

BBS COURSE GUIDE

Yale University

**A comprehensive listing of graduate level courses affiliated with the
Yale Combined Program in the Biological & Biomedical Sciences**

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YALE
BBS Combined Program in the
Biological & Biomedical Sciences

This guide contains all courses offered by the 12 Ph.D. programs affiliated with the Yale BBS Program. Some courses are offered only every other year and are noted as such. Some courses are limited to students in special programs and are noted as such

Visit the Online Course Information system at <https://courses.yale.edu/> to find course times, dates, and locations.

CELL BIOLOGY

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/cell-biology/>

CBIO 5501/5502, Molecules to Systems

This course is designed to provide medical students with a current and comprehensive review of biologic structure and function at the cellular, tissue, and organ system levels. Areas covered include structure and organization of cells; regulation of the cell cycle and mitosis; protein biosynthesis and membrane targeting; cell motility and the cytoskeleton; signal transduction; cell adhesion; cell and tissue organization of organ systems. Clinical correlation sessions, which illustrate the contributions of cell biology to specific medical problems, are interspersed in the lecture schedule. Histophysiology laboratories provide practical experience with an understanding of exploring cell and tissue structure. The course is offered only to M.D. and M.D./Ph.D. students. It runs for three terms from September to December of the next academic year to coincide with the School of Medicine curriculum. Registration and the release of grades takes place in the third term. The course is equivalent to two graduate credits.

CBIO 6600/6601, Science at the Frontiers of Medicine

This full year course is a graduate credit course for first-year MD-PhD students and an elective course for medical students, emphasizes the connections between basic and clinical science, human physiology and disease. It parallels the content of Yale Medical School's first-year courses and is designed for students who are considering a career in medical research or who choose to explore scientific topics in depth, learn about cutting-edge research and improve their presentation skills. Discussions cover the challenges faced in research, selecting your topic and pursuing an academic career. Enrollment is limited to those who have taken or are taking the Masters Courses. Select topics are presented by eminent faculty who serve as excellent role models for your academic careers. In most sessions, two students review relevant manuscripts under the guidance of a faculty mentor and present the material to the group. Prior to the start of class, students are required to submit questions concerning techniques and concepts that may not be clear from the assigned papers. These questions will then be addressed during the presentation. Student evaluations are graded on attendance, participation in group discussions and formal presentations. The course runs from September to mid-May and provides graduate credit if needed. It is equivalent to two graduate credits.

CBIO 6020/MB&B 6020/MCDB 6020, Molecular Cell Biology

A comprehensive introduction to the molecular and mechanistic aspects of cell biology for graduate students in all programs. Emphasizes fundamental issues of cellular organization, regulation, biogenesis, and function at the molecular level.

CBIO 6030/MCDB 6030, Seminar in Molecular Cell Biology

A graduate-level seminar course in modern cell biology. The class is devoted to the reading and critical evaluation of classical and current papers. The topics are coordinated with the CBIO 602a lecture schedule. Thus, concurrent enrollment in CBIO 602a is required.

CBIO 6606, Advanced Topics in Cell Biology

This seminar course, which meets once weekly, covers advanced topics in cell biology. Each topic is spread over two or three sessions, which start with an introductory overview and are followed by a discussion of key papers led by an expert in the field.

CBIO 6550/GENE 6550, Stem Cells: Biology and Application

This course is designed for first-year or second-year students to learn the fundamentals of stem cell biology and to gain

familiarity with current research in the field. The course is presented in a lecture and discussion format based on primary literature. Topics include stem cell concepts, methodologies for stem cell research, embryonic stem cells, adult stem cells, cloning and stem cell reprogramming, and clinical applications of stem cell research. Prerequisites: undergraduate-level cell biology, molecular biology, and genetics.

CBIO 7701, Illuminating Cellular Function

Introduction to the principles and practical methods of live cell imaging. Covers principles of fluorescent microscopy (including genetically encoded probes and physiological indicators), image formation, image detection, and image analysis. Includes hands-on demonstrations of state-of-the-art instrumentation, such as video-rate confocal and super-resolution "nanoscopes." The course is equivalent to 1 graduate credit.

CBIO 9000/GENE 9000/MCDB 9000, Research Skills and Ethics I

This course consists of seminars that covers ethics, grant writing, and training for scientific speaking for Molecular Cell Biology, Genetics, and Development track students.

CBIO 9010/GENE 9010/MCDB 9010, Research Skills and Ethics II

This course consists of seminars that covers ethics, grant writing, and training for scientific speaking for Molecular Cell Biology, Genetics, and Development track students.

CBIO 9110/GENE 9110/MCDB 9110, First Laboratory Rotation

First laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

CBIO 9120/GENE 9120/MCDB 9120, Second Laboratory Rotation

Second laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

CBIO 9130/GENE 9130/MCDB 9130, Third Laboratory Rotation

Third laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

CBIO 9140/GENE 9140/MCDB 9140, Fourth Laboratory Rotation (optional)

Fourth laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

CELLULAR AND MOLECULAR PHYSIOLOGY

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/cellular-molecular-physiology/>

C&MP 5500/ENAS 550/MCDB 5500/PHAR 550/PTB 5500, Physiological Systems (Required Course)

The course develops a foundation in human physiology by examining the homeostasis of vital parameters within the body, and the biophysical properties of cells, tissues, and organs. Basic concepts in cell and membrane physiology are synthesized through exploring the function of skeletal, smooth, and cardiac muscle. The physical basis of blood flow, mechanisms of vascular exchange, cardiac performance, and regulation of overall circulatory function are discussed. Respiratory physiology explores the mechanics of ventilation, gas diffusion, and acid-base balance. Renal physiology examines the formation and composition of urine and the regulation of electrolyte, fluid, and acid-base balance. Organs of the digestive system are discussed from the perspective of substrate metabolism and energy balance. Hormonal regulation is applied to metabolic control and to calcium, water, and electrolyte balance. The biology of nerve cells is addressed with emphasis on synaptic transmission and simple neuronal circuits within the central nervous system. The special senses are considered in the framework of sensory transduction. Weekly discussion sections provide a forum for in-depth exploration of topics. Graduate students evaluate research findings through literature review and weekly meetings with the instructor.

C&MP 5560/ENAS 570/MCDB 5600/PHAR 5600, Cellular and Molecular Physiology: Molecular Machines in Human Disease

The course focuses on understanding the processes that transfer molecules across membranes at the cellular, molecular, biophysical, and physiological levels. Students learn about the different classes of molecular machines that mediate membrane transport, generate electrical currents, or perform mechanical displacement. Emphasis is placed on the relationship between the molecular structures of membrane proteins and their individual functions. The interactions among transport proteins in determining the physiological behaviors of cells and tissues are also stressed. Molecular motors are introduced and their mechanical relationship to cell function is explored. Students read papers from the scientific literature that establish the connections between mutations in genes encoding membrane proteins and a wide variety of human genetic diseases.

C&MP 5580, Mitochondrial Bioenergetics and Intermediary Metabolism.

The course will present a comprehensive introduction to the fundamentals of mitochondrial physiology and pathophysiology, with topics including glucose, lipid, amino acid, and cholesterol metabolism; mitochondrial bioenergetics; flux modeling; inherited and acquired metabolic disorders; and common methods used to characterize metabolism. In addition to these key topics, students will gain experience in reviewing papers and critically evaluating experimental design and implementation. The material will be presented in a mixed lecture/discussion format. The class will be offered Wednesdays and Fridays from 10:30-11:45 this semester. Please contact either of the instructors (rachel.perry@yale.edu, Richard.kibbey@yale.edu) if you have any questions.

C&MP 5570, Sensory Physiology

The course provides an overview of the mammalian special sensory systems, including molecular and cellular bases of vision, audition, taste, olfaction, and somatosensation. Faculty with focus in those areas lead presentations and discussions on peripheral and central mechanisms. Psychophysical aspects of sensation are introduced.

C&MP 5600, Medical Physiology Case Conferences (open only to MD/PhD & MRSP students)

Two-term course taught in groups of ten to twelve students by the same group leader(s) throughout the year. Workshop format permits students to apply basic concepts of physiology to clinical syndromes and disease processes. Students are expected to participate actively in a weekly discussion of a clinical case that illustrates principles of human physiology and pathophysiology at the whole-body, system, organ, cellular, or molecular level. Prerequisites: C&MP 550a and permission of the instructor. Credit for full year only.

C&MP 5610/PTB 5610, Medical Research Scholars Program: Mentored Clinical Experience (open only to MRSP students)

The purpose of the Mentored Clinical Experience (MCE), a PTB and MRSP-specific course, is to permit students to gain a deep understanding of and appreciation for the interface between basic biomedical research and its application to clinical practice. The MCE is intended to integrate basic and translational research with direct exposure to clinical medicine and patients afflicted with the diseases or conditions under discussion. The course provides a foundation and a critically important forum for class discussion because each module stimulates students to explore a disease process in depth over four 90 min sessions led by expert clinician-scientists. The structure incorporates four perspectives to introduce the students to a particular disease or condition and then encourages them to probe areas that are not understood or fully resolved so they can appreciate the value and challenge inherent in using basic science to enhance clinical medicine. Students are provided biomedical resource material for background to the sessions as well as articles or other publicly available information that offers insight to the perspective from the non-scientific world. During this course students meet with patients who have experienced the disease and/or visit and explore facilities associated with diagnosis and treatment of the disease process. Students are expected to prepare for sessions, to participate actively, and to be scrupulously respectful of patients and patient facilities. Prior to one of the sessions students receive guidance as to what they will observe and how to approach the experience; and at the end of the session, the students discuss their thoughts and impressions. All students receive HIPAA training and appropriate training in infection control and decorum relating to patient contact prior to the course.

C&MP 5620, Fundamentals in Neurophysiology

The course is designed for students who wish to gain a theoretical and practical knowledge of modern neurophysiology. Graduate students specializing in neurophysiology and non-neurophysiology are encouraged to attend, as the course begins at a very basic level and progresses to more complicated topics. Topics include properties of ion channels, firing properties of neurons, synaptic transmission, and neurophysiology methodology.

C&MP 5630/PATH 5680/PHAR 5502/PTB 5630, Seminar in Molecular Medicine, Pharmacology, and Physiology

Readings and discussion on a diverse range of current topics in molecular medicine, pharmacology, and physiology. The class emphasizes analysis of primary research literature and development of presentation and writing skills. Contemporary articles are assigned on a related topic every week, and a student leads discussions with input from faculty who are experts in the topic area. The overall goal is to cover a specific topic of medical relevance (e.g., cancer, neurodegeneration) from the perspective of three primary disciplines (i.e., physiology: normal function; pathology: abnormal function; and pharmacology: intervention).

C&MP 5650/PATH 5660/PHAR 5580, Ethics

Organized to foster discussion, the course is taught by faculty in the Pharmacology, Pathology, and Physiology departments and two or three senior graduate students. Each session is based on case studies from primary literature, reviews, and two texts: Francis Macrina's *Scientific Integrity* and Kathy Barker's *At the Bench*. Each week, students are required to submit a reaction paper discussing the reading assignment. Students take turns leading the class discussion; a final short paper on a hot topic in bioethics is required.

