Course Syllabus

BioE c112/c215 MEc115/c216:

Molecular Biomechanics and Mechanobiology of the Cell

SPRING 2020

Instructor:

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Office Hours: Mondays-Thursdays 6-7PM and Fridays-Sundays 12-1PM

GSI:

Andrew Dickson (amdickson@berkeley.edu)

Office Hours: Mondays 5:30-6:30PM and Fridays 5-6PM (Stanley Hall atrium level B1)

Lectures:

Tuesdays/Thursdays 2-3:30PM 180 Tan Hall

Discussion Section:

Wednesdays 4-5PM 1165 Etcheverry

Course website: http://bcourses.berkeley.edu

Course Objectives:

This course develops and applies quantitative methods, drawn from statistical and continuum mechanics, to understand cell biomechanics and mechanobiology over a range of length scales, from molecular (nanometer) to cellular (micrometer) levels. It is intended for senior undergraduate students and graduate students who have been exposed to differential equations, mechanics and certain aspects of modern biology. Topics include:

Molecular mechanics and dynamics: Mechanics at the nanoscale: Intermolecular forces and their origins; Single molecules; Thermodynamics and statistical mechanics; Formation and dissolution of bonds: Mechanochemistry; Experimental methods at the single molecule level; Molecular modeling; Steered molecular dynamics.

Cell mechanics and dynamics: Static and dynamic cell processes; Mechanics of biomembranes; The cytoskeleton and cortex; Microrheological properties and their implications; Mechanotransduction; Experimental methods – passive and active rheology; Mechanics of the nucleus;

Prerequisites: Math 54; Physics 7A

Grading: Letter

Estimated hours spent per week: 15

Core Specialization:

- Biomechanics and Tissue Engineering

- Computational Bioengineering

- Biomedical Systems Engineering

- Computational Biology/Biophysics

BioE Content: biological, design, clinical

Textbook:

There is a required Course Reader for this course that has drawn chapters from three textbooks. Please purchase the reader from **CopyCentral (2411 Telegraph Ave. Berkeley)**.

Other recommended references:

- Mofrad MRK and Kamm RD Eds. **Cellular Mechanotransduction: Diverse Perspectives from Molecules to Tissues**, Cambridge University Press, 2014.
- Mofrad MRK and Kamm RD Eds. **Cytoskeletal Mechanics: Models and Measurements in Cell Mechanics**, Cambridge University Press, 2011.
- Howard J., **Mechanics of Motor Proteins and the Cytoskeleton**, 2001.
- Dill K. and Bromberg S., **Molecular Driving Forces**, 2003.
- McQuarrie Dr. and Simon JD. **Molecular Thermodynamics**, 1999.

Course structure and assignments:

This course will be taught in lecture format, along with interactive discussions, to link the course material with various biological issues with a unified theme of "**cellular mechanotransduction**". In addition, readings will be drawn from a variety of primary and text sources. Problem sets will be assigned in most weeks. There will be one exam, three projects and presentations (details below).

Grading:

- Homework assignments 10%
- Journal Club Presentation and Participation 10%
- Project 1: Mechanobiology of Cell-Cell and Cell-Matrix Adhesion (due February 25) 15%
- Project 2: Nuclear Mechanobiology and Mechanotransduction (due April 2) 15%
- Project 3: Mechanobiology "Educational Outreach" or "Transformational Endeavor" (due April 28) 15%
- Midterm test (in class March 10) [open Reader] 15%
- Final Exam [open Reader] 20%

Homework Problem Sets: Exercises on lecture material to reinforce engineering principles and biological understandings of molecular cell biomechanics to prepare the student for the exam. The problem sets will be assigned in most weeks to be submitted electronically and graded. Homework grading is intended to show you how well you are progressing in learning the course material. You are encouraged to seek advice or help from other students and/or to work in study groups. **However, the work that is turned in must be your own. The homework exercise should be viewed as a learning experience.**

Late homework will **NOT** be accepted.

Class Presentation: This course is planned to involve an interactive and engaging setting. All students are required to present and lead a journal club discussions in class once during the course of the semester (in addition to the group presentation of the course projects). The presentations are done in groups of 2-3 There will be one 15-minute presentation slot during (often in the middle of) certain lectures devoted to student presentations (see 'Class Presentations' page on the bCourses website). The topics of student presentations are given with a *starting* reference but you are encouraged to consult other resources, especially more recent journal papers, to enrich your presentation. Grading of these presentations will include your ability to lead a class discussion and promote class participation. Class participation during other students' presentations will also be graded as part of active participation.

Topics Covered in Lecture Hours:

Introduction to Molecular Biomechanics and Cellular Mechanobiology

Biological Scales: Length, Time, Energy, and Forces in Biology

From Biomolecules to the Cell Mechanics

Models and measurements of the cell

Molecular mechanics of cell

Molecular forces

kBT as ruler of molecular forces

Structure of the Cell

Cellular anatomy

Membrane

Cytoskeleton

Nucleus, the nuclear pore complex

Cellular Mechanotransduction

Intracellular signaling relating to physical force

Molecular mechanisms of force transduction

Force estimates and distribution within the cell

Molecular Mechanics and Dynamics: Fundamentals

Macromolecular structure and modeling

Force Fields

Normal modes

Bond length, bond angle, and torsional potentials, van der Waals potential, Coulomb potential

Micro- and Nanoscale Force Techniques for Mechanotransduction

Force application techniques, traction force measurement approaches

Introduction to VMD

Thermal Forces and Brownian Motion

Molecular life and motion at low Re

Langevin and Brownian Dynamics

Mechanics of DNAs, RNAs, and Proteins

A brief review of elementary statistical mechanics

Biomolecules as Ideal Polymers

Ideal Polymer Chains and Entropic Elasticity

Statistics of random walks

Gaussian polymer

Freely jointed chain (FJC)

Origins of elastic forces

The worm-like chain model

Persistence length as a measure of rigidity

Continuum Mechanics of the Cell

Theories of elasticity and viscoelasticity

Storage and loss moduli and their measurements

Active and passive measures of deformation

Rheology of the Cell

Models of the cytoskeleton

Experimental measurements of mechanical behavior

Cell peeking and poking

Mechanics of the Cellular Adhesion

Types of attachment to neighboring cells or the ECM, receptors

Focal adhesions

Mechanics of the Nucleus

The structure and mechanics of the nucleus

Modeling and experimental approaches to understand the nucleus

Mechanics and transport in the nucleus

Nuclear pore biomechanics

Nucleo-cytoskeletal linkages

Bacterial Adhesions

Mechanics of force sensing and mechanotransduction in bacteria

Emerging topics, environmental impact

Microbiome

Important Dates:

February 25: Project I term paper and presentation

March 10: MIDTERM EXAM in class

April 2: Project II term paper and presentation

April 28: Project III term paper and presentation