1. Course number and name: BMED 4477 Biological Networks and Genomics
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Mark Brodovsky
4. Textbook: Alon U., An Introduction to Systems Biology: Design Principles of Biological Circuits, Chapman and Hall, 2019
5. Specific course information
    a. Catalog description: Introduction to modeling of biological networks involved in gene regulation, cell signaling and metabolism. Mathematical modeling of cellular processes, such as gene expression, using genomic data.
    b. Prerequisites or co-requisites: BMED 3520 and [ISYE/CEE 3770 or BMED 2400]
    c. Elective
6. Specific goals for the course
    a. Understand research publications that apply machine learning techniques to infer new facts about biological networks relevant to modeling function of a particular gene or a set of genes of interest (Student Outcomes 1 and 3)
    b. Apply standard computational techniques to analyze new experimental data on gene expression, such as RNA-Seq data from literature or from a lab experiment, and to infer subnetworks of co-regulated genes (Student Outcomes 1 and 6)
    c. Apply standard data mining methods to retrieve information on the structure of metabolic, signal transduction pathway as well as protein-protein interaction networks related to a particular gene or protein of interest from existing databases (Student Outcomes 1 and 6)
    d. Apply analytical and computational techniques to model dynamic of gene expression of a set of genes controlled by several regulators under various conditions. (Student Outcomes 1)
    e. Understand principles of design of synthetic regulatory networks and come up with initial design of synthetic network using sets of binary or combinatorial regulators. (Student Outcomes 2)
7. Brief list of topics to be covered
    a. Introduction to OMICS data types and next generation data production techniques.
    b. Machine learning methods for identification of "system parts" from genomic sequence
    c. Examples of real life networks: transcriptional, protein-protein interaction, metabolic,
    d. signaling networks.
    e. Experimental methods for discovery of network structure.
    f. Random graph network models, structural patterns in random networks and in networks
    g. emerged as a result of biological evolution.

h. Use of conservation patterns in evolution of genome structure to infer elements of
i. structure of metabolic networks.
j. Use of RNA-seq for measuring gene expression. Clustering of gene expression data.
k. Identification of sets of co-expressed genes as modules of transcriptional networks
l. Global and local structure of transcriptional networks. Network motifs.
m. Dynamics of transcriptional regulation. Autoregulation.
n. Synthetic design of gene circuits. Binary and combinatorial regulation.

1. Course number and name: BMED 4500 Cell and Tissue Engineering Laboratory
2. Credits and contact hours: (1-0-6-3)
3. Prepared by: Julia Babensee
4. Textbook: Tissue Engineering, Palsson et al, Pearson Prentice Hall, Inc. (2004)
5. Specific course information
    a. Catalog description: The principles of cell and tissue engineering will be presented as a laboratory course to give students a hands-on experience. Cell engineering topics include receptor/ligand interactions, cell cycle/metabolism, cell adhesion, cellular mechanics, cell signal transduction, and cell transfection. Tissue engineering topics include applications, biomaterials/scaffolds and cells for reparative medicine, bioreactors and bioprocessing, functional assessment, in vivo issues.
    b. Prerequisites or co-requisites: BMED 3610 (w/concurrency)
    c. Elective
6. Specific goals for the course
    a. Apply their acquired laboratory skills and experimental design skills to cell and tissue engineering experiments (Student Outcomes 1, 3, and 6)
        i. Use experimental variables and controls
        ii. Generate and analyze data
        iii. Present experimental results
    b. Identify the engineering and biological issues relevant to cell and tissue engineering (Student Outcomes 1 and 6)
        i. Evaluate the critical issues in developing a tissue engineered construct
        ii. Evaluate the governing principles of cell and tissue engineering through a comparison of what is physically performed in the laboratory with what is presented in the corresponding lecture component
7. Brief list of topics to be covered
    a. Fundamentals of cellular engineering
    b. Tissue culture fundamentals
        i. Cells and Tissues, Cell/Tissue Culture Cell Growth and Differentiation
        ii. Tissue development
        iii. Cell cycle and metabolism
        iv. Receptor-ligand interactions
        v. Cell adhesion
        vi. Cell migration
    c. Fundamentals of tissue engineering
        i. Biomaterials for tissue engineering
        ii. Cells for repair
        iii. Bioreactors and bioprocessing
        iv. Functional assessments
        v. Host integration