C&MP 5700, Physiology in Medicine

This discussion-based course makes use of medical case studies and scientific literature to illustrate key physiological concepts at the whole-body, system, organ, cellular, and molecular levels. Students are expected to actively participate in small-group discussions to deepen their understanding of human physiology and pathophysiology and how it relates to laboratory findings.

C&MP 5710/MB&B 5710, Electron Cryo-Microscopy for Protein Structure Determination

Understanding cellular function requires structural and biochemical studies at an ever-increasing level of complexity. The course is an introduction to the concepts and applications of high-resolution electron cryo-microscopy. This rapidly emerging new technique is the only method that allows biological macromolecules to be studied at all levels of resolution from cellular organization to near atomic detail. Counts as 0.5 credit.

COMPUTATIONAL BIOLOGY AND BIOMEDICAL INFORMATICS

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/computational-biology-biomedical-informatics/>

CB&B 5230/MB&B 5230/PHYS 5230/ENAS 5410, Biological Physics (Course offered every other year).

The course has three aims: 1) to introduce students to the physics of biological systems, 2) to introduce students to the basics of scientific computing, and 3) to familiarize students with characterization methods and analysis tools. We focus on studies of a broad range of biophysical phenomena including diffusion, polymer statistics, entropic forces, membranes and, cell motion using computational tools and methods. We provide intensive tutorials for Matlab including basic syntax, arrays, functions, plotting, and importing and exporting data.

CB&B 5620/AMTH 765/INP 7562/MB&B 5620/PHYS 5620, Modeling Biological Systems II

This course covers advanced topics in computational biology. How do cells compute, how do they count and tell time, how do they oscillate and generate spatial patterns? Topics include time dependent dynamics in regulatory, signal-transduction, and neuronal networks; fluctuations, growth, and form; mechanics of cell shape and motion; spatially heterogeneous processes; diffusion. This year, the course spends roughly half its time on mechanical systems at the cellular and tissue level, and half on models of neurons and neural systems in computational neuroscience. Prerequisite: a 200-level biology course or permission of the instructor

CB&B 5710, Data Science Grant Writing Practicum

This is a hands-on course where students review funded and non-funded grant proposals for different types of NIH awards, as well as the critiques provided by the reviewers. Proposals in informatics and data science are different than traditional basic sciences proposals and clinical research proposals, so this course is specific for those proposing data science and informatics innovation that can be applied in biology and/or medicine. Although there is an emphasis on K (mentored) and F awards, we also cover the basics of R (non-mentored) research awards. Instructors and classmates review proposals that students prepare as part of the course.

CB&B 5740, Biomedical Natural Language Processing: Methods and Applications

This course examines current natural language processing (NLP) methods and their applications in the biomedical domain. It provides a systematic introduction to basic knowledge on NLP and AI (e.g., linguistics, machine learning, and deep learning algorithms), advanced NLP tasks (e.g., information extraction, information retrieval, question answering), and corresponding approaches including the recent large language models (LLMs) and hands-on experience in developing biomedical NLP systems for different applications, ranging from biomedical literature mining to clinical decision support. Assessment in this course consists of technical exercises, exams, and projects, to demonstrate the applicability of skills learned during the course.

CB&B 5750, Bioinformatics Applications in Biomedicine

This course covers the latest advances in bioinformatics in the context of human diseases. Students learn background knowledge and practical skills to analyze omics data for human disease research. By the end of this course, students should be able to: (1) process bioinformatics data with linux-based pipelines and data tools, (2) apply exploratory data analysis techniques in Python and R, (3) perform analysis of DNA, RNA, and protein data, and (4) conduct a biobank-scale analysis using the platform such as the All of Us Research Workbench.

CB&B 6010/IBIO 6010, Fundamentals of Research: Responsible Conduct of Research

A weekly seminar presented by faculty trainers on topics relating to proper conduct of research. Required for first-year CB&B students, first year Immunobiology students, and training grant-funded postdocs. Pass/Fail.

CB&B 6340, Comp Methods for Informatics

This course introduces the key computational methods and concepts necessary for taking an informatics project from start to finish using APIs to query online resources, reading, and writing common biomedical data formats, choosing appropriate data structures for storing and manipulating data, implementing computationally efficient and parallelizable algorithms for analyzing data, and developing appropriate visualizations for communicating health information. The FAIR data-sharing guidelines are discussed. Current issues in big health data are discussed, including

successful applications as well as privacy and bias concerns. This course has a significant programming component, and familiarity with programming is assumed. Prerequisite: CPSC 223 or equivalent, or permission of the instructor.

CB&B 6380/BIS 6380, Clinical Database Management Systems and Ontologies

This course introduces database and ontology in the clinical/public health domain. It reviews how data and information are generated in clinical/public health settings. It introduces different approaches to representing, modeling, managing, querying, and integrating clinical/public health data. In terms of database technologies, the course describes two main approaches—SQL database and non-SQL (NoSQL) database—and shows how these technologies can be used to build electronic health records (EHR), data repositories, and data warehouses. In terms of ontologies, it discusses how ontologies are used in connecting and integrating data with machine-readable knowledge. The course reviews the major theories, methods, and tools for the design and development of databases and ontologies. It also includes clinical/public health use cases demonstrating how databases and ontologies are used to support clinical/public health research.

CB&B 6450/BIS 6450, Statistical Methods in Human Genetics and Bioinformatics (Course offered every other year)

Introduction to problems, algorithms, and data analysis approaches in computational biology and bioinformatics. We discuss statistical issues arising in analyzing population genetics data, gene expression microarray data, next-generation sequence data, microbiome data, and network data. Statistical methods include maximum likelihood, EM, Bayesian inference, Markov chain Monte Carlo, and methods of classification and clustering; models include hidden Markov models, Bayesian networks, and graphical models. Prerequisite: S&DS 538, S&DS 542, or S&DS 661. Prior knowledge of biology is not required, but some interest in the subject and a willingness to carry out calculations using R is assumed.

CB&B 6663/CPSC 4520/AMTH 5520/GENE 6630, Deep Learning Theory and Applications (Course offered every other year)

Deep neural networks have gained immense popularity within the past decade due to their success in many important machine-learning tasks such as image recognition, speech recognition, and natural language processing. This course provides a principled and hands-on approach to deep learning with neural networks. Students master the principles and practices underlying neural networks, including modern methods of deep learning, and apply deep learning methods to real-world problems including image recognition, natural language processing, and biomedical applications. Course work includes homework, a final exam, and a final project—either group or individual, depending on enrollment—with both a written and oral (i.e., presentation) component. The course assumes basic prior knowledge in linear algebra and probability. Prerequisites: [CPSC 202](#) and knowledge of Python programming.

CB&B 7110, 7120, 7130, Lab Rotations

Three 2.5–3-month research rotations in faculty laboratories are required during the first year of graduate study. These rotations are arranged by each student with individual faculty members.

CB&B 7140, Research Paper in Computational Biology and Biomedical Informatics

This two-semester single credit pass/fail course must be completed as part of the terminal M. S. degree program in computational biology and biomedical informatics (CB&B). Students work with a faculty supervisor in designing their project and writing their research paper. The syllabus details the intended scope and process for writing the research paper. In the broadest terms, the research paper must be of publishable quality and defensible in a public scientific forum. The student's research supervisor is responsible for managing the intended product. The preferred format of the research paper for students is one that is in the style and length of a publishable, peer-reviewed paper, templated based on the journal submission. Prerequisite: second year enrollment in program.

CB&B 7400/BIS 560, Introduction to Health Informatics

The course provides an introduction to clinical and translational informatics. Topics include (1) overview of biomedical informatics, (2) design, function, and evaluation of clinical information systems, (3) clinical decision-making and practice guidelines, (4) clinical decision support systems, (5) informatics support of clinical research, (6) privacy and confidentiality of clinical data, (7) standards, and (8) topics in translational bioinformatics. Permission of the instructor required.

CB&B 7520/MB&B 7520/ CPSC 7520 / MCDB 7520/ S&DS 3520, Biomedical Data Science: Mining and Modeling

Biomedical data science encompasses the analysis of gene sequences, macromolecular structures, and functional genomics data on a large scale. It represents a major practical application for modern techniques in data mining and simulation. Specific topics to be covered include sequence alignment, large-scale processing, next generation sequencing data, comparative genomics, phylogenetics, biological database design, geometric analysis of protein structure, molecular-dynamics simulation, biological networks, normalization of microarray data, mining of functional genomics data sets, and machine-learning approaches to data integration. Prerequisites: biochemistry and calculus, or permission of the instructor.

GENETICS

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/genetics/>

GENE 6250/MB&B 6250/MCDB 6250, Basic Concepts of Genetic Analysis

The universal principles of genetic analysis in eukaryotes are discussed in lectures. Students also read a small selection of primary papers illustrating the very best of genetic analysis and dissect them in detail in the discussion sections. While other Yale graduate molecular genetics courses emphasize molecular biology, this course focuses on the concepts and logic underlying modern genetic analysis.

GENE 6550/CBIO 6550, Stem Cells: Biology and Application

This course is designed for first-year or second-year students to learn the fundamentals of stem cell biology and to gain familiarity with current research in the field. The course is presented in a lecture and discussion format based on primary literature. Topics include stem cell concepts, methodologies for stem cell research, embryonic stem cells, adult stem cells, cloning and stem cell reprogramming, and clinical applications of stem cell research. Prerequisites: undergraduate-level cell biology, molecular biology, and genetics.

GENE 6750 and 6760, Graduate Student Seminar: Critical Analysis and Presentation of Scientific Literature

Students gain experience in preparing and delivering seminars and in discussing presentations by other students. A variety of topics in molecular, cellular, developmental, and population genetics are covered. Required for all second-year students in Genetics. Graded Satisfactory/Unsatisfactory.

GENE 7340/MBIO 7340/MB&B 7340, Molecular Biology of Animal Viruses

Lecture course with emphasis on mechanisms of viral replication, oncogenic transformation, and virus-host cell interactions.

GENE 7430/MB&B 7430/MCDB 7430, Advanced Eukaryotic Molecular Biology

Selected topics in transcriptional control, regulation of chromatin structure, mRNA processing, mRNA stability, RNA interference, translation, protein degradation, DNA replication, DNA repair, site-specific DNA recombination, somatic hypermutation. Prerequisite: biochemistry or permission of the instructor.

GENE 7600, Genomic Methods for Genetic Analysis

Introduction to the analysis and interpretation of genomic datasets. The focus is on next-generation sequencing (NGS) applications including RNA-seq, ChIP-seq, and exome and whole genome sequencing. By the end of this time-intensive, practical problem-set based course, each student will be able to process and analyze large-scale NGS datasets and interpret the results. This course is intended only for graduate students who are interested in applying genomic approaches in their thesis research. A basic familiarity with working in a UNIX/Linux computing environment or prior experience with a programming language is not required but can be useful. Extra resources will be made available prior to the course starting for students without any programming experience.

