prerequisites: Background in fluid dynamics (incompressible and compressible), thermodynamics, and basic undergraduate physics and chemistry.)

ME 513. Thermodynamics
Review of the zeroth, first and second laws of thermodynamics and systems control volume. Applications of the laws to heat engines and their implications regarding the properties of materials. Equations of state and introduction to chemical thermodynamics.

ME 515. Computational Methods for PDEs in Engineering Science
This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite difference and finite element methods are introduced and developed in a logical progression of complexity. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class.

ME 516. Heat Transfer
Review of governing differential equations and boundary conditions for heat transfer analysis. Multidimensional and unsteady conduction, including effects of variable material properties. Analytical and numerical solution methods. Forced and free convection with laminar and turbulent flow in internal and external flows. Characteristics of radiant energy spectra and radiative properties of surfaces. Radiative heat transfer in absorbing and emitting media. Systems with combined conduction, convection and radiation. Condensation, evaporation, and boiling phenomena. (Prerequisite: Background in thermodynamics, fluid dynamics, ordinary and partial differential equations, and basic undergraduate physics.)

ME 611. Turbulence
Material to be covered: introduction and motivation, statistical techniques for analysis, mean flow dynamics (Reynolds decomposition), Kolmogorov’s theory, instrumentation, classical turbulent flows—shear layers, jets, wakes, boundary layers—and pipe flow. (Prerequisites: Fundamentals of mechanics and thermodynamics, graduate level course in fluid mechanics and knowledge of advanced mathematics.)

ME 612. Computational Fluid Dynamics
Computational methods for incompressible and compressible viscous flows. Navier Stokes equations in general coordinates and grid generation techniques. Finite volume techniques including discretization, stability analysis, artificial viscosity, explicit and implicit methods, flux-vector splitting, TVD schemes and multi-grid methods. Finite elements. Concepts of vectorization and parallel computing. Applications are drawn from internal, external flows, materials processing. (Prerequisites: Single and multicomponent systems. Computational techniques. Selected special topics and applications may include turbulent convective flows, combustion and materials processing.

Dynamics and Controls
ME 522. Mechanical Vibrations
Vibration analysis for both discrete and continuous linear systems. Start with an enhanced review of the fundamentals of single-degree-of-freedom vibration analysis. Both Newton’s and Lagrangian equations are discussed. General properties of related stiffness, mass and damping matrices are addressed. Modal analysis for linear systems is emphasized. Computational methods in vibration analysis are introduced. Applications include vehicles for the purpose of evaluation will be collected by the students throughout the term, when appropriate. If the project includes classroom implementation, the experiment will last for the duration of a semester.

Mechanical Engineering
Fluids Engineering
ME 511. Incompressible Fluid Dynamics
An introduction to graduate level fluid dynamics including dimensional analysis, Eulerian and Lagrangian descriptions, flowlines, conservation equations, governing equations of viscous fluid motion, exact solutions of Navier-Stokes and Euler equations, unsteady flows, laminar boundary layer theory, turbulence, separation, Stokes flow, vorticity dynamics, potential flow and surface flows. (Prerequisites: Fundamentals of thermodynamics and mechanics, knowledge of advanced mathematics, undergraduate courses in fluid mechanics.)

ME 512. Gas Dynamics and Real Gas Effects
Kinetic theory of gases including equilibrium and nonequilibrium gas properties, macroscopic equations, binary and inelastic collisions, chemical reactions. Equilibrium flows including steady and unsteady shock waves, nozzle flow, Prandtl-Meyer flow, theory of characteristics, effects of head addition and friction, linearized compressible flow and acoustics. Compressible flows with vibrational, chemical or translational nonequilibrium including variable transport properties, nozzle flow and shock waves. (Prerequisites: Background in fluid dynamics (incompressible and compressible), thermodynamics, and basic undergraduate physics and chemistry.)

ME 513. Thermodynamics
Review of the zeroth, first and second laws of thermodynamics and systems control volume. Applications of the laws to heat engines and their implications regarding the properties of materials. Equations of state and introduction to chemical thermodynamics.