vi. Regulatory and Ethical Issues

1. Course number and name: BMED 4603 Advanced Design
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: James K. Rains
4. Textbook: Design of Biomedical Devices and Systems, 2nd edition, King and Fries, Marcel-Dekker (2008)
5. Specific course information
    a. Catalog description: Continuation of a team-oriented design experience initiated in BMED 4602 Capstone Design. Includes more advanced relevant regulatory, intellectual property, and business management topics.
    b. Prerequisites or co-requisites: BMED 4602
    c. Elective
6. Specific goals for the course
    a. Tackle a complex, real-world problem (Student Outcomes 1, 2, 3 7)
        i. Define the problem and identify the problem goals
        ii. Explore the problem statement to identify critical problem features
        iii. Develop provisional models and hypotheses that frame problem-solving
        iv. Plan an attack strategy, carry it out, and evaluate the results
    b. Conduct self-directed inquiry (Student Outcomes 3 and 4)
        i. Recognize inadequacies of existing knowledge, identify learning needs, set specific learning objective, and make a plan to address these objectives
        ii. Evaluate inquiry, assess reliability of sources, digest findings and communicate them effectively to self and others
        iii. Apply the newly acquired knowledge to the problem
    c. Demonstrate effective group skills (Student Outcome 2, 3, 4)
        i. Help group develop team skills, and willingly forego personal goals for group goals
        ii. Complete tasks on time, and avoid contributing excessive or irrelevant information
        iii. Express disappointment or disagreement directly, give emotional support to others, demonstrate enthusiasm and involvement
        iv. Monitor group progress, facilitate interaction with other members, and assess group skills of self and others
7. Brief list of topics to be covered
    a. Design for Manufacturing
    b. Prototyping Methods
    c. Design Verification
    d. Advanced Regulatory Affairs (FDA, CE, and International)
    e. Advanced Intellectual Property (U.S. and International)
    f. Business Strategies for Medical Products
    g. Societal Impact

1. Course number and name: BMED 4739 Medical Robotics
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Jaydev P. Desai
4. Textbook: Medical Robotics, by Schweikard, Achim, Ernst, Floris, Springer, ISBN 978-3-319-22891-4
5. Specific course information
    a. Catalog description: An interdisciplinary course focusing on fundamental understanding of robot kinematics and dynamics as well as the design, development, and evaluation of a medical robotic system.
    b. Prerequisites or co-requisites: BMED 3110 and BMED 3400
    c. Elective
6. Specific goals for the course
    a. Have a fundamental understanding of robot kinematics and dynamics
    b. Understand the challenges in the design of a medical robotic system given the specific requirements for a particular application
    c. Appreciate the design, development, and evaluation of a medical robotic systems
7. Brief list of topics to be covered
    a. Introduction to Medical Robotics
    b. Minimally Invasive Surgery
    c. Review of Mathematical Preliminaries
    d. Robot Forward Kinematics - Position, velocity, and acceleration analysis
    e. Robot Inverse Kinematics and Manipulator Jacobian
    f. Introduction to various imaging modalities – Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Ultrasound
    g. Image-guided surgical robotics
    h. Robot dynamics
    i. Introduction to Haptics and its applications in medical robotics

1. Course number and name: BMED 4750 Diagnostic Imaging Physics
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: John Oshinski
4. Textbook: Introduction to Biomedical Imaging, Webb, Wiley-IEEE Press (2002)
5. Specific course information
    a. Catalog description: We examine evolutionary adaptation as a source for engineering design inspiration, utilizing principles of scaling, adaptability, and robust multifunctionality that characterize biological systems.
    b. Prerequisites or co-requisites: BMED 3110
    c. Elective
6. Specific goals for the course
    a. Understand x-ray, ultrasound, and magnetic resonance interactions with tissue and the various components of imaging systems (Student Outcome 1)
    b. Use fundamentals of mathematics and physics to analyze image data (Student Outcomes 1)
    c. Understand modern imaging devices and their application in medicine and industry (1)
7. Brief list of topics to be covered
    a. Conventional planar imaging
    b. Digital x-ray imaging and computed tomography
    c. Nuclear medicine imaging
    d. Magnetic resonance imaging (MRI)
    e. Ultrasound imaging