GENE 7770/MCDB 6770, Mechanisms of Development

An advanced course on mechanisms of animal and plant development focusing on the genetic specification of cell organization and identity during embryogenesis and somatic differentiation. The use of evolutionarily conserved signaling pathways to carry out developmental decisions in a range of animals is highlighted. Course work includes student participation in critical analysis of primary literature and a research proposal term paper.

GENE 9000/CBIO 9000/MCDB 9000, Research Skills and Ethics I

This course consists of seminars that covers ethics, grant writing, and training for scientific speaking for Molecular Cell Biology, Genetics, and Development track students.

GENE 9010/CBIO 9010/MCDB 9010, Research Skills and Ethics II

This course consists of seminars that covers ethics, grant writing, and training for scientific speaking for Molecular Cell Biology, Genetics, and Development track students.

GENE 9110/CBIO 9110/MCDB 9110, First Laboratory Rotation

First laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

GENE 9120/CBIO 9120/MCDB 9120, Second Laboratory Rotation

Second laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

GENE 9130/CBIO 9130/MCDB 9130, Third Laboratory Rotation

Third laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

GENE 9140/CBIO 9140/MCDB 9140, Fourth Laboratory Rotation (optional)

Fourth laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

GENE 9210, Reading Course in Genetics and Molecular Biology

Directed reading with faculty. Term paper required. Prerequisite: permission of Genetics DGS.

IMMUNOBIOLOGY

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/immunobiology/>

IBIO 5503, Responsible Conduct in Research, Refresher Course

NIH requirement, 4th year students to receive training in the responsible conduct of research every 4 years, and Immunobiology 5503 meets this requirement.

Immunobiology faculty facilitate discussions based on RCR topics which are gathered in advance from the students. These anonymous-hypothetical stories are selected by the faculty and discussed. A workshop environment where students are then asked to analyze each case and suggest courses of actions.

IBIO 5300/MCDB 5300, *Biology of the Immune System*,

The development of the immune system. Cellular and molecular mechanisms of immune recognition. Effector responses against pathogens; autoimmunity. Also, MCDB 4300 – Required for all First Year Immunology/BBS students

IBIO 5310, Advanced Immunology

The historical development and central paradigms of key areas in immunology. The course attempts to develop a clear understanding of how these paradigms were established experimentally. Landmark studies are discussed to determine how the conclusions were obtained and why they were important at the time they were done. Lecture and discussion format; readings of primary research papers and review articles. Prerequisite: IBIO 5300 or equivalent. Enrollment limited to fifteen. Required for all first year BBS/Immunology Students.

Two Advanced Immunobiology seminar courses (choose from IBIO 5320, 5360, 5370, 5380, 5390)

Seminar courses are typically available every Fall and every other Spring. First seminar must be taken for a grade. If the student has completed six courses, then the seventh class (seminar) can be audited.

IBIO 6010/CB&B 6010/MBIO 6010, Fundamentals of Research: Responsible Conduct of Research

Faculty led presentations on topics relating to proper conduct of research. Required for first year Immunobiology students. Pass/Fail.

IBIO 6110, *Research rotation 1*

Intensive experience in the design and execution of experiments in immunology or other areas of biology. Students design a focused research project in consultation with a faculty mentor and execute the designed experiments in the mentor's laboratory. Students are expected to read relevant background papers from the literature, design and perform experiments, interpret the resulting data, and propose follow up experiments. Students are also expected to attend the mentor's weekly lab meeting(s) as well as weekly Immunobiology departmental seminars and Research in Progress seminars. The course concludes with the student giving a brief presentation of the work performed at Rotation Talks, attended by other first year Immunology Track graduate students. Evaluation is by the mentor and trainee. Pass/Fail. (1 course credit; minimum of 20 hours/week). *Required for all first year Immunology/BBS students.*

IBIO 6120, *Research Rotation 2*

See description under IBIO 6110.

IBIO 6130, *Research Rotation 3*

See description under IBIO 6110.

INTERDEPARTMENTAL NEUROSCIENCE PROGRAM

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/interdepartmental-neuroscience-program/>

INP 5503, Bioethics Refresher course

The required fourth-year bioethics refresher course runs during the spring semester. This involves both an independent component based around a series of videos on ethics and an in-person discussion component. The requirement is that we have eight hours of in-person instruction time. We have a two-hour component based on video content generated by the BBS and three classroom sessions of two hours each. These sessions are NIH-mandated, so please plan to attend.

INP 5580, Bioethics in Neuroscience

This course is an introduction to ethics and ethical decision-making in the neurosciences. Format for the course is an informal discussion. Each week we are joined by members of the Yale faculty and community who share their experiences and expertise as it relates to the topic of the week. Required of first year INP students. Grading is Satisfactory/Unsatisfactory and is based on attendance/participation, weekly reaction papers, and a final term paper. Enrollment limited to Neuroscience track students.

INP 5701, Principles of Neuroscience

General neuroscience seminar: lectures, readings, and discussion of selected topics in neuroscience. Emphasis is on how approaches at the molecular, cellular, physiological, and organismal levels can lead to understanding of neuronal and brain function. Course is restricted to graduate students.

INP 5702, Foundations of Cellular and Molecular Neurobiology

A comprehensive overview of cellular and molecular concepts in neuroscience. Each exam (of three) covers one-third of the course (Cell Biology, Electrophysiology, and Synaptic Function) and is take-home, with short answer/essay questions.

INP 5703, Foundations of Systems Neuroscience

An examination of the neural circuits that subserve sensory, motor, cognitive, and affective function, and their relationships to human disorders. A comparative species approach is used to highlight the evolution of neural circuits and their functions. Required of first-year Neuroscience track students.

INP 6511/INP 6512, Lab Rotation for First-Year Students

Required for all first-year Neuroscience graduate students. Rotation period is one term. Grading is Sat/Unsat based on PI's rotation evaluation.

INP 6513/INP 6514, Second Year Thesis Research

Required for all second year INP graduate students. Both terms required. Grading is Sat/Unsat based on PI's certification.

INP 6519, Tutorial

By arrangement with faculty and approval of DGS.

INP 7538 Computational Methods in Decision Making

This course provides training on how to use computational models to understand human behavior with a focus on learning, decision making, and happiness. Data is collected in a variety of tasks including new experiments designed by students, and is analyzed using computational models.

INP 7558/PSYC 558, Computational Methods in Human Neuroscience

This course provides training on how to use computational science for the advanced analysis of brain imaging data, primarily from functional magnetic resonance imaging (fMRI). Topics include scientific programming, high-performance computing, machine learning, network/graph analysis, real-time neurofeedback, nonparametric statistics, and functional alignment. Prerequisite: some prior experience with programming (Matlab, R or Python), data preprocessing, and basic fMRI analysis. Permission of instructor required.

INP 7560, R Stats for Neuroscience

The course is designed for graduate students with little or no programming experience but with a desire to learn how to use and develop software to aid in neuroscience and genomics research. Given the popularity of R and R packages in neurogenomics labs worldwide, the course is conducted predominantly in R. However, much of what is learned is easily translated into other programming languages (e.g. Matlab or Python). In addition to lecture material, each class includes laboratory time during which students work on specific data sets and get direct instruction and assistance. The course includes introductions to HPC and command line programming; R packages for data analysis with Rstudio and common packages such as ggplot2, DESeq2, limma, and WGCNA, and analysis of datasets including bulk and single-cell RNA-sequencing; spatial transcriptomics; DNA methylation; and genotype data. We also include best practices of using GitHub.

INP 7562/ CB&B 5620/ MB&B 5620, Modeling Biological Systems II

This course covers advanced topics in computational biology. How do cells compute, how do they count and tell time, how do they oscillate and generate spatial patterns? Topics include time-dependent dynamics in regulatory, signal-transduction, and neuronal networks; fluctuations, growth, and form; mechanics of cell shape and motion; spatially heterogeneous processes; diffusion. This year, the course spends roughly half its time on mechanical systems at the cellular and tissue level, and half on models of neurons and neural systems in computational neuroscience.

INP 7575/CPSC 575, Computational Vision and Biological Perception

An overview of computational vision with a biological emphasis. Suitable as an introduction to biological perception for computer science and engineering students, as well as an introduction to computational vision for mathematics, psychology, and physiology students.

INP 7598 Computing and Informatics for Biomedical Research

How does a biomedical scientist navigate the dynamic and rapidly evolving landscape of computing and information technologies for data operations that are of growing importance for cutting-edge research? This course lies at the intersection of modern computing architectures, data orchestration, and software development. It is intended for students across fields of neuroscience, biomedical engineering, bioinformatics, psychology, and related disciplines who aim to develop practical skills and learn tools for computing and informatics applicable to cutting-edge biomedical research. This course does not focus on analytics and/or statistics per se and does not require prior programming experience. Instead, scientific examples drawn from neuroimaging, genomics, computational neuroscience, and behavioral/psychological experiments help the student develop a transferable knowledge base and technical know-how around accessing, using, and deploying computing technologies and informatics tools in the service of biomedical research. Topics include the LINUX shell, BASH scripting, leading programming languages for applied scientific computing, IDEs, data transfer and information technology basics, cloud computing, high-performance computing, modern database principles, git version control, containerization, software design and development principles, software documentation, licensing best practices, and research software distribution considerations. Collectively, the course aims to confer literacy and useful real-world skills around state-of-the-art computing/informatics technologies that are practically relevant for biomedical research.

INP 7599, Statistics and Data Analysis in Neuroscience

This course focuses on practical applications of various statistical models and tests commonly used in neuroscience research. It covers basic probability theory, hypothesis testing, and maximum likelihood estimation, as well as model comparison. The specific models and tests covered include ANOVA, regression, time series analyses, and dimension reduction techniques (e.g., PCA). Examples and homework will be given in MATLAB, which will be introduced at the beginning of the course. Previous experience in programming and basic statistics is desirable but not required. Offered in the Spring term. Permission of instructor required for registration.

INP 7630 Research Methods in Developmental Neuroscience and Psychopathology

This course is available only to students enrolled in the Developmental Neuroscience and Psychopathology MRes program. The purpose of Year 2 Research Methods is to build on existing research skills to hear discussions on novel perspectives as they apply to developmental and clinical research. This includes in-person work within designated laboratories at the Yale Child Study Center, as well as monthly in-person check-in meetings with instructors/mentors.

INP 7638 Computational Models of Human Behavior

Why do we do the things we do? How do we adapt to changes in the environment? And how does our happiness depend on our choices and what happens to us? How can computational models help us to gain new insights into psychological processes? The goal of this course is to use computational models to understand human behavior and its relationship to our emotions. Data is collected in a variety of tasks, including new experiments designed by students, and is analyzed using computational models.

INP 8540 How to Give a Talk

This course is a practical introduction to the art and science of giving a data-based neuroscience seminar. The ability to give a clear, convincing, and engaging talk about your work is one of the key career skills of successful scientists. Content, visual presentation, body language, and delivery all combine to determine your impact on your audience. The focus in class is on student presentation skills and detailed feedback, interspersed with short example talks by invited guests. Students give at least two talks over the course of the term and participate in weekly Q&A and feedback. Grading is based on class participation. Enrollment limited to ten.