ME 515. Computational Methods for PDEs in Engineering Science
This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite difference and finite element methods are introduced and developed in a logical progression of complexity. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class.

ME 516. Heat Transfer
Review of governing differential equations and boundary conditions for heat transfer analysis. Multidimensional and unsteady conduction, including effects of variable material properties. Analytical and numerical solution methods. Forced and free convection with laminar and turbulent flow in internal and external flows. Characteristics of radiant energy spectra and radiative properties of surfaces. Radiative heat transfer in absorbing and emitting media. Systems with combined conduction, convection and radiation. Condensation, evaporation, and boiling phenomena. (Prerequisite: Background in thermodynamics, fluid dynamics, ordinary and partial differential equations, and basic undergraduate physics.)

ME 611. Turbulence
Material to be covered: introduction and motivation, statistical techniques for analysis, mean flow dynamics (Reynolds decomposition), Kolmogorov’s theory, instrumentation, classical turbulent flows—shear layers, jets, wakes, boundary layers—and pipe flow. (Prerequisites: Fundamentals of mechanics and thermodynamics, graduate level course in fluid mechanics and knowledge of advanced mathematics.)

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Computational methods for incompressible and compressible viscous flows. Navier Stokes equations in general coordinates and grid generation techniques. Finite volume techniques including discretization, stability analysis, artificial viscosity, explicit and implicit methods, flux-vector splitting, TVD schemes and multi-grid methods. Finite elements. Concepts of vectorization and parallel computing. Applications are drawn from internal, external flows, materials processing. (Prerequisites: Single and multicomponent systems. Computational techniques. Selected special topics and applications may include turbulent convective flows, combustion and materials processing.

Dynamics and Controls
ME 522. Mechanical Vibrations
Vibration analysis for both discrete and continuous linear systems. Start with an enhanced review of the fundamentals of single-degree-of-freedom vibration analysis. Both Newton’s and Lagrangian equations are discussed. General properties of related stiffness, mass and damping matrices are addressed. Modal analysis for linear systems is emphasized. Computational methods in vibration analysis are introduced. Applications include vehicles
traveling on a rough surface, multistory buildings subjected to seismic and wind loading, and vibration analysis of bars, beams and plates.

ME 523. Applied Linear Control
Modeling of complex systems used in various areas of engineering. Analytical description of dynamic physical systems, time and frequency domain representations. System characteristics such as controllability, observability and stability. Design of feedback controllers using state-space methods including pole placement and optimal control. State observers and introduction to Kalman filters. Performance limitations of control systems and trade-offs in control design. Design of control synthesis is performed using Matlab/Simulink. Term projects focus on design, analysis and implementation of current engineering control problems. (Prerequisites: Differential equation and fundamentals of linear algebra.)

ME 527. Dynamics
Basic concepts and general principles of classical kinematics and dynamics of particles, system of particles, and rigid and deformable bodies are presented. Particle motion along arbitrary trajectories is discussed in general coordinate systems. The governing equations of motion are derived by both Newton-D'Alembert's vectorial approach and Lagrange-Hamilton's variational approach. Applications include central-force orbital motion, binary collisions, motion in nonlinear reference frames, rigid body motion, vibration of continuous systems and dynamic stability.

ME 621. Dynamics and Signal Analysis
A laboratory-based course which applies Fourier and cepstral signal analysis techniques to mechanical engineering problems. The theory and application of the Fourier series, Fast Fourier Transform (FFT) and the cepstrum to the analysis of mechanical and acoustical systems is presented. Digital sampling theory, windowing, aliasing, filtering, noise averaging and deconvolution are discussed. Limitations of and errors in implementation of these techniques are demonstrated. Students will perform weekly experiments in the Structural Dynamics and Vibration Laboratory, which reinforce the theories presented in lectures. Application will include structures, acoustics, rotating machinery and cans.

