<u>Engineering Sciences 228: Biomaterials</u>

Spring 2017 (TuTh 10-11:30am)
Location: Maxwell Dworkin 123

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General

Course Website: https://canvas.harvard.edu/courses/2602
Office Hours: By appointment
<u>Prerequisites</u>: One semester of college-level organic chemistry and biochemistry at the level of LS1B. At least one semester of molecular or cellular biology. Physics at the level of Physics 11a,b. Mathematics at the level of Math 1B.

Description

Engineers have been drawing inspiration from biology in order to design man-made systems for centuries. Structural designs that mimic biology are alluring, often because they look and function completely differently than designs that are born out of a relatively modern tradition of industrial engineering. Traditional materials engineering focuses on square shapes that are monolithic, easily fabricated using top-down methods and can be combined into larger structures whose properties can be easily predicted by straightforward mathematical models. This is in stark contrast to biological systems, which build from the bottom up, using self-assembly and accretion processes, exhibit hierarchical order over many length scales, and are usually more difficult to explain using models. As a result of the apparent gulf between these two different approaches to arriving at a material design, engineers have long been attracted to mimicking biological materials. After all, one could argue that biology has had billions years to arrive at the solutions to material design problems through the slow, but effective method of natural selection. How can we as engineers learn from biological designs to make more effective materials? Are the best possible designs arrived at by mimicking biology as closely as possible, or by extracting select design elements and recombining them in new ways?

This course addresses these intriguing questions by investigating the methods by which biology builds structures and determining what makes their design effective. It simultaneously surveys notable examples of engineers using these design parameters to design new materials for use in biomedical or biotechnological applications.

Course Objectives

At the end of this course, students will be able to:

- Draw the molecular structure of the major classes of biomaterials (proteins, polysaccharides, bioceramics).
- Analyze the composition of naturally occurring materials to derive rational design elements that contribute to performance and function.
- Describe how the biosynthesis and assembly of biomaterials (including but not restricted to bone, cartilage, basement membrane, wool, silk, cellulose) leads to desirable functional properties (mechanical strength, adhesion, lubrication, etc.).
- Examine the molecular structure of a material and predict its behavior in various contexts.
- Use quantitative models to describe material performance, especially with regard to viscoelastic theory.
- Rationally design new materials for applications such as therapeutics/diagnostics, improved textiles, smarter coatings, or smaller electronics.
- Present and defend an original design project, communicating ideas clearly and effectively to peers and teaching staff.

Expectations

Students are expected to attend all lectures and participate in all class activities. The course will require a commitment of about 4-8 hours a week outside of lectures for work on homework, projects, and exams. Some portions of the class will be driven by the students so as to give them an opportunity to explore and discuss topics within biomaterials engineering that they find particularly interesting. The success of these assignments will be determined by the student's ability to do independent research, effectively communicate their findings to the class, and field questions from the teaching staff. Undergraduates may take the course, but must seek approval from Prof. Joshi before enrolling.

Reading Material

There is no textbook that will be used as required reading for this class. Reading material will be supplied to the students in the form of book chapters or journal papers as needed. Two books that are intended to serve as reference material will be kept on reserve at the library and are recommended to students who intend to continue researching the field of biomaterials or bio-inspired materials.

- *Biomaterials Science: An introduction to Materials and Medicine, 3rd Ed.* Ratner, Academic Press, 2013
- *Structural Biomaterials, 3rd Ed.* Vincent, Princeton Press, 2012

Assignments and Grades

The following assignments are planned for the class:

Problem Sets and Exam:
Problem sets will require students to demonstrate knowledge of key concepts introduced during the lectures, research relevant literature, and propose new connections between naturally occurring biomaterials and engineered materials. The exam will cover all of the material presented during lectures.

Literature Review/Design Presentation:
Individuals or teams of students will research a bio-inspired engineered material of interest and present their findings to the rest of the class. As part of the class presentation, the presenting team will lead the rest of the class in a brainstorming and analysis session that relates the technology in question to practical application, explores alternative or competitive technologies, and assesses its potential for transformation from a research project to a useful product or procedure.