INP 8542, How to Write a Grant

In this course, graduate students will learn how fellowship award review panels are run and what the selection criteria are. The NIH National Research Service Award (NRSA) Fellowship will be used as the main framework for learning. Students will develop NIH style Biosketches, learn to generate key points in the NIH Research Training Plan, and learn how to write a Specific Aims page and what to consider for the Project Narrative. Through student-led groups, students will learn how to critique Specific Aims pages, with input from instructors, and will then develop Project Narratives with specific focuses on effective communication of the underlying hypotheses, impact and significance, and experimental plans. Grading is H/HP/P/F and is based on class participation.

INP 9507, Cellular and Molecular Mechanisms of Neurological Diseases

This course focuses on diseases such as Alzheimer's, Parkinson's, Schizophrenia, Multiple Sclerosis, and Epilepsy, in which modern neuroscience has advanced mechanistic explanations for clinical conditions. The course will highlight recent genetic, molecular, electrophysiological, and imaging experiments in parsing disease mechanisms.

INP 9510, Structural and Functional Organization of the Human Nervous System

An integrative overview of the structure and function of the human brain as it pertains to major neurological and psychiatric disorders. Neuroanatomy, neurophysiology, and clinical correlations are interrelated to provide essential background in the neurosciences. Lectures in neurocytology and neuroanatomy survey neuronal organization in the human brain, with emphasis on long fiber tracts related to clinical neurology. Lectures in neurophysiology cover various aspects of neural function at the cellular and systems levels, with a strong emphasis on the mammalian nervous system. Clinical correlations consist of sessions applying basic science principles to understanding pathophysiology in the context of patients. Seven three-hour laboratory sessions are coordinated with lectures throughout the course to provide an understanding of the structural basis of function and disease. Case-based conference sections provide an opportunity to integrate and apply the information learned about the structure and function of the nervous system in the rest of the course to solving a focused clinical problem in a journal club format. Variable class schedule; contact course instructors.

INP 9521, Neuroimaging in Neuropsychiatry II: Clinical Applications

Neuroimaging methodologies including Positron Emission Tomography (PET); Single Photon Emission Computed Tomography (SPECT); Magnetic Resonance Imaging (MRI); functional Magnetic Resonance Imaging (fMRI); Magnetic Resonance Spectroscopy (MRS) are rapidly evolving tools used to study the living human brain. Neuroimaging has unprecedented implications for routine clinical diagnosis, for assessment of drug efficacy; for determination of psychotropic drug occupancy and for the study of pathophysiological mechanisms underlying neurologic and psychiatric disorders. This course is designed to provide an overview the application of state-of-the-art neuroimaging methods to research in neurologic and psychiatric disorders.

INP 9523/ENAS 880, Imaging Drugs in the Brain

Seminar course to explore the uses of functional imaging (PET and fMRI) to study the mechanisms of action and long-term effects of drugs (legal and illegal) on brain function. Basic research findings are the main topics, augmented by some discussion of imaging in drug development by Pharma. The central theme of the course is experiment design. How to design the proper imaging experiment to ask the question. What are the endpoints of the experiment? What are the limitations of interpretation? What are the proper controls and what are the proper analyses to ensure reliable, interpretable results?

INP 9530 Foundations of Neuroscience: Biological Bases of Human Behavior

The purpose of this course is to provide students with an understanding of the biological factors underlying human cognition and behavior. Particular emphasis is placed on the mechanisms associated with individual differences in healthy functions (including emotion regulation, stress sensitivity, higher cognition, reward sensitivity, impulsivity, and social functions) and their relations with psychiatric and neurological disorders. Biological factors to be covered include genetic, neuroanatomical, neurophysiological, neurochemical, hormonal, and neuropsychological influences. Several of the initial sessions are devoted to basic topics (e.g., neurons, neuronal signaling, brain systems), before we begin our discussion of the neural basis of behavior and cognition. We also cover seminal work on animal models for mechanistic insights into the neurobiology of human behavior. Graduate students with any neuroscience research interest are encouraged to take this course. Required of Psychology Ph.D. students in the neuroscience area.

INP 9532, Neurobiology of Cortical Systems

An examination of the neural circuits that subserve sensory, motor, cognitive, and affective function, and their relationships to human disorders. A comparative species approach is used to highlight the evolution of neural circuits and their functions. Offered in the Spring term. Permission of instructors required for registration.

INP 9533, Function and Dysfunction of the Visual System

A survey course on the visual system, covering the retina, central visual pathways, and visual centers. Topics on the development, structure, function, dysfunction, and repair of the visual system will be introduced by faculty members and discussed among students, postdoctoral fellows, and faculty members. The class will meet for one 1.5 hr lecture and one 1.5 hr paper discussion session per week.

INP 9550 The Gut-Brain Axis and Behavior

All organisms must procure energy to survive. As such, many strategies have evolved to optimize the acquisition, use, and storage of energy sources. Energetic value must be sensed, and costs determined and balanced against the physiological state of the organism and competing demands on behavior, such as seeking safety or showing aggression to secure a mate. To accomplish this, peripheral signals about acute and stored energy must be integrated with brain mechanisms regulating both metabolism and behavior. Until recently, metabolic and behavioral regulation were treated as operating relatively independently and often described as competing homeostatic and hedonic forces over behavior. However, this artificial boundary has begun to dissolve and with it the realization has emerged that mind and metabolism are highly integrated. More specifically, the biological imperative of optimal energy management results in metabolic signals having the potential to influence every facet of cognition, from basic perception to executive functioning, mood, affect, and social interactions. Likewise, cognitive operations can directly impact metabolism, enabling organisms to bring all sources of information together to ensure optimal metabolic and behavioral “decision-making.” This course introduces the student to the gut-brain axis and its role in behavior. We begin with a series of lectures on the basics to provide an understanding of the types of signals that are used to communicate between the brain and the body. Then we review functions that are shaped or impacted by the gut-brain pathways. The didactic aspect of the course concludes with lectures that overview disorders in which gut-brain signaling plays a pathophysiological role. Students are asked to make journal-club-style presentations, work together in small groups to design a conference symposium proposal, and write a final paper on a topic of their choice. The course concludes with symposium proposal presentations by the students.

INP 9552, Critical Thinking in Learning and Memory

Are you interested in a neuroscience approach and its dual perspectives to understanding neuronal ensemble mechanisms underlying learning and episodic memory formation? This course aims to engage students in critical thinking of classic neuroscience readings in learning and memory. Pairs of key studies in the field of learning and memory are discussed and debated either as dual perspectives on a given topic or as complementary approaches to

aspects of learning and memory. The course goals are twofold: first, to develop and further students' critical thinking in neuroscience and related fields; second, to acquire key concepts and knowledge in the field of learning and memory. The focus is on studies revealing the role of medial temporal lobe and limbic structures in learning and memory, primarily in humans and rodents.

INP 9554, Human Molecular Diversity in the Context of Neuropsychiatric Disorders and Behavioral Traits

This course aims to provide students with a comprehensive understanding of human molecular diversity and its implications with respect to the study of neuropsychiatric disorders and behavioral traits. Every class will be organized around the discussion of recent articles published in the primary literature. Initially, the discussion will focus on basic concepts related to variability between individuals, within a population, and between populations across different omics domains including genetics, transcriptomics, epigenetics, and proteomics. Two aspects will be also thoroughly discussed: i) the definitions of ancestry, race, and ethnicity and how they should be considered when designing a molecular study and ii) the systematic underrepresentation of certain minorities in human molecular studies and its consequences. Subsequently, the classes will focus on different aspects related to the modeling of human molecular variation to investigate the pathogenesis of neuropsychiatric disorders and their comorbidities with behavioral traits. These will include the discussion of different study designs (e.g., case-control and case-only), the approaches needed to account for potential biases (e.g., population stratification), statistical power, effect sizes across different omics domains, and causal inference.

INP 9585/BENG 585, Fundamentals of Neuroimaging

The neuroenergetic and neurochemical basis of several dominant neuroimaging methods, including fMRI. Topics range from technical aspects of different methods to interpretation of the neuroimaging results. Controversies and/or challenges for application of fMRI and related methods in medicine are identified.

INP 9597 Neuroeconomics

This course introduces some of the main topics in decision-making research. We discuss how behavioral economics methods are combined with neuroscientific tools, in particular functional MRI and single-neuron recordings, to study the neural mechanisms underlying decision and valuation processes. The course includes both introductory presentations by the instructors and paper presentations by the students. Offered every other year.

INP 9610/GENE 680, Advanced Topics in Neurogenomics

This course focuses on the rapidly changing field of functional genomics of psychiatric disease, centered on validations using human cell-based models. It is designed for students who already have basic knowledge of neuroscience and human genetics.

INP 9640 Current Topics in Neuroscience

In this course, students select three modular "mini-courses" from a list of mini-courses spanning a wide range of topics and techniques in molecular, cellular, systems, and behavioral neuroscience.

INP 9704 Comparative Neuroanatomy

This laboratory-based course examines the fundamental structural organization of the brain in a comparative context. For example, principles of the organization of systems and circuits are compared across human and nonhuman primates and rodents. Labs also explore the organization of the nervous system in zebrafish, drosophila, and *c. elegans*. The course is open only to graduate students enrolled in the Interdepartmental Neuroscience Program and complements the lecture course INP 703. Graded Satisfactory/Unsatisfactory.

INP 9720/MCDB 720, Neurobiology

Examination of the excitability of the nerve cell membrane as a starting point for the study of molecular, cellular, and intracellular mechanisms underlying the generation and control of behavior.

MICROBIOLOGY

<http://catalog.yale.edu/gsas/degree-granting-departments-programs/microbiology/#coursestext>

MBIO 5300/MCDB 5300/IBIO 5300, Biology of the Immune System

The development of the immune system. Cellular and molecular mechanisms of immune recognition. Effector responses against pathogens. Immunologic memory and vaccines. Human diseases including allergy, autoimmunity, cancer, immunodeficiency, HIV/AIDS. (Fall)

MBIO 6010/IBIO 6010/ CBB 6010, Fundamentals of Research: Responsible Conduct of Research

A weekly seminar presented by faculty trainers on topics relating to proper conduct of research. Required of first year Immunobiology students, first-year CB&B students, and training grant-funded postdocs. (Spring)

MBIO 6700, 6710, 6720, 6740, Laboratory Rotations

Rotation in three laboratories. Required for all first-year graduate students.

MBIO 6860, The Biology of Bacterial Pathogens I

The course provides an introduction to basic principles in bacterial pathogenesis. Topics focus on the bacterial determinants mediating infection and pathogenesis, as well as strategies to prevent and treat diseases. Each week a lecture is given on the topic, followed by student presentations of seminal papers in the field. All participants are required to participate in the discussion of papers. (Fall)

MBIO 6850, The Biology of Bacterial Pathogens II

This interdisciplinary course focuses on current topics related to host-bacterial interactions. Each week a lecture is given on the topic, followed by student presentations of seminal papers in the field. All participants are required to present a paper. (Spring)

MBIO 7000, Seminal Papers on the Foundations of Modern Microbiology

All first-year students in the Microbiology program are required to take this course directed by Priti Kumar. Students present and discuss papers describing fundamental discoveries in areas related to microbiology. The goal is to familiarize students with the process of scientific discovery, and with major developments in the field. Topics include important discoveries involving major human pathogens, fundamental processes in molecular biology, and the development of technology that has majorly impacted current biomedical research. This is a non-credit course offered every Spring.