1. Course number and name: BMED 4751 Introduction to Biomaterials
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Johnna Temenoff
4. Textbook: J.S. Temenoff, A.G. Mikos, Biomaterials: The Intersection of Biology and Materials Science.
5. Specific course information
    a. Catalog description: Introduction to different classes of biomaterials (polymers, metals, ceramics) and physiological responses to biomaterial implantation. Topics include material properties, host response, and biomaterial characterization techniques.
    b. Prerequisites or co-requisites: MSE 2001
    c. Elective
6. Specific goals for the course
    a. Understand the structure-properties relationships iwn ceramic, metal, and polymer biomaterials (Student Outcomes 1)
    b. Understand the biological environment and mechanisms within the host that interacts with implanted biomaterials and ultimately determine their function in vivo (Student Outcomes 1)
    c. Understand the basic principles and applications of characterization techniques for surface and bulk properties of materials, as well as biological responses to materials (Student Outcomes 6)
    d. Understand basic biomedical applications of ceramic, metal, and polymer biomaterials (Student Outcome 2)
7. Brief list of topics to be covered
    a. Materials science of biomaterials
        i. Classes of materials for biomedical applications
        ii. Chemical composition, structure, physical and mechanical properties of biomaterials
        iii. Processing and degradation of polymer-based biomaterials
        iv. Surface properties of biomaterials
    b. Biological implications of biomaterials
        i. Protein and cell interactions with biomaterials
        ii. Effects of biomaterials on thrombosis, acute inflammation, wound healing, and immune responses of host
        iii. Infection due to biomaterials

1. Course number and name: BMED 4757 Biofluid Mechanics
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Ajit P. Yoganathan, Shelly Singh, Alan Wei
4. Textbook: Chandran KB, Yoganathan AP, and Rittgers S. "Biofluid Mechanics: The Human Circulation", CRC 2nd Edition (February 24, 2012), ISBN: 1439845166
5. Specific course information
    a. A brief description of the content of the course (catalog description): Introduction to the study of blood flow in the cardiovascular system. Emphasis on modeling and the potential of flow studies for clinical research applications. Crosslisted with AE, CHE and ME 4757.
    b. Prerequisites or co-requisites: AE 2020 or BMED 3310 or ME 3340
    c. Elective
6. Specific goals for the course
    a. Understand physiologically-relevant fluid and solid mechanics (Student Outcome 1)
        i. Understand fluid and solid mechanics that are pertinent to blood flow in the heart and blood vessels
        ii. Understand cardiovascular physiology
    b. Apply fluid mechanical analyses relevant to biomedical engineering problems (Student Outcomes 1)
        i. Conduct fluid mechanical analyses of human circulation, primarily applied to blood flow at the arterial level
        ii. Conduct fluid mechanical analyses of vascular implants (e.g., prosthetic valves) and measurements in the cardiovascular system
    c. Understand and analyze velocity measurement techniques relevant to blood flow (e.g., MRI, Ultrasound, Doppler) (Student Outcomes 1)
    d. Understand the use of computational techniques in simulating blood flow (Student Outcomes 1)
    e. Understand the process of literature review related to a given subject, preparation of a review article for publication and presenting it to a panel of 3-5 experts (Student outcomes 3, 5, and 7)
7. Brief list of topics to be covered
    a. Review of fluid dynamics
    b. Introduction to solid mechanics
    c. Review of cardiovascular physiology
    d. Blood rheology and blood vessel mechanics
    e. Hydrostatics and steady flow models
    f. Unsteady flow and non-uniform geometric models
    g. Native heart valve dynamics
    h. Prosthetic heart valve fluid dynamics
    i. Vascular therapeutic techniques

j. Fluid dynamics measurement techniques relevant to blood flow
k. Introduction to computational fluid dynamics

