7 Summary

Student feedback I think it's the right amount of material and it's just enough for us to understand different scopes in cell mechanics. ○ Some things do apply but most topics won't really transfer to my research. ○ I learned a lot about cell mechanics which is what this class is about. ○ I would also be interested in the function of cells which is maybe more a cell biology class. ○ This class was too fundamental for me. ○ While other courses have given me a more in-depth review of cell signaling and other anatomical processes, this class concentrates on different single cell or sub-cellular models. ○ Some more detail of the functions of the cell's various organelles could have been very interesting. ○ It would be very valuable to understand in greater detail how the different systems within the cell interact.

Stuff students liked the most...

01	Introduction	Motivation, movies	3.29
02	Introduction	Cell biology	3.86
03	Introduction	Cell mechanics	4.00
04	Biopolymers	Polymerization kinetics	3.86
05	Biopolymers	Energy, tension, bending	3.71
06	Biopolymers	Entropy, persistence length	4.14
07	Cytoskeleton	Filopodia buckling	4.14
08	Cytoskeleton	Red blood cells	4.71
09	Cytoskeleton	Tensegrity model	3.00
10	Biomembranes	Micropipette aspiration	3.14
11	Biomembranes	Lipid bilayers	3.86
12	Biomembranes	Energy, tension, bending	4.29
13	Mechanotransduction	Signaling, probing	4.57
14	Mechanotransduction	Membrane potential	4.29
15	Mechanotransduction	Action potential	4.71

Table 7.1: Course topics rated by students. Rating on a scale from boring (1) to really cool (5)

Things to remember

42 Answers to life, the universe, and everything 01 Even simple mechanics can give a lot of insight... ◦ 02 ... but different cell types can have totally different mechanical characteristics! ◦ 03 Most cells consist of a cytoskeleton and organelles embedded in a membrane. ◦ 04 And as always, energy minimization rulez! ◦ 05 ... but the free energy can consist of an energetic and an entropic contribution! ◦ 06 For jiggly filaments, the entropic term dominates the energetic term. ◦ 07 Biofilament entropy can be modeled by the statistics of long chain molecules. ◦ 08 Based on the chain shape uncorrelated or correlated chain models can be used. ◦ 09 Correlated chains can be characterized through the persistence length. ◦ 10 Polymerization governs the dynamic assembly and disassembly of filaments. ◦ 11 Cell movement is driven by filament assembly at the leading edge. ◦ 12 Treadmilling is the simultaneous growth and shrinkage at opposite filament ends. ◦ 13 Filament growth is limited by buckling when pushing against the outer envelope. ◦ 14 The Euler buckling modes explain filopodia buckling and filament crosslinking. ◦ 15 The interaction with the environment lowers the critical buckling length. ◦ 16 Homogenization can relate subcellular and cellular mechanical properties. ◦ 17 The flexible membrane of red blood cells can be modeled as a spring network. ◦ 18 Six fold networks explain the rigidity of red blood cells, four fold networks don't. 19 The cytoskeleton is made of microtubules, intermediate filaments and actin. ◦ 20 Cytoskeletal filaments possess a highly organized hierarchical mircostructure. ◦ 21 Tensegrity models view the cell as trusses tied together by pre-stressed ropes. ◦ 22 Lightweight engineering structures use tensegrity concepts similar to some cells. ◦ 23 Membrane phospholipids consist of hydrophilic heads and hydrophobic tails. ◦ 24 The lipid bilayer is the energetically favorable configuration of phospholipids. ◦ 25 The Law of Laplace can describe both soap bubbles and cell membranes. ◦ 26 Surface tension is important in thin membranes and in micropipette aspiration. ◦ 27 Depending on their stiffness, cells can act as elastic solid or liquid drop. ◦ 28 Structural elements display in plane tension and shear and out-of-plane bending. ◦ 29 The tension and shear equation is of 2nd order, the bending equation of 4th order. ◦ 30 Mechanotransduction is the conversion of forces into biochemical signals. ◦ 31 Its complex cascades of biochemical events are illustrated in funny figures. ◦ 32 To improve understanding, it is usually probed in tension, compression, or shear. ◦ 33 The cell membrane is selectively permeable. ◦ 34 Membrane transport is passive along and active against concentration gradients. ◦ 35 Cells consist mainly of water with charged sodium, potassium, and chloride ions. ◦ 36 At the resting state, cells are negatively charged. ◦ 37 At rest, concentration gradient and membrane potential are balanced. ◦ 38 Action potentials are responsible for an all-or-none response of excitable cells. ◦ 39 Pacemaker cells continuously re-excite themselves, muscle cells usually don't. ◦ 40 Stem cells differentiate according to their mechanical environment. ◦ 41 Cell mechanics uses weird super large and super small units. ◦ 42 Cell mechanics still faces lots of exciting open problems that will be fun to solve!

Cell types covered in this course

01	all cells	filament growth
02	stem cells	differentiation is partially based on micro-environmental stimuli and growth factors, such as ECM
03	eukaryotic cells	tensegrity structure
04	amoeba	movement via polymerization
05	red blood cells	representative volume elements, 4-fold vs 6-fold network models, characteristic shape to fit through small cross sections, lack of shear resistance when going through capillaries
06	neutrophils (white blood cells)	liquid drop model, micropipette aspiration
07	chondrocytes (cartilage cells)	elastic solid model, micropipette aspiration
08	endothelial cells	elastic solid model, micropipette aspiration mechanotransduction, probing in flow chambers, shear
09	neurons (nerve cells)	really long length, communication via action potentials
10	skeletal muscle and cardiomyocytes (cardiac muscle cells)	mechanotransduction, ion channels, action potentials, contraction probe contractile forces on force posts
11	bone cells	density adaptation due to stress/loading conditions
12	skin cells	mechanotransduction in wound healing
13	hair cells	mechanotransduction through stereocilia

Table 7.2: Different cell types and their mechanical characteristics