MBIO 7010, 7020, Research in Progress

All students, beginning in their third year, are required to present their research once a year at the Graduate Student Research in Progress. These presentations are intended to give each student practice in presenting the student's own work before a sympathetic but critical audience and to familiarize the faculty with the research. (Fall & Spring)

MBIO 7030, 7040, Microbiology Seminar Series

All students are required to attend all Microbiology seminars scheduled throughout the academic year. Microbiologists from around the world are invited to describe their research. (Fall & Spring)

MBIO 7340/GENE 7340/ MB&B 7340, Molecular Biology of Animal Viruses

Lecture course with emphasis on mechanisms of viral replication, oncogenic transformation, and virus-host cell interactions. Prerequisite: graduate standing or permission of the instructor. (Spring)

MOLECULAR BIOPHYSICS AND BIOCHEMISTRY

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/molecular-biophysics-biochemistry/>

MB&B 3300/MCDB 3310/NSCI 3240/BENG 3230/MCDBC 5310/MB&B 5310/PHYS 5610, Modeling Biological Systems I

Biological systems make sophisticated decisions at many levels. This course explores the molecular and computational underpinnings of how these decisions are made, with a focus on modeling static and dynamic processes in example biological systems. This course is aimed at biology students and teaches the analytic and computational methods needed to model genetic networks and protein signaling pathways. Students present and discuss original papers in class. They learn to model using MatLab in a series of in-class hackathons that illustrate the biological examples discussed in the lectures. Biological systems and processes that are modeled include: (i) gene expression, including the kinetics of RNA and protein synthesis and degradation; (ii) activators and repressors; (iii) the lysogeny/lysis switch of lambda phage; (iv) network motifs and how they shape response dynamics; (v) cell signaling, MAP kinase networks and cell fate decisions; and (vi) noise in gene expression

MB&B 4490, Medical Impact of Basic Science

Examples of recent discoveries in basic science that have elucidated the molecular origins of disease or that have suggested new therapies for disease. Readings from the primary scientific and medical literature, with emphasis on developing the ability to read this literature critically. Prerequisites: MB&B 300 and 301 or equivalents, or permission of instructor. 1 credit for Yale College students

MB&B 5000/MCDB 5000/MB&B 3000/MCDB 2000, Biochemistry

An introduction to the biochemistry of animals, plants, and microorganisms, emphasizing the relations of chemical principles and structure to the evolution and regulation of living systems.

MB&B 5170/ENAS 5170/MCDB 5170/PHYS 5170, Methods and Logic in Interdisciplinary Research

This full PEB class is intended to introduce students to integrated approaches to research. Each week, the first of two sessions is student-led, while the second session is led by faculty with complementary expertise and discusses papers that use different approaches to the same topic (for example, physical and biological or experiment and theory).

MB&B 5200, Boot Camp Biology

An intensive introduction to biological nomenclature, systems, processes, and techniques for graduate students with previous backgrounds in non-biological fields including physics, engineering, and computer science who wish to perform graduate research in the biological sciences. Counts as 0.5 credit toward MB&B graduate course requirements. ½ Course cr; Required for students in IGPPEB.

MB&B 5230/ CB&B 5230/ ENAS 5410/ PHYS 5230, Biological Physics

The course has two aims: (1) to introduce students to the physics of biological systems and (2) to introduce students to the basics of scientific computing. The course focuses on studies of a broad range of biophysical phenomena including diffusion, polymer statistics, protein folding, macromolecular crowding, cell motion, and tissue development using computational tools and methods. Intensive tutorials are provided for MATLAB including basic syntax, arrays, for-loops, conditional statements, functions, plotting, and importing and exporting data.

MB&B 5529/ PHAR 5529, Structural Biology and Drug Discovery

A comprehensive introduction to the concepts and practical uses of structural biology and structural biology-related techniques in drug discovery. The first half of the course focuses on techniques used to discover and optimize small and macromolecule drugs. Students are introduced to topics such as small molecule lead discovery, X-ray crystallography, cryo-electron microscopy, and biophysical techniques. The first half of the course also includes a practical component where students conduct hands-on structural biology experiments and learn about biophysical techniques in a laboratory setting. The second half of the course focuses on drug discovery, particularly for protein kinases. It includes a field trip to the Yale Center for Drug Discovery, where the students are introduced to the in-house Yale screening facilities for small molecule drug discovery. Two half-credit courses—PHAR 530 and PHAR 531—are also offered for the two halves of PHAR 529.

MB&B 5310/ PHYS 5610/BENG 3232/MB&B 3300/ MB&B 3310/NSCI 3240, Modeling Biological Systems I

Biological systems make sophisticated decisions at many levels. This course explores the molecular and computational underpinnings of how these decisions are made, with a focus on modeling static and dynamic processes in example biological systems. This course is aimed at biology students and teaches the analytic and computational methods needed to model genetic networks and protein signaling pathways. Students present and discuss original papers in class. They learn to model using MatLab in a series of in-class hackathons that illustrate the biological examples discussed in the lectures. Biological systems and processes that are modeled include: (1) gene expression, including the kinetics of RNA and protein synthesis and degradation; (2) activators and repressors; (3) the lysogeny/lysis switch of lambda phage; (4) network motifs and how they shape response dynamics; (5) cell signaling, MAP kinase networks and cell fate decisions; and (6) noise in gene expression. Prerequisites: MATH 115 or 116, BIOL 101–104, or with permission of instructors. This course also benefits students who have taken more advanced biology courses (e.g. MCDB 200, MCDB 310, MB&B 300/301). 1 credit for Yale College students

MB&B 5450, Methods and Logic in Molecular Biology

An examination of fundamental concepts in molecular biology through analysis of landmark papers. Development of skills in reading the primary scientific literature and in critical thinking. Open only to MB&B students pursuing the B.S./M.S. degree.

MB&B 5620/AMTH 765/ CB&B 5620/PHYS 5620 / AMTH 765 / ENAS 5620 / INP 562 / INP 7562 Modeling Biological Systems II

This course covers advanced topics in computational biology. How do cells compute, how do they count and tell time, how do they oscillate and generate spatial patterns? Topics include time-dependent dynamics in regulatory, signal-transduction, and neuronal networks; fluctuations, growth, and form; mechanics of cell shape and motion; spatially heterogeneous processes; diffusion. This year, the course spends roughly half its time on mechanical systems at the cellular and tissue level, and half on models of neurons and neural systems in computational neuroscience.

MB&B 5650 Biochemistry and Our Changing Climate

Climate change is impacting how cells and organisms grow and reproduce. Imagine the ocean spiking a fever: cold-blooded organisms of all shapes, sizes, and complexities struggle to survive when water temperatures go up two–four degrees. Some organisms adapt to extremes, while others cannot. Predicted and observed changes in temperature, pH, and salt concentration do and will affect many parameters of the living world, from the kinetics of chemical reactions and cellular signaling pathways to the accumulation of unforeseen chemicals in the environment, the appearance and dispersal of new diseases, and the development of new foods. In this course, we approach climate change from the molecular point of view, identifying how cells and organisms—from microbes to plants and animals—respond to changing environmental conditions. To embrace the concept of “one health” for all life on the planet, this course leverages biochemistry, cell biology, molecular biophysics, and genetics to develop an understanding of the impact of climate change on the living world. We consider the foundational knowledge that biochemistry can bring to the table as we meet the challenge of climate change. Prerequisites: MB&B 5000, MB&B 6000, and MB&B 6010, or permission of the instructor.

MB&B 5910/ ENAS 5710/ MCDB 5910/ PHYS 5710, Integrated Workshop

This required course for students in the PEB graduate program involves a series of modules, co-taught by faculty, in which students from different academic backgrounds and research skills collaborate on projects at the interface of physics, engineering, and biology. The modules cover a broad range of PEB research areas and skills. The course starts with an introduction to MATLAB, which is used throughout the course for analysis, simulations, and modeling.

MB&B 6000/MB&B 3000, Principles of Biochemistry I

Discussion of the physical, structural, and functional properties of proteins, lipids, and carbohydrates, three major classes of molecules in living organisms. Energy metabolism, hormone signaling, and muscle contraction as examples of complex biological processes whose underlying mechanisms can be understood by identifying and analyzing the molecules responsible for these phenomena.

MB&B 6010, Principles of Biochemistry II

A continuation of MB&B 6000 that considers the chemistry and metabolism of nucleic acids, the mechanism and regulation of protein and nucleic acid synthesis, and selected topics in macromolecular biochemistry.

MB&B 6020/ CBIO 6020/ MCDB 6020/MBIO TBD-2, Molecular Cell Biology

A comprehensive introduction to the molecular and mechanistic aspects of cell biology for graduate students in all programs. Emphasizes fundamental issues of cellular organization, regulation, biogenesis, and function at the molecular level. Prerequisites: none, but some knowledge of basic cell biology and biochemistry is assumed. Students who have not taken courses in these areas can prepare by reading relevant sections in basic molecular cell biology texts. We recommend Pollard et al., *Cell Biology* (3rd ed., 2016), Alberts et al., *Molecular Biology of the Cell* (6th ed., 2014), or Lodish et al., *Molecular Cell Biology* (8th edition, 2016).

MB&B 6250/GENE 6250/MCDB 6250, Basic Concepts of Genetic Analysis

The universal principles of genetic analysis in eukaryotes are discussed in lectures. Students also read a small selection of primary papers illustrating the very best of genetic analysis and dissect them in detail in the discussion sections. While other Yale graduate molecular genetics courses emphasize molecular biology, this course focuses on the concepts and logic underlying modern genetic analysis.

MB&B 6300/ MCDB 6300, Biochemical and Biophysical Approaches in Molecular and Cellular Biology

In this course, we provide an overview of various biochemical and biophysical approaches used in modern research in molecular and cellular biology, ranging from spectroscopic tools, microscopy, to X-ray crystallography. The goal of the course is to make students familiar with these techniques so that they can find relevant materials in their future research. Does not count for graduate course credit for BQBS graduate students.

MB&B 6350/ ENAS 5180/ MB&B 4350, Quantitative Approaches in Biophysics and Biochemistry

An introduction to quantitative methods relevant to analysis and interpretation of biological data. Topics include statistical testing, data presentation, and error analysis; introduction to artificial intelligence-based data analysis tools, Alpha Fold Tutorial, introduction to mathematical modeling of biological dynamics; and Fourier analysis in signal/image processing and macromolecular structural studies. Instruction in basic programming skills and data analysis using MATLAB; study of real data from MB&B research groups. Prerequisites: MATH 120 and MB&B 600 or equivalents, or permission of the instructors. 1 credit for Yale College students

MB&B 6500 and 6510, Lab Rotation for BQBS First-Year Students

Required of all first-year BQBS graduate students. Credit for full year only.