1. Course number and name: BMED 4758 Biosolid Mechanics
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: C. Ross Ethier and Brandon Dixon
4. Textbook: Cardiovascular Solid Mechanics, JD Humphrey, Springer, 2004.
5. Specific course information
    a. Catalog description: The mechanics of living tissue, e.g., arteries, skin, heart muscle, ligament, tendon, cartilage, and bone. Constitutive equations and some simple mechanical models. Mechanics of cells. Applications.
    b. Prerequisites or co-requisites: BMED 3410 or COE 3001
    c. Elective
6. Specific goals for the course
    a. Perform basic tensor algebra operations and employ index notation to manipulate expressions containing scalar, vector and second-order tensors (Student Outcome 1)
    b. Understand the concepts and various definitions of stress and strain and identify the 3D state of stress and strain under different loading scenarios (Student Outcome 1)
        i. Uniaxial and biaxial extension and compression
        ii. Simple and pure shear
        iii. Inflation and extension of a residually stressed tube
    c. Delineate the general mechanical characteristics of different biological materials and identify an appropriate theoretical framework to perform stress analysis on these materials (Student Outcome 1)
    d. Apply the basic postulates of classical physics (conservation of mass, linear and angular momentum, and energy and the entropy inequality) to determine the 3D distribution of stress and strain in biological tissues under various loading scenarios with a given constitutive equation (Student Outcome 1)
    e. Apply the basic postulates of classical physics to formulate constitutive equations and determine material parameters for biological tissues modeled as non-linear, elastic, heterogeneous, anisotropic, incompressible materials (Student Outcome 1)
7. Brief list of topics to be covered
    a. Introduction
    b. Mathematical Preliminaries
        i. Properties and Manipulation of Scalars, Vectors, and Tensors
        ii. Matrix Methods
    c. Continuum Mechanics
        i. Kinematics: Deformation and Concept of Strain
        ii. Stress, Traction
        iii. Balance Relations
        iv. Constitutive Formulation

d. Finite Elasticity for Soft Tissue Biomechanics
    i. Uniaxial Extension
    ii. Planar Biaxial Extension
    iii. Inflation, Extension, and Torsion of a Thick Walled, Residually Stressed Tube
e. Soft Tissue Viscoelasticity
    i. Finite Viscoelasticity
    ii. Linear and Quasi-Linear Viscoelasticity

1. Course number and name: BMED 4765 Drug Design, Development, and Delivery
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Mark Prausnitz
4. Textbook: None
5. Specific course information
    a. Catalog description: Introduction to the pharmaceutical development process, including design of new drugs, synthesis and manufacturing issues, and methods for delivery into the body. Includes student presentations.
    b. Prerequisites or co-requisites: CHEM 3511 or CHEM 4511
    c. Elective
6. Specific goals for the course
    a. Appreciate critical issues, perform analysis, and make quantitative calculations related to drug design (Student Outcome 1)
    b. Appreciate critical issues, perform analysis, and make quantitative calculations related to drug development (Student Outcome 1)
    c. Appreciate critical issues, perform analysis, and make quantitative calculations related to drug delivery (Student Outcome 1)
    d. Integrate concepts from drug design, development and delivery and appreciate their interdependence (Student Outcome 1)
    e. Understand the different phases of the pharmaceutical process (Student Outcome 2)
    f. Appreciate the role of alternative methods and broader implications of the pharmaceutical process (Student Outcome 4)
    g. Communicate with professionals in the pharmaceutical community (Student Outcome 3).
7. Brief list of topics to be covered
    a. Introduction
    b. Drug Design
    c. Drug Development
    d. Drug Delivery
    e. Case Study 1: Testosterone patch
    f. Case Study 2: Ocular Dorzolamide
    g. Case Study 3: Leuprolide Implant