ME 622. Advanced Dynamics and Vibrations
The course presents advanced topics in dynamics and vibrations of machines and structures. Depending on the instructor, the course will include a selection of the following topics: extended discussion of vibration analysis of linear systems with distributed parameters, an introduction to vibration of nonlinear systems, numerical methods for vibration analysis, random vibrations, stability of dynamic systems, flow induced vibrations and rotordynamics.

ME 623. Applied Nonlinear Control
Introduction to the analysis and design of nonlinear control systems. Stability analysis using Lyapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability, sliding modes, adaptive, and feedback linearization. Applications include control design for robot systems (position and trajectory control), flexible structures (vibration control), spacecraft attitude control, manufacturing systems. Case studies for systems with smart actuators/sensors (Piezo, SMA, Magnetostrictive), deadzones and hysteresis, etc. Design of control synthesis is performed using Matlab/Simulink. Term projects will focus on design, analysis and implementation of current engineering control problems. (Prerequisites: Differential equations and fundamentals of linear algebra.)

ME 624. Random Vibration and Mechanical Signature Analysis
Probabilistic methods in dynamics are described, as they are used to predict systems' response to highly irregular or random loadings, such as that of civil engineering structures to earthquakes, of aircraft structures to turbulent gusts, and of ships and offshore structures to ocean waves. Applications of random vibration analysis for reliability predictions and for mechanical signature analysis (MSA) will be illustrated, where MSA means on-line condition monitoring for an operating machine or structure by using proper processing of its measured response signal. The course contains brief introduction into theory of probability and theory of random processes, which makes it self-contained.

Structures and Materials
ME 531. Applied Elasticity
This course is intended for students with undergraduate backgrounds in mechanics of materials. It includes two- and three-dimensional states of stress, linear and nonlinear measures of strain, and generalized Hooke’s Law. Also covered are exact solutions for bending and torsion: thick-walled pressure vessels, rotating disks, stress functions for two- and three-dimensional problems and bending and torsion of unsymmetric beams.

ME 532. Continuum Mechanics
Emphasis on the distinction between general principles that apply to all deforming materials and the specific constitutive assumptions that are made when modeling material behavior. The course includes a brief review of the necessary mathematics and then proceeds to the kinematics of deformable media, the concepts of stress and stress transformations, and the general balance laws. The remainder of the course deals with general constitutive theory and constitutive relations for selected materials that have relevance to structural, fluid dynamics, materials processing and materials handling.

ME 533/CE 524. Finite Element Method and Applications
This course serves as an introduction to the basic theory of the finite element method. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium problem. Examples focus on elasticity and heat flow with reference to broader applications. Students are supplied microcomputer programs and gain experience in solving real problems. (Prerequisites: Elementary differential equations, solid mechanics and heat flow.)

ME 534. Laser Engineering Science and Applications
In this course, a unified account of the present-day knowledge of lasers and their applications in varied professional and industrial fields will be given through a series of in-class lectures and laboratory demonstration. Special attention will be given to factors that must be evaluated when a laser system is being devised for a specific application. Course coverage will include types of lasers and their characteristics, shaping of laser beams, measurement of laser beam parameters, transmission of laser beams, interaction of laser beams with materials, mathematical modeling of laser processes, laser processing of materials, fiber-optic applications of lasers, laser metrology and related
topics.

ME 535/MTE 582. Mechanical Behavior of Materials
Theory of strengthening mechanisms with emphasis on dislocation theory for single and multiphase alloys and composite structures. Application of theory to produce engineered structures. (Prerequisites: ME 3823 and ME 4840 or equivalent.)

ME 631. Advanced Mechanics of Solids
This course is a continuation of ME 531. Depending on the instructor, it will include a selection of the following topics: exact solutions for three-dimensional problems using vector potentials, Hertz contact solution, energy methods, elastic stability, an overview of plates and shells, and an introduction to plasticity and viscoelasticity theory.

ME 632. Dynamics of Composite Structures
The course covers topics related to dynamics of composite structures, including introduction to composite materials, fiber-reinforced composites, governing equations of motion of composite beams, plates and shells, vibration of thick composite plates and shell, and response of composite structures due to impact.