Original Research Proposal:
Students will write an NIH-style research proposal with an original idea for a new biomaterial. Students will identify a real world problem that could be solved or diminished by the development of and engineered material. Students will be expected to conduct a market review to identify any technologies that represent the current state-of-the-art and any other emerging technologies that may compete with their proposed material innovation. The results of this review will be presented in class in order to get critical feedback from their peers and the teaching staff.

The second part of the assignment will be a written proposal. For this assignment, students should take into account the feedback they obtained from their class presentation to refine the design of their new material. This should also involve an independent effort to delve deeper into the scientific literature to support their claims. The proposal itself will outline the design, synthesis/fabrication, and implementation of the new material. The presentation and submissions will be assessed based on their ability to identify an appropriate and well-defined problem, suggest a reasonable and innovative material design to solve that problem, and systematically describe how it will be implemented. Grades will be assigned based on the teaching staff's assessment of these parameters and may include a component of peer evaluation.

Grades

All grading will be carried out by the ES228 teaching staff. Grades will be assigned based on the following breakdown:

Problem Sets	30%
Literature Review/Design Presentation	20%

Exam	10%
Original Research Proposal (Presentation)	20%
Original Research Proposal (Written)	20%

Expectations of Professionalism

You are expected to abide by the Harvard University policies on academic honesty and integrity as given in the Student Handbook. Violations of these policies will not be tolerated. Discussion among students, professor, TF, former students, and/or any colleagues is permitted and encouraged. You are free to seek help through all avenues. All materials submitted (homework, quizzes, and the final project) must be your own work. Copying from any source without explicit reference is a violation of this policy (plagiarism). Late work will only be accepted at the discretion of the instructor.

Class Schedule

Week	Class 1 (Tuesday)	Class 2 (Thursday)	Comments
Week 1 (Jan 24, 26)	Course Overview	Introduction to naturally occurring polymers	
Week 2 (Jan 31, Feb 2)	Module 1.1: Biological Fibers – Cellulose, Silk, Collagen	Module 1.2: Bio-inspired fibrous materials	
Week 3 (Feb 7, 9)	Module 1.3: Student presentations	***NO CLASS***	
Week 4 (Feb 14, 16)	Module 2.1: Biological Adhesion (irreversible) – mussel byssus, surgical adhesives	Module 2.2: Biological Adhesion (reversible) – gecko feet, tissue adhesives, climbing robots	
Week 5 (Feb 21, 23)	Module 2.3: Biological Lubrication – mucins, boundary lubrication in eyes and internal organs	***NO CLASS***	PS#1 Due
Week 6 (Feb 28, Mar 2)	Module 2.4: Bio-inspired lubricants – brush polymers, GAGs, lubricin, joint lubrication	Module 2.5: Student presentations	
Week 7 (Mar 7, 9)	Module 3.1: Composites and Gradient Biomaterials – bone, mollusk shells, squid beak Module	***NO CLASS***	PS#2 Due
Week 8 (Mar 14, 16)	***SPRING BREAK***	***SPRING BREAK***	
Week 9 (Mar 21, 23)	Module 3.2: Bio-inspired composites and gradient materials	Module 3.3: Student presentations	
Week 10 (Mar 28, 30)	Module 4.1: Vertebrate Connective Tissue – cartilage, tendon, skin, muscle	Module 4.2: Vertebrate Connective Tissue – complex structure of cartilage, tendon, skin, muscle	PS#3 Due
Week 11 (Apr 4, Apr 6)	Module 4.3: Vertebrate Connective Tissue – regenerative medicine	Module 4.4: Student Presentations	
Week 12 (Apr 11, 13)	Exam Review	Proposal design and writing	
Week 13 (Apr 18, Apr 20)	*EXAM*	Student proposal presentations (during Reading Period)	