1. Course number and name: BMED 4781 Biomedical Instrumentation
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Omer Inan
4. Textbook: Webster, Medical Instrumentation: Application and Design, 2009, (Optional)
5. Specific course information
    a. Catalog description: A study of physiological sensing topics from a systems viewpoint. Pertinent physiological and electro-physiological concepts will be covered.
    b. Prerequisites or co-requisites: ECE 3030 [min C] or ECE 3040 [min C] or ECE 3710 [min C] or ECE3043 [min C]
    c. Elective
6. Specific goals for the course
    a. Analyze op amp based circuits and systems for biomedical sensing
    b. Describe challenges in real-world biomedical sensing problems such as motion artifacts, skin-electrode interface, and low signal to noise ratio
    c. Develop strategies for mitigating these real-world challenges including through the design of multi-modal sensing systems and high performance circuit design
    d. Design biomedical sensing systems based on discrete analog and embedded systems hardware
    e. Communicate the design of biomedical sensing systems to a diverse audience of engineers and / or clinicians via written and oral presentation
7. Brief list of topics to be covered
    a. (5 hours) Basic Concepts of Biomedical Circuits and Systems
        i. Static and dynamic characteristics
        ii. Design criteria
        iii. Instrumentation Amplifiers
    b. (5 hours) Fundamentals of Transducers and Interface Circuits
        i. Basic op amp circuits
        ii. Filters
        iii. Sensor interfacing and specifications
    c. (5 hours) Membrane Biophysics
        i. Diffusion across cell membranes
        ii. Nernst potentials
        iii. Diffusion potentials
        iv. Goldman equation
    d. (6 hours) Action Potentials
        i. Membrane behavior
        ii. Origin of action potential
        iii. Hodgkin-Huxley equations
        iv. Modeling
        v. Propagation of action potentials

   vi. Subthreshold stimuli

e. (4 hours) Biopotential Electrodes
   i. Fundamentals
   ii. Body surface electrodes
   iii. Microelectrodes
f. (5 hours) Electrophysiology of the Heart
   i. Anatomy/physiology of heart
   ii. Body surface potentials
   iii. Electrocardiogram
   iv. Heart vector
   v. Standard leads
g. (4 hours) Miscellaneous Electrophysiology
   i. Electroencephalography
   ii. Electromyography
h. (5 hours) Biomedical Transducers
   i. Pressure sensors
   ii. Strain gauges
   iii. Accelerometers
i. (2 hours) Elements of Wearable Sensing Systems
   i. Battery powering and charging
   ii. Wireless transmission
   iii. Embedded systems concepts
j. (2 hours) Special Topics (Guest Lectures on Research Topics in Biomedical Sensing)
k. (2 hours) Final Project Presentations

1. Course number and name: BMED 4782 Biosystems analysis
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Omer Inan
4. Textbook: Khoo, Michael C. K., Physiological Control Systems : Analysis, Simulation, and Estimation, 2001, (Optional)
5. Specific course information
    a. Catalog description: Signal processing and modeling tools are presented for analyzing biomedical signals, with a particular focus on physiologic monitoring for human health and performance.
    b. Prerequisites or co-requisites: ECE 2026 [min C] or BMED 3510 [min C] or CHBE 4411 [min C] or ME 3015 [min C]
    c. Elective
6. Specific goals for the course
    a. Design and implement pre-processing algorithms for reducing noise and artifacts from biosignal recordings
    b. Describe challenges in real-world biomedical signal processing problems such as motion artifacts and low signal-to-noise ratio
    c. Develop strategies for mitigating these real-world challenges including through the design of multi-modal signal processing and machine learning techniques
    d. Communicate the design of biosignal processing algorithms to a diverse audience of engineers and / or clinicians via written and oral presentation
7. Brief list of topics to be covered
    a. Fundamentals of digital signals and systems
        i. Convolution
        ii. Fourier transform
        iii. Digital filters
    b. Fundamentals of probability and statistics, and basic machine learning for biosignals
        i. Probability distribution and density functions
        ii. Basics of machine learning
        iii. Regression and classification
        iv. Signal modeling techniques
    c. Physiologic monitoring
        i. Cardiovascular and pulmonary physiological and signals
        ii. Nervous system and neurological disorders
        iii. Biomechanics: posture, balance, and movement
        iv. Acoustic signals: speech, heart sounds, snoring
        v. Trauma, hemorrhage and other acute monitoring
    d. Special topics in biosignal processing and modeling
        i. Cuffless blood pressure estimation
        ii. Extreme environment human performance augmentation

