ME 339 – Mechanics of the Cell

Tue/Thu 3:15-4:30pm, 380-380d
Ellen Kuhl (ekuhl@stanford.edu)

I. YOUR BACKGROUND

Some information about yourself

14.3%	undergrad
14.3%	grad student, 1st year
42.8%	grad student, 2nd year
14.3%	grad student, 3rd year
14.3%	other

100%	mechanical engineering

Cell mechanics is primarily part of my …

28.6%	course work
28.6%	research
42.8%	other interest

Please describe your background in cells and in mechanics before taking this class.

cells: some research, but no coursework, nothing other than a 10th grade poorly taught high school bio class, basic undergrad physiology, some grad biomechanics, not much biology background at all, undergraduate course on cell locomotion and the cytoskeleton, very little before taking this class, I initially did protein folding modeling using molecular dynamics, but that was mostly a numerical exercise.

mechanics: continuum mechanics and tissue mechanics, general mechanical engineering background, some undergrad mechanics classes, too many mechanics to describe, decent background in mechanics, mechanics and continuum mechanics.

Please describe why you took this class.

research: to build FE models of subcellular filaments, I thought it would be beneficial to my research

general interest: biotech, medical devices, learn about mechanics of cells, I thought it would be interesting, better understanding of the fundamentals of the cell's functional processes and how these can be modeled numerically, general interest in axons and spinal cord injuries.

Now, after you have taken this class, do you think it has fulfilled this purpose?

33.3%	yes, absolutely
50.0%	almost
16.7%	not really
0.0%	not at all

Please describe why.

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, 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 ME284A, has 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.

II. FORMAT OF THE CLASS

What kind of class format do you prefer in general?

85.7%	blackboard, slides, and handouts
14.3%	blackboard only
0.0%	slides and handouts

Now, after you have taken this class, do you think the class format was appropriate?

42.9%	yes, absolutely
57.1%	yes, for the most part
0.0%	not really
0.0%	not at all

What would you improve concerning the class format?

Nothing, the lecture handout/chapters were perfect, improve overview session before the midterm, more complex examples and theory, make notes available before class, it would be nice to have the class notes before class started for a particular lecture. I enjoyed the overall structure of the class and I think it was pretty straightforward to follow. I think it would have been helpful though to have class notes posted on the coursework page closer to when the discussions were made in class.

Which way would like to address the equations of cell mechanics?

14.3%	theoretical on the blackboard / restricted to simple problems
0.0%	computational, e.g., with matlab / more complex problems
85.7%	combined theoretical and computational

Now, after you have taken this class, do you think this was addressed the right way?

16.67%	yes, absolutely
66.66%	yes, for the most part
16.67%	not really
0.00%	not at all

How many homework problems are appropriate for this class?

0.00%	one
0.00%	two
66.67%	three
33.33%	more than three

How many exams are appropriate for this class?

14.3%	none
71.4%	one
14.3%	two

Do you think a final project is appropriate for this class?

50.0%	yes, absolutely
50.0%	yes
0.0%	not really
0.0%	not at all

What kind of grading would you consider appropriate (currently 30% / 30% / 40%)?

85.7%	30 % homework	30 % exam	40 % final project
14.3%	30 % homework	40 % exam	30 % final project

Additional comments concerning the format of the class.

start talking about final project sooner, homework is too easy, perhaps a computational homework, this should become two courses: one theoretical continuum heavy course with lots of homework and exams and one applied, computational follow-up course with a final modeling project, this would be a lot more interesting and useful, computational assignment, one exam is good to review the materials, more paper reading, the grading format is appropriate, it would be nice to have a few computational assignments to illustrate some of the applications of the modeling techniques we learned in class, thus a few more assignments.

III. TEACHING MATERIALS

What kind of class materials do you prefer?

14.3%	single textbook / focus on “relatively basic” knowledge
0.0%	multiple textbooks / focus on “relatively broad” knowledge
14.3%	recent journal papers / focus on “current state of the art” knowledge
71.4%	a combination of a textbook and some recent manuscripts

Now, after you have taken this class, do you think the class material was appropriate?

14.3%	yes, absolutely
85.7%	yes, for the most part
0.0%	not really
0.0%	not at all

Do you think there should be more textbook material?

14.3%	yes, absolutely
28.6%	yes, for the most part
57.1%	not really
0.0%	not at all

Do you think there should be more journal clubs, paper reading and discussion?

0.0%	yes, absolutely
42.9%	yes, for the most part
42.9%	not really
14.2%	not at all

What would you improve concerning the materials used in class?

more journal papers, if anything more different types of cells, more movies, I think the notes are actually very good, I think very little, if any changes need to be made to them, a few additions could be made in regards to computational modeling techniques, but in general the notes are very clear.

Do you think the posted class notes were appropriate?

57.1%	yes, absolutely
42.9%	yes, for the most part
0.0%	not really
0.0%	not at all

Several publishers have asked us to turn the notes into a textbook. How could the notes / textbook be improved?

clearer vision of the content and covering, the course feels like “random examples of using equations you already know to talk about cells”, the goal of the class is not clear right now, I thought the notes were good, the notation takes some time to get used to, notes followed the class well but are too short (example: connection between entropic elasticity and material modeling), notes should contain more details and background information than what is presented in class, topics need to be tied together, more problems and examples, more relevance to current research, class notes are really good and helpful, notes are precise, there could definitely be more examples and pictures, more detail in terms of theory and a few rather complex examples would be good especially since it could be used like a reference, too, maybe a little more bio/chem/biochem would make sense if you don’t assume the reader already has either the background or the relevant references, otherwise, most detailed notes I’ve ever seen, except maybe the continuum mechanics ones, proofreading!, I think the notes are actually very good. I think a few computational discussions and possibly some additional background on the biology of the cell could be valuable additions, but perhaps in the context of a quarter, i.e. a 10 week class session, it might be a little too much information.

IV. CONTENT OF THE CLASS AND NOTES

Do you think the overall concent of the class (and of the notes) is appropriate?

28.6%	yes, absolutely
42.8%	yes, for the most part
28.6%	not really
0.0%	not at all

Do you think the class topics (and notes) are well-structured?

71.4%	yes, absolutely
14.3%	yes, for the most part
14.3%	not really
0.0%	not at all

Do you think class topics (and notes) are well-balanced in math mechanics/biology?

16.67%	yes, absolutely
66.66%	yes, for the most part
16.67%	not really
0.00%	not at all

Please rank the importance of the topics covered in class.

cool ☐5 ☐4 ☐3 ☐2 ☐1 boring

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

Which three topics did you like the most?

01 Mechanotransduction – Action potential
02 Cytoskeleton – Red blood cells
03 Mechanotransduction – Signaling, probing

Are there any other topics you would have liked to see in class?

More mechanotransduction, more cell types, neurons, how shell theory is exactly applied to cells, red blood cells in vivo subjected to shear in blood vessels, more models on crosslinking, tensegrity models, nerve cell mechanics, general stem cell theory and more detail on differentiation, axon re-growth.

Do you have any other suggestions to improve the content of the class (and notes)?

there needs to be a tie between entropy and elasticity, more movies, more mechanics.

V. AND THE TAKE HOME MESSAGE IS…

Which cell types do you remember from the class? In which context?

01 all cells	filament growth
02 stem cells	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 nerve cells	really long length, communication via action potentials
10 skeletal and 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

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!