ME 633/CE 526. Advanced Finite Element Methods
Second course in the theory of the finite element method. Topics to be covered include alternate variational methods for formulating the finite element equations, methods for treating material and geometric nonlinearity, methods for transient analysis, plate and shell analysis, and an introduction to the boundary element method. (Prerequisite: ME 533. Helpful, but not mandatory to have a background in elasticity, dynamics and vibrations.)

ME 634. Holographic Numerical Analysis
Recent advances in holographic analysis of body deformations are discussed. Included in the course are topics covering sandwich holography, opto-electronic fringe interpolation technique, theory of fringe localization, use of projection matrices and the fringe tensor theory of holographic strain analysis. The application of interactive computer programs for holographic analysis of engineering and biological systems will be outlined. Lectures are supplemented by laboratory demonstrations and experiments. (Prerequisites: Matrix algebra, vector calculus and consent of instructor.)

Manufacturing and Design

ME 542/MFE 510. Control and Monitoring of Manufacturing Processes
Covers a broad range of topics centered on control and monitoring functions for manufacturing, including process control, feedback systems, data collection and analysis, scheduling, machine-computer interfacing, and distributed control. Typical applications are considered with lab work.

ME 543/MFE 520. Design and Analysis of Manufacturing Processes
The first half of the course covers the axiomatic design method, applied to simultaneous product and process design for concurrent engineering, with the emphasis on process and manufacturing tool design. Basic design principles as well as qualitative and quantitative methods of analysis of designs are developed. The second half of the course addresses methods of engineering analysis of manufacturing processes, to support machine tool and process design. Basic types of engineering analysis are applied to manufacturing situations, including elasticity, plasticity, heat transfer, mechanics and cost analysis. Special attention will be given to the mechanics of machining (traditional, nontraditional and grinding) and the production of surfaces. Students, with the advice and consent of the professor, select the topic for their term project.

ME 544/MFE 530. Computer-Integrated Manufacturing
An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management, to demonstrate the strategic importance of integration.

ME 545. Computer-Aided Design and Geometric Modeling
This course covers topics in computer-aided geometric design and applications in mechanical engineering. The objectives of the course are to familiarize the students with complex geometric modeling and analytical techniques used in contemporary computer-aided design systems. Topics to be covered may include complex curve and surface generation, Boolean algebra and solid modeling, transformations, computational and analytic geometry, automatic mesh generation, tool path generation, offsets and intersections of complex shapes, graphics standards and data transfer, rendering techniques, parametric design and geometric optimization, numerical methods for geometric analysis and graphics design programming. (Prerequisites: calculus, linear algebra, computer programming, and some familiarity with a CAD system.)

ME 641. Cam Design
Basic and advanced methods of cam design for high-speed production machinery and automotive applications will be addressed. Classical as well as polynomial and spline-based methods will be used to design cam contours. Issues of cam manufacturing and vibrations as related to cam dynamic behavior will be discussed. Practical aspects of cam design will be exercised through projects and laboratory assignments. (Recommended background: Undergraduate level courses in kinematics and vibrations. Familiarity with the techniques of dynamic signal analysis [ME 621] would be helpful.)

Biomechanical Engineering

ME 550. Tissue Engineering
This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering issues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented. (Recommended preparation: A first course in biomaterials equivalent to ME/BE 4814 and a basic understanding of physiology and cell biology.)

ME 552. Tissue Mechanics
This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues, and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties and design of medical devices and prostheses. (Recommended preparation: A first course in biomechanics equivalent to ME/BE 4504.)

ME 554. Composites with Biomedical and Materials Applications
Introduction to fiber/particulate reinforced, engineered and biologic materials. This course
focuses on the elastic description and application of materials that are made up of a combination of submaterials, i.e., composites. Emphasis will be placed on the development of constitutive equations that define mechanical behavior of a number of applications including: biomaterial, tissue, and material science. (Prerequisites: Understanding of stress analysis and basic continuum mechanics.)