MB&B 6750, Seminar for First-Year Students

Required of all first-year BQBS graduate students.

MB&B 6760, Responsible Conduct of Research

Designed for students who are beginning to do scientific research. The course seeks to describe some of the basic features of life in contemporary research and some of the personal and professional issues that researchers encounter in their work. Approximately six sessions, run in a seminar/discussion format. Required of all first-year BQBS graduate students.

MB&B 6770, RCR Refresher for Senior MB&B students

This course meets the NIH requirement that students receive training in the responsible conduct of research at least every four years. The course consists of eight half-hour recorded lectures combined with four one-hour small-group discussions. Required of and open only to senior MB&B graduate students, typically in their fourth year. The course is graded Satisfactory/Unsatisfactory.

MB&B 7100, Electron Cryo-Microscopy for Protein Structure Determination

Understanding cellular function requires structural and biochemical studies at an ever-increasing level of complexity. The course is an introduction to the concepts and applications of high-resolution electron cryo-microscopy. This rapidly

emerging new technique is the only method that allows biological macromolecules to be studied at all levels of resolution from cellular organization to near atomic detail.

MB&B 7110, Practical cryo-EM Workshop

This laboratory course provides hands-on training in the practical aspects of macromolecular structure determination by cryo-electron microscopy (cryo-EM). Topics include cryo-EM data collection, image preparation and correction, single-particle picking and 2-D classification, 3-D classification, refinement and post-processing, model building, refinement and evaluation. The course includes training in the use of computer programs used to perform these calculations. Prerequisite: MB&B 7100/C&MP 7100. ½ Course credit

MB&B 7200, Macromolecular Structure and Biophysical Analysis

An in-depth analysis of macromolecular structure and dynamics using modern methods of structural biology, microscopy and single-molecule techniques. Topics include architecture of proteins, RNA, and DNA; X-ray crystallography; electron cryomicroscopy; optical microscopy. A recurring theme is the use of diffraction to elucidate structure. Prerequisites: at least one upper-level course in physical chemistry, biochemistry, or electromagnetism/optics.

MB&B 7300, Methods and Logic in Molecular Biology

The course examines fundamental concepts in molecular biology through intense critical analysis of the primary literature. The objective is to develop primary literature reading and critical thinking skills. Required of and open only to first-year graduate students in BQBS.

MB&B 7340/GENE 7340/MBIO 7340, Molecular Biology of Animal Viruses

Lecture course with emphasis on mechanisms of viral replication, oncogenic transformation, and virus-host cell interactions.

MB&B 7430/GENE 7430/MCDB 7430/MB&B 4430, Advanced Eukaryotic Molecular Biology

Selected topics in transcriptional control, regulation of chromatin structure, mRNA processing, mRNA stability, RNA interference, translation, protein degradation, DNA replication, DNA repair, site-specific DNA recombination, somatic hypermutation. Prerequisite: biochemistry or permission of the instructor.

MB&B 7520/ CB&B 7520/ CPSC 7520/ MCDB 7520 /S&D 3520, Biomedical Data Science: Mining and Modeling

Biomedical data science encompasses the analysis of gene sequences, macromolecular structures, and functional genomics data on a large scale. It represents a major practical application for modern techniques in data mining and simulation. Specific topics to be covered include sequence alignment, large-scale processing, next-generation sequencing data, comparative genomics, phylogenetics, biological database design, geometric analysis of protein structure, molecular-dynamics simulation, biological networks, normalization of microarray data, mining of functional genomics data sets, and machine-learning approaches to data integration. Prerequisites: biochemistry and calculus, or permission of the instructor.

MB&B 8000, Advanced Topics in Molecular Medicine

The seminar, which covers topics in the molecular mechanisms of disease, illustrates timely issues in areas such as protein chemistry and enzymology, intermediary metabolism, nucleic acid biochemistry, gene expression, and virology. M.D. and M.D./Ph.D. students only. Prerequisite: biochemistry (may be taken concurrently).

MOLECULAR, CELLULAR, AND DEVELOPMENTAL BIOLOGY

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/molecular-cellular-developmental-biology/>

MCDB 3210L / NSCI 320L, Laboratory for Neurobiology

Introduction to the neurosciences. Projects include the study of neuronal excitability, sensory transduction, CNS function, synaptic physiology, and neuroanatomy.

MCDB 3300/ CB&B 5610/ MB&B 3300/ NSCI 3240, Modeling Biological Systems I

Study of the analytic and computational skills needed to model genetic networks and protein signaling pathways. Review of basic biochemical concepts including chemical reactions, ligand binding to receptors, cooperativity, and Michaelis-Menten enzyme kinetics. Deep exploration of biological systems including kinetics of RNA and protein synthesis and degradation; transcription activators and repressors; lysogeny/lysis switch of lambda phage and the roles of cooperativity and feedback; network motifs such as feed-forward networks and how they shape response dynamics; cell signaling, MAP kinase networks and cell fate decisions; bacterial chemotaxis; and noise in gene expression and phenotypic variability. Students learn to model using MatLab in a series of in-class hackathons that illustrate biological examples discussed in lectures.

MCDB 5000/MB&B 5000, Biochemistry

An introduction to the biochemistry of animals, plants, and microorganisms, emphasizing the relations of chemical principles and structure to the evolution and regulation of living systems.

MCDB 5040, Responsible Conduct of Research

This course meets the NIH requirement that students receive training in the responsible conduct of research at least every four years. Two ninety-minute sessions for MCDB students; additional sessions for fourth year MCDB students. Attendance is taken, and students who attend both sessions receive a grade of Satisfactory. Graded Satisfactory/Unsatisfactory.

MCDB 5170/ENAS 5170/MB&B 5170/PHYS 5170, Methods, and Logic in Interdisciplinary Research

This full PEB class is intended to introduce students to integrated approaches to research. Each week, the first of two sessions is student-led, while the second session is led by faculty with complementary expertise and discusses papers that use different approaches to the same topic (for example, physical and biological or experiment and theory).

MCDB 5300/IBIO 5300/MBIO 5300, Biology of the Immune System

The development of the immune system. Cellular and molecular mechanisms of immune recognition. Effector responses against pathogens. Immunologic memory and vaccines. Human diseases including allergy, autoimmunity, cancer, immunodeficiency, HIV/AIDS.

MCDB 5500/C&MP 5500/ENAS 5500/PHAR 5500/PTB 5500, Physiological Systems

The course presents a foundation in human physiology by examining the homeostasis of vital parameters within the body, and the biophysical properties of cells, tissues, and organs. Basic concepts in cell and membrane physiology are integrated by exploring the function of skeletal, smooth, and cardiac muscle as well as the function of epithelial tissues. The physical basis of blood flow, mechanisms of vascular exchange, cardiac performance, and regulation of overall circulatory function are discussed. Respiratory physiology explores the mechanics of ventilation, gas diffusion, and acid-base balance. The discussion of renal physiology focuses on the regulation of electrolyte, fluid, and acid-base balance. The digestive system is discussed from the perspective of organ function, as well as substrate metabolism and energy balance. Hormonal regulation is discussed in relation to metabolic control and to calcium, water, and electrolyte balance. The nervous system is addressed with emphasis on synaptic transmission and simple neuronal circuits within the central nervous system, as well as sensory transduction. Weekly discussion sections provide a forum for in-depth exploration of topics, where graduate students evaluate research findings through weekly meetings accompanied by computer simulations of physiological functions with the instructor.

MCDB 5600/C&MP 5600/ENAS 5700/PHAR 5600, Cellular and Molecular Physiology: Molecular Machines in Human Disease

The course focuses on understanding the processes that transfer molecules across membranes at the cellular, molecular, biophysical, and physiological levels. Students learn about the different classes of molecular machines that mediate membrane transport, generate electrical currents, or perform mechanical displacement. Emphasis is placed on the relationship between the molecular structures of membrane proteins and their individual functions. The interactions among transport proteins in determining the physiological behaviors of cells and tissues are also stressed. Molecular motors are introduced and their mechanical relationship to cell function is explored. Students read papers from the scientific literature that establish the connections between mutations in genes encoding membrane proteins and a wide variety of human genetic diseases.

MCDB 5700, Biotechnology

The principles and applications of cellular, molecular, and chemical techniques that advance biotechnology. Topics include the most recent tools and strategies used by government agencies, industrial labs, and academic research to adapt biological and chemical compounds as medical treatments, as industrial agents, or for the further study of biological systems.

MCDB 5850, Research in MCDB for B.S./M.S. Candidates

A two-credit course taken in the third-to-last term (typically the second term of the junior year). At the start of this course, each student forms a committee composed of his or her adviser and two faculty members that meets to discuss the research project. At the end of this course, students complete a detailed prospectus describing their thesis project and the work completed thus far. The committee evaluates an oral and written presentation of this prospectus; the evaluation determines whether the student may continue in the combined program. Required of students in the joint B.S./M.S. program with Yale College.

MCDB 5910/ENAS 5710/MB&B 5910/PHYS 5710, Integrated Workshop

This required course for students in the PEB graduate program involves a series of modules, co-taught by faculty, in which students from different academic backgrounds and research skills collaborate on projects at the interface of physics, engineering, and biology. The modules cover a broad range of PEB research areas and skills. The course starts with an introduction to MATLAB, which is used throughout the course for analysis, simulations, and modeling.

MCDB 5950, Intensive Research in MCDB for B.S./M.S. Candidates

A four-credit, yearlong course (two credits each term) that is similar to MCDB 4950/4960 and is taken during the senior year. During this course, students give an oral presentation describing their work. At the end of the course, students are expected to present their work to the department in the form of a poster presentation. In addition, students are expected to give an oral thesis defense, followed by a comprehensive examination of the thesis conducted by the thesis committee. Upon successful completion of this examination, as well as other requirements, the student is awarded the combined B.S./M.S. degree. Required of students in the joint B.S./M.S. program with Yale College.

MCDB 6020/CBIO 6020/MB&B 6020, Molecular Cell Biology

A comprehensive introduction to the molecular and mechanistic aspects of cell biology for graduate students in all programs. Emphasizes fundamental issues of cellular organization, regulation, biogenesis, and function at the molecular level. Graduate Prerequisites: Some knowledge of basic cell biology and biochemistry is assumed. Students who have not taken courses in these areas can prepare by reading relevant sections in basic molecular cell biology texts. We recommend Pollard et al., *Cell Biology* (4th ed., 2024), Alberts et al., *Molecular Biology of the Cell* (7th ed., 2022), or Lodish et al., *Molecular Cell Biology* (9th edition, 2021). Undergraduate Prerequisites: This is a graduate-level cell biology class. Any undergraduates wishing to enroll must have already taken MCDB 2050. In addition, undergraduates are strongly encouraged to reach out to the course directors prior to enrollment.

MCDB 6030/CBIO 6030, Seminar in Molecular Cell Biology

A graduate-level seminar in modern cell biology. The class is devoted to the reading and critical evaluation of classical and current papers. The topics are coordinated with the CBIO 602 lecture schedule. Thus, concurrent enrollment in CBIO 602 is required.