1. Course number and name: BMED 4783 Introduction to Medical Image Processing
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: May Dongmei Wang
4. Textbook: Gonzalez RC, and Woods RE: Digital Image Processing (3rd ed.). Prentice Hall; 2002 (strongly recommended)
5. Specific course information
    a. Catalog description: A study of mathematical methods used in medical acquisition and processing. Concepts, algorithms, and methods associated with acquisition, processing, and display of two- and three-dimensional medical images are studied.
    b. Prerequisites or co-requisites: (ECE 2025/2026 [min C]) and (CEE/ISYE/MATH 3770* or ISYE 2027* or ECE 3077 or BMED 2400)
    c. Elective
6. Specific goals for the course
    a. Master the concepts and methods in medical imaging processing.
    b. Learn and practice biomedical image analysis skills.
7. Brief list of topics to be covered
    a. Organ-level imaging modality
    b. Microscopic-level imaging modality
    c. Fundamentals of digital image processing
    d. Intensity Transformations and Spatial Filtering
    e. Image enhancement and filtering in frequency domain, image restoration
    f. Color image processing
    g. Image segmentation
    h. Image representation and description
    i. Morphological image processing

1. Course number and name: BMED 4784 Engineering Electrophysiology
2. Credits and contact hours: (3-0-0-3)
3. Prepared by: Bill Hunt
4. Textbook: Bioelectricity: A Quantitative Approach Plonsey, Robert; Barr, Roger C. 3rd edition, 2007, 528 pages, Hardcover ISBN: 978-0-387-48864-6, Springer

   Supplemental: The PN Junction Diode: Volume II (2nd Edition) (Modular Series on Solid State Dev., Vol 2) 2nd Edition, G.W. Neudeck, Chapters 2 and 3 ISBN-10: 0201122960
5. Specific course information
   a. Catalog description: Basic concepts of electrophysiology from an engineering perspective. Functionality of relevant organs and systems; instrumentation tools which monitor electrophysiological function.
   b. Prerequisites or co-requisites: ECE3040 or BMED 3500
   c. Elective
6. Specific goals for the course
   a. Explain the basic concepts of electrophysiology and the analogies to active / passive electrical circuits.
   b. Explain the function of relevant organs, systems in the body as well as the analysis tools used to monitor and quantify those biological systems.
7. Brief list of topics to be covered
   a. Membrane Biophysics: Diffusion across cell membrane, Nernst potentials, Diffusion potentials, Goldman equation
   b. Action Potentials: Membrane behavior, Origin of action potentials, Hodgkin-Huxley equations, Modeling, Propagation of action potentials, Subthreshold stimuli
   c. Electrical Stimulation of Excitable Tissue: Space Constants and Time Constants, Single Cell stimulation, Differential Equations and Green's Functions for nerve fibers
   d. Extracellular Fields: Monopole and Dipole models
   e. Electrophysiology of the Heart: Anatomy/physiology of heart, Heart Vector, Electrode configurations , Recording, Body surface potentials, Interface electronics
   f. Neuromuscular Junction: Transmitters, Poisson statistics, Post-junctional responses
   g. Skeletal Muscle: Anatomy/physiology of muscle, Myofibrils and filaments, Excitation contraction
   h. Functional Neuromuscular Stimulation: Electrodes, Nerve Excitation
   i. Quantitative Sensory Physiology: Auditory Physiology, Retinal Physiology
   j. Interface Circuitry / Systems(Supplemental material may include): Brain Machine Interfaces, Skeletal Muscle interfaces

6. Specific goals for the course

a. Student will demonstrate a basic understanding of the five structural elements- atomic/molecular structure, defects, solutes, precipitates, grain boundaries and noncrystalline structures and how they manifest themselves in each class of material.

b. Student will demonstrate a basic understanding of how the key microstructural elements are controlled by composition, temperature, and deformation.

c. Student will demonstrate a basic understanding of how material structure relates to mechanical performance.

d. Student will demonstrate the ability to calculate parameters that describe the structure, chemical composition, and phase fractions in solids

e. Student will demonstrate the ability to calculate materials properties from empirical data

7. Brief list of topics to be covered
   a. Atomic bonding
   b. Crystal structures
   c. Imperfections in crystalline solids
   d. Diffusion
   e. Non-crystalline and semi-crystalline solids
   f. Phase equilibria and phase diagrams
   g. Elastic and plastic deformation
   h. Ductile and brittle fracture