ME 558. Biofluids and Biotransport
The emphasis of this course is on modeling fluid flow within the cardiovascular and pulmonary systems, and the transport processes that take place in these systems. Applications include artificial heart valves, atherosclerosis, arterial impedance matching, clinical diagnosis, respiration, aerosol and particle deposition. Depending upon class interest, additional topics may include reproductive fluids, animal propulsion in air and water, and viscoelastic testing. (Recommended preparation: A first course in biofluids equivalent to ME/BE 4506.)

Other Activities
ME 591. Graduate Seminar
0 credit
Seminars on current issues related to various areas of mechanical engineering are presented by authorities in their fields. All full-time mechanical engineering students are required to register.

ME 593. Special Topics
Arranged by individual faculty with special expertise, these courses cover advanced topics that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Department well in advance of the offering. (Prerequisite: Consent of instructor.)

ME 598. Directed Research
For M.S. students wishing to gain research experience peripheral to their thesis topic, or for doctoral students wishing to obtain research credit prior to admission to candidacy. (Prerequisite: Consent of Thesis Advisor.)

ME 699. Dissertation Research
Intended for doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations. (Prerequisite: Consent of Dissertation Advisor.)

Physics
PH 501. Mathematical Methods of Physics I
Vector calculus, special functions, calculus of variations, linear transformation theory, Green’s functions, complex variables and integral equations. Course may be offered by special arrangement.

PH 502. Mathematical Methods of Physics II
Probability theory, harmonic analysis, integral equations and functions of a complex variable. Course may be offered by special arrangement.

PH 503. Group Theory
Theory of group representations; point groups and continuous groups of physical interest; applications to molecular vibrations, crystal properties, quantum mechanics and particle physics. Course may be offered by special arrangement.

PH 511. Classical Mechanics
Lagrangian and Hamiltonian formulations. Rigid body motion. Poisson brackets, Hamilton-Jacobi theory. (Prerequisite: B.S. in physics or equivalent.)

PH 514. Quantum Mechanics I
Schrodinger wave equation, potential wells and barriers, harmonic oscillator, hydrogen atom, angular momentum and spin. (Prerequisite: B.S. in physics or equivalent.)

PH 515. Quantum Mechanics II
Perturbation theory, scattering theory, Born approximation, quantum theory of radiation, the Dirac equation. (Prerequisite: PH 514.)

PH 522. Thermodynamics and Statistical Mechanics
Ensemble theory; canonical, microcanonical and grand canonical ensembles. Quantum statistical mechanics, Bose-Einstein and Fermi-Dirac statistics. (Prerequisite: PH 511.)

PH 533. Advanced Electromagnetic Theory
Classical electrodynamics including boundary-value problems using Green’s functions. Maxwell’s equations, electromagnetic properties of matter, wave propagation and radiation theory. (Prerequisite: B.S. in physics or equivalent.)

PH 542. Modern Optics

PH 554. Solid-State Physics
Phonons and specific heat of solids; electronic conductivity and band theory of solids; Fermi and Bose gases; magnetic interactions. (Prerequisite: PH 514.)

PH 597. Special Topics
Credits as arranged
Titles of recently offered courses include Superlattices and Semiconductor Heterostructures, Numerical Methods in Physics, Topics in 20th Century Physics, Excitations and Wave Interactions, and Wave Interactions in Crystals.

PH 597P. Special Topics: Photonics
Fiber optics, lasers, light emitting diodes, photodetectors, planar optical waveguides, fiber lasers and fiber amplifiers. (Prerequisite: a B.S. degree in physics or equivalent.)

PH 616. Quantum Mechanics III
Quantum theory of radiation and introduction to quantum field theory. Course may be offered by special arrangement. (Prerequisite: PH 515.)

PH 634. Electrodynamics
Classical electron theory, retarded potentials, radiation. Course may be offered by special arrangement. (Prerequisite: PH 533.)

PH 644. Seminar in the Interaction of Radiation and Matter
Quantum theory of radiation, interacting systems, magnetic resonance, laser models and