MCDB 6250/GENE 6250/MB&B 6250, Basic Concepts of Genetic Analysis

The universal principles of genetic analysis in eukaryotes are discussed in lectures. Students also read a small selection of primary papers illustrating the very best of genetic analysis and dissect them in detail in the discussion sections. While other Yale graduate molecular genetics courses emphasize molecular biology, this course focuses on the concepts and logic underlying modern genetic analysis.

MCDB 6300/MB&B 6300, Biochemical and Biophysical Approaches in Molecular and Cellular Biology

In this course, we provide an overview of various biochemical and biophysical approaches used in modern research in molecular and cellular biology, ranging from spectroscopic tools, microscopy, to X-ray crystallography. The goal of the course is to make students familiar with these techniques so that they can find relevant materials in their future research. Does not count for graduate course credit for BQBS graduate students.

MCDB 6500 Epigenetics

Study of epigenetic states and the various mechanisms of epigenetic regulation, including histone modification, DNA methylation, nuclear organization, and regulation by noncoding RNAs. Detailed critique of papers from primary literature and discussion of novel technologies, with specific attention to the role of epigenetics in development and its impact on human health. Prerequisite: permission of the instructor.

MCDB 6700, Advanced Seminar in Biochemistry and Genetics

This seminar is designed to expand students' abilities to critically read and evaluate the primary scientific literature relevant to some of the most active areas of biochemical and genetic research. Special emphasis is placed on topics that deal with recent discoveries in nucleic acids, such as catalytic RNA and DNA, functions of noncoding RNA, gene regulation by RNA, and genomic processing and instability. Students read assigned papers in advance. Discussion focuses on experimental design used by the authors, results of the experiments, and conclusions drawn by the authors.

MCDB 6770/GENE 7770, Mechanisms of Development

An advanced graduate seminar on animal development focusing on conserved mechanisms that govern germline development, embryogenesis, and somatic differentiation in molecular detail. The course runs in parallel to the Spring session of the Department of Genetics Seminar Series and is divided into two components: six Yale faculty-led lectures on core concepts in development and six combined journal club/student-led discussions with outside developmental biology speakers on their cutting-edge research. Over the course of the term, small student groups are responsible for presenting one journal club-formatted discussion on two papers selected from the outside speaker's lab, as well as emceeding a dedicated question and answer session between the class and the speaker. This course provides a rare opportunity for students to actively engage with world leaders on their work in developmental genetics, epigenetics, and cell biology, as well as learn essential skills in experimental thinking and scientific communication. The course grade is based on 40 percent take-home problems, 40 percent class participation and 20 percent student-led journal club / distinguished speaker question and answer session. There are no official prerequisites. However, some familiarity with concepts and techniques of modern biology is necessary to get the most out of the course.

MCDB 6800, Advances in Plant Molecular Biology

The study of basic processes in plant growth and development to provide a foundation for addressing critical agricultural needs in response to a changing climate. Topics include the latest breakthroughs in plant sciences with emphasis on molecular, cellular, and developmental biology; biotic and abiotic plant interactions; development, genomics, proteomics, epigenetics, and chemical biology in the context of plant biology; and the current societal debates about agrobiotechnology.

MCDB 7200/INP 7200, Neurobiology

Examination of the excitability of the nerve cell membrane as a starting point for the study of molecular, cellular, and intercellular mechanisms underlying the generation and control of behavior.

MCDB 743/GENE 743/MB&B 743, Advanced Eukaryotic Molecular Biology

Selected topics in transcriptional control, regulation of chromatin structure, mRNA processing, mRNA stability, RNA interference, translation, protein degradation, DNA replication, DNA repair, site-specific DNA recombination, somatic hypermutation. Emphasis is placed on how these processes are regulated and the experiments that led to their discovery and understanding. Prerequisite: biochemistry or permission of the instructor.

MCDB 7520/MB&B 7520/CBB7520/CPSC 7520, Biomedical Data Science: Mining and Modeling

Biomedical data science encompasses the analysis of gene sequences, macromolecular structures, and functional genomics data on a large scale. It represents a major practical application for modern techniques in data mining and simulation. Specific topics to be covered include sequence alignment, large-scale processing, next-generation sequencing data, comparative genomics, phylogenetics, biological database design, geometric analysis of protein structure, molecular-dynamics simulation, biological networks, normalization of microarray data, mining of functional genomics data sets, and machine-learning approaches to data integration. Prerequisites: biochemistry and calculus, or permission of the instructor.

MCDB 9000/CBIO 9000/GENE 9000, Research Skills and Ethics I

This course consists of a weekly seminar that covers ethics, writing, and research methods in cellular and molecular biology as well as student presentations (“rotation talks”) of work completed in the first and second laboratory rotations.

MCDB 9010/CBIO 9010/GENE 9010, Research Skills and Ethics II

This course consists of a weekly seminar that covers ethics, writing, and research methods in cellular and molecular biology as well as student presentations (“rotation talks”) of work completed in the third laboratory rotation.

MCDB 9020 & MCDB 9030 Advanced Graduate Seminar

The course allows students to hone their presentation skills through yearly presentation of their dissertation work. Two students each give thirty-minute presentations in each class session. Students are required to present every year beginning in their third year in the MCDB program. Each MCDB graduate student is expected to attend at least 80 percent of the class sessions. Two faculty members co-direct the course, attend the seminars, and provide feedback to the students.

MCDB 9110/CBIO 9110/GENE 9110, First Laboratory Rotation

First laboratory rotation for Molecular Cell Biology, Genetics, and Development (MCGD) and Plant Molecular Biology (PMB) track students

MCDB 9120/CBIO 9120/GENE 9120, Second Laboratory Rotation

Second laboratory rotation for Molecular Cell Biology, Genetics, and Development (MCGD) and Plant Molecular Biology (PMB) track students.

MCDB 9130/CBIO 9130/GENE 9130, Third Laboratory Rotation

Third laboratory rotation for Molecular Cell Biology, Genetics, and Development (MCGD) and Plant Molecular Biology (PMB) track students

MCDB 9140/CBIO 9140/GENE 9140, Fourth Laboratory Rotation (optional)

Fourth laboratory rotation for Molecular Cell Biology, Genetics, and Development track students.

MCDB 9500 and 9510, Second-Year Research

By arrangement with faculty.

PATHOLOGY AND MOLECULAR MEDICINE

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/pathology-molecular-medicine>

PATH 5620, 5622, Laboratory Rotations in Pathology and Molecular Medicine

Laboratory rotations for first-year graduate students.

PATH 5625, Pathobiology of Neurodegeneration

Aging individuals throughout the world suffer from neurodegenerative diseases that resist treatment and prevention and are among the costliest chronic diseases in the United States. In this course, we will cover their causes, complications, and the rationale behind the treatments that are now available. We will begin by reviewing normal brain functions and how they are impaired and then evaluate the evidence linking toxic protein deposits of amyloid and tau to Alzheimer's dementia. Our inability to design effective anti-amyloid treatments has turned our attention to many other pathogenic factors, which we will also cover. These include toxic mutations, blood vessel damage, myelin dysfunction, Inflammation, autophagy, and neuronal cell death. We will also explore immune therapy, brain training, protective lifestyles, false alarms and uncertain claims, and the economics of dementia. This course will require a working knowledge of molecular and cell biology and protein biochemistry. It will be geared to the interests of students planning a career in neurobiology/brain-related research either in academics or industry. Applicants interested in this course should send me a brief description of their background and future goals (Vincent.Marchesi@yale.edu). Enrollment will be limited.

PATH 5630/ENAS 535, Biomaterial-Tissue Interactions

The course addresses the interactions between tissues and biomaterials, with an emphasis on the importance of molecular- and cellular-level events in dictating the performance and longevity of clinically relevant devices. In addition, specific areas such as biomaterials for tissue engineering and the importance of stem/progenitor cells, and biomaterial-mediated gene and drug delivery are addressed.

PATH 5640/BBS 5640, Developing and Writing a Scientific Research Proposal

The course will cover the intricacies of scientific writing and guide students in the development of a scientific research proposal on the topic of their research. All elements of an NIH fellowship application will be covered, and eligible students will submit their applications for funding.

PATH 5650, Biology of Cancer

A comprehensive survey of cancer research from the cellular to the clinical level. The relation of cancer to intracellular and intercellular regulation of cell proliferation is emphasized, as are animal models for cancer research. Background in molecular genetics and cell biology is assumed. Open to advanced undergraduates with permission of the organizers.

PATH 5660/C&MP 5650/PHAR 5580, The Responsible Conduct of Research

Organized to foster discussion, the course is taught by faculty in the Pharmacology, Pathology, and Physiology departments and two or three senior graduate students. Each session is based on case studies from primary literature, reviews, and two texts: Francis Macrina's *Scientific Integrity* and Kathy Barker's *At the Bench*. Each week, students are required to submit a reaction paper discussing the reading assignment. Students take turns leading the class discussion; a final short paper on a hot topic in bioethics is required.

PATH 5670, Biological Mechanisms of Reaction to Injury

An introduction to human biology and disease as a manifestation of reaction to injury. Topics include organ structure and function, cell injury, circulatory and inflammatory responses, disordered physiology, and neoplasia.

PATH 5679/5680/C&MP 5630/PHAR 5502, Seminar in Molecular Medicine, Pharmacology, and Physiology

Readings and discussion on a diverse range of current topics in molecular medicine, pharmacology, and physiology. The class emphasizes analysis of primary research literature and development of presentation and writing skills. Contemporary articles are assigned on a related topic every week, and a student lead discussion with input from faculty who are experts in the topic area. The overall goal is to cover a specific topic of medical relevance (e.g., cancer, neurodegeneration) from the perspective of three primary disciplines (i.e., physiology: normal function; pathology: abnormal function; and pharmacology: intervention).

PATH 5681/BBS 5681, Advanced Topics in Cancer Biology

This advanced graduate level course focuses on readings and discussion on three to four major topics in cancer biology, such as targeted therapy, tumor immunology, tumor metabolism, and genomic evolution of cancer. For each topic, the class starts with an interactive lecture, followed by critical analysis of primary research literature. Recent research articles are assigned on these topics, and a student lead discussion with input from faculty who are experts in the topic area. Pre-requisites: PATH 650b or at the discretion of the instructor.

PATH 5682, Cancer Clinical Translation

This course builds upon basic cancer biology knowledge to see the impact of scientific knowledge on real-world clinical oncology issues through didactic sessions, working tumor board attendance, and workshop discussions. The first half of the course emphasizes practical issues in moving research ideas into the clinic, design and execution of standard and novel forms of clinical trials, and statistical analysis of clinical trial data. The second half covers the perspectives of clinicians on the most important outstanding biological questions that should be addressed by cancer investigators. Class size is limited, with priority for Cancer Biology Training Program trainees. Advanced undergraduates or graduate students may be admitted with permission of the organizers.

PATH 5690, Molecular Mechanisms of Disease

This course covers aspects of the fundamental molecular and cellular mechanisms underlying various human diseases. Many of the disorders discussed represent major forms of infectious, degenerative, vascular, neoplastic, and inflammatory disease. Additionally, certain rarer diseases that illustrate good models for investigation and/or application of basic biologic principles are covered in the course. The objective is to highlight advances in experimental and molecular medicine as they relate to understanding the pathogenesis of disease and the formulation of therapies.

PATH 5503, Responsible Conduct of Research, 4th-Year Refresher

The NIH requires that students receive training in the responsible conduct of research every four years. This mandatory course meets that requirement for fourth-year students. The course meets a total of eight hours (four two-hour) sessions. Faculty facilitate discussions based on RCR topics.

PHARMACOLOGY

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/pharmacology/>

PHAR 5501/C&MP 5629/PTB 629/PATH 5679 & PHAR 5502/C&MP 5630/PATH 5680, Courses Topics in Molecular Medicine, Pharmacology and Physiology.

This two-semester seminar course is required for first year students in the TMMPP track. The objectives of this course are to critically evaluate and discuss the scientific literature, improve the ability of the students to give oral presentations, and provide students with the opportunity to learn about individual topics from a physiological, pathological, and pharmacological perspective.

PHAR 5504/PTB 5504, Molecular Mechanisms of Drug Actions

This course provides fundamental background in core principles of pharmacology, molecular mechanisms of drug action, and key research areas in contemporary pharmacology. Core material includes drug-receptor theory, multiple equilibria and kinetics, pharmacokinetics and drug metabolism, therapeutic drug monitoring, drug discovery process, and emerging approaches such as AI-based drug design. Specific content on the mechanisms of drug action includes agents to treat inflammatory, autoimmune, infectious, neoplastic, cardiovascular, and neurological disease. The course includes a self-study component consisting of video modules produced in collaboration between Yale faculty and Merck that explore the preclinical and clinical phases of drug development. Students will review these videos independently and then present and discuss what they learned in groups.

PHAR 5528, Principles of Signal Transduction.

The majority of FDA-approved drugs target proteins involved in cell signaling such as G protein-coupled receptors and protein kinases. This course starts with an introduction to the basic principles of intracellular signal transduction and the major classes of signaling molecules. Students will then learn about specific intracellular signaling pathways relevant to a variety of physiological and pathological settings. Finally, students will learn about cutting-edge methods and approaches for analyzing signaling processes, including proteomics, functional genomics, computational modeling, and live cell imaging.

PHAR 5529, Structural Biology and Drug Discovery.

This course provides a comprehensive introduction to the concepts and practical uses of structural biology and structural biology-related techniques in drug discovery. The first half of the course focuses on techniques used to discover and optimize small molecule and biologic drugs. The second half of the course focuses on drug discovery, particularly for protein kinases. The course includes a practical component, where students conduct hands-on structural biology and biophysical experiments in a laboratory setting, and a field trip to the Yale Center for Molecular Discovery, where the students are introduced to in-house small molecule screening facilities.

PHAR 5537, Systems Pharmacology, and Integrated Therapeutics (SPIT).

This course provides an in-depth experience in drug design, drug discovery, high throughput screening, state-of-the-art proteomics, and target validation. The course is divided into four modules consisting of 1) Lectures from faculty experts on advanced topics in pharmacology, 2) Panel Discussions on principles of drug discovery and development, 3) Workshops providing hands-on experience with cutting-edge instrumentation used in the drug discovery process, and 4) Case Studies in Drug Development featuring faculty and guest speakers with direct experience in taking a drug from the bench and moving it towards the clinic.

PHAR 5538, Pharmacokinetics & Pharmacodynamics in Neuropharmacology.

This course provides a historical account of drug discovery and development for psychiatric and neurological diseases and introduce state-of-the-art methods to study the impact of drugs on the nervous system. It provides a scientific foundation in medicinal chemistry, neuroscience, and molecular imaging for students interested in quantitative neuropharmacology. This course also introduces the theoretical basis of advanced imaging technologies (PET, MRI, optogenetics) and their applications in preclinical and clinical neuropharmacology. Classroom sessions include didactic lectures and interactive discussion sections.

PHAR 5540, Qualifying Exam Prep Class for Pharmacology

The goal of this class is to teach students to conceive, write, and defend a grant proposal. The timing of this half-term course is aligned with the Pharmacology qualifying exam in the Spring term, for which a written research proposal is required. This course takes students through the steps of proposal writing, guiding them in defining a problem of their own and training them in the mechanics of writing. Students learn about the structure and components of fellowship and grant proposals. They engage in “mock study sections”, providing written critiques and participating in discussion of sample proposals assigned by the instructors. Students give oral presentations of their specific aims followed by classroom discussion. By mid-March, students will have made substantial progress toward completing the written portion of their qualifying exam. The class will take a break while students complete their oral exams, and then restart once all exams are done to discuss how to turn their qualifying exam proposals into an NIH F31 Fellowship application, which is also the format for the dissertation prospectus. Open to graduate students only. Priority is given to Pharmacology students.

PHAR 5580/C&MP 5650/PATH 5660/PTB 5650, The Responsible Conduct of Research.

This course is taught by faculty in the Pharmacology, Pathology, Physiology, and PTB programs and two or three senior graduate students. Each session is based on case studies from primary literature, reviews, and two texts: Francis Macrina’s *Scientific Integrity* and Kathy Barker’s *At the Bench*. Each week, students submit a reaction paper discussing the reading assignment. Students take turns leading the class discussion. The final assignment consists of a 5-page paper on a hot topic in bioethics.

Translational Biomedicine

<https://catalog.yale.edu/gsas/degree-granting-departments-programs/translational-biomedicine/>

PTB 5504/PHAR 5504, Molecular Mechanisms of Drug Actions

This course covers the molecular mechanisms of therapeutics, which are presented in a conceptual framework to increase understanding but decrease memorization. Topics include (but are not limited to) receptor affinity, efficacy, multiple equilibria, pharmacokinetics, and toxicity; enzyme kinetics and inhibition, drug discovery and design; molecular basis of antimicrobial therapy, cardiology drugs, anticancer and antiviral therapies; and therapeutics for inflammatory disorders, asthma, and allergy.

PTB 5550/C&MP 5550/ENAS 5550/MCDB 5550/PHAR 5550, Physiological Systems

The course develops a foundation in human physiology by examining the homeostasis of vital parameters within the body, and the biophysical properties of cells, tissues, and organs. Basic concepts in cell and membrane physiology are synthesized through exploring the function of skeletal, smooth, and cardiac muscle. The physical basis of blood flow, mechanisms of vascular exchange, cardiac performance, and regulation of overall circulatory function are discussed. Respiratory physiology explores the mechanics of ventilation, gas diffusion, and acid-base balance. Renal physiology examines the formation and composition of urine and the regulation of electrolyte, fluid, and acid-base balance. Organs of the digestive system are discussed from the perspective of substrate metabolism and energy balance. Hormonal regulation is applied to metabolic control and to calcium, water, and electrolyte balance. The biology of nerve cells is addressed with emphasis on synaptic transmission and simple neuronal circuits within the central nervous system. The special senses are considered in the framework of sensory transduction. Weekly discussion sections provide a forum for in-depth exploration of topics. Graduate students evaluate research findings through literature review and weekly meetings with the instructor.

PTB 5604/CBIO 5604, Physiologic Function and Cellular Structure of Organ Systems (Required)

Introduction to the organization and function of cells within complex multicellular systems as encountered in the human body. Covers major tissues and organs as well as the cardiovascular, immune, and nervous systems, with special emphasis on the molecular and cellular bases of developmental processes and human diseases. Lectures supplemented by electronic-based tutorials on the histology of tissues and organs.

PTB 5605, Grantsmanship and preparing training award applications (Required)

This course is designed to further refine an existing draft of a research and training proposal in the structure of an NIH F31 application in preparation for submission. In addition to providing peer and mentored feedback on the scientific proposal, this course will focus on the preparations of other materials required for the F31 application, including development of a statement of training goals. While student's ineligible (or not intending) to apply for an F31 are welcome to participate (and indeed transferable skills in scientific writing and goal setting will benefit all PhD students), the course will be structured to prepare an F31 application for the April F31 deadline.

PTB 5610/CMP 5610, Medical Research Scholars Program: Mentored Clinical Experience (open only to MRSP and PTB students, Required)

The purpose of the Mentored Clinical Experience (MCE), a PTB and MRSP-specific course, is to permit students to gain a deep understanding of and appreciation for the interface between basic biomedical research and its application to clinical practice. The MCE is intended to integrate basic and translational research with direct exposure to clinical medicine and patients afflicted with the diseases or conditions under discussion. The course provides a foundation and a critically important forum for class discussion because each module stimulates students to explore a disease process in depth over four 90 min sessions led by expert clinician-scientists. The structure incorporates four perspectives to introduce the students to a particular disease or condition and then encourages them to probe areas that are not understood or fully resolved so they can appreciate the value and challenge inherent in using basic science to enhance clinical medicine. Students are provided biomedical resource material for background to the sessions as well as articles or other publicly available information that offers insight to the perspective from the non-scientific world. During this course students meet with patients who have experienced the disease and/or visit and explore facilities associated with diagnosis and treatment of the disease process. Students are expected to prepare for sessions, to participate actively, and to be scrupulously respectful of patients and patient facilities. Prior to one of the sessions students receive guidance

as to what they will observe and how to approach the experience; and at the end of the session, the students discuss their thoughts and impressions. All students receive HIPAA training and appropriate training in infection control and decorum relating to patient contact prior to the course.

PTB 5630/C&MP 5630/PATH 5680/PHAR 5502, Seminar in Molecular Medicine, Pharmacology, and Physiology

Readings and discussion on a diverse range of current topics in molecular medicine, pharmacology, and physiology. The class emphasizes analysis of primary research literature and development of presentation and writing skills. Contemporary articles are assigned on a related topic every week, and a student leads discussions with input from faculty who are experts in the topic area. The overall goal is to cover a specific topic of medical relevance (e.g., cancer, neurodegeneration) from the perspective of three primary disciplines (i.e., physiology: normal function; pathology: abnormal function; and pharmacology: intervention).

PTB 5650/PHAR 5580/C&MP 5650/PATH 5660, Responsible Conduct of Research

Organized to foster discussion, the course is taught by faculty in the Pharmacology, Pathology, and Physiology departments and two or three senior graduate students. Each session is based on case studies from primary literature, reviews, and two texts: Francis Macrina's *Scientific Integrity* and Kathy Barker's *At the Bench*. Each week, students are required to submit a reaction paper discussing the reading assignment. Students take turns leading the class discussion; a final short paper on a hot topic in bioethics is required.

PTB 5690/PATH 5690, Molecular Mechanisms of Disease

This course covers aspects of the fundamental molecular and cellular mechanisms underlying various human diseases. Many of the disorders discussed represent major forms of infectious, degenerative, vascular, neoplastic, and inflammatory disease. Additionally, certain rarer diseases that illustrate good models for investigation and/or application of basic biologic principles are covered in the course. The objective is to highlight advances in experimental and molecular medicine as they relate to understanding the pathogenesis of disease and the formulation of therapies.