Mechanics Meets Genomics: Modern Biotech, Synthetic Biology, and Therapeutic Engineering for Mechanical Engineers

Prof. Sung Jin Park (Biomedical Engineering, Georgia Tech and Emory University, USA)

Course Overview:

Modern biotechnology is rapidly transforming medicine through cell and gene therapies, synthetic biology, and advanced biopharmaceuticals, all of which rely on engineered physical systems for delivery, control, and manufacturing. This course presents contemporary biotech and therapeutic modalities—including stem cells and organoids, CRISPR and gene editing, optogenetics, CAR-T cells, antibody–drug conjugates (ADCs), and digital-twin-enabled biomanufacturing—through a lens tailored to mechanical engineers.

We emphasize how mechanical and systems engineering principles (transport phenomena, soft tissue mechanics, biomaterials design, sensing and actuation, control, and process engineering) underpin the development, deployment, and scale-up of these technologies. Applications span engineered tissues and organoids for disease modeling, biohybrid robots and mechano-responsive therapies, immuno-engineering platforms for CAR-T and ADCs, and precision biopharma manufacturing integrating automation, AI, and soft robotics.

The objective of this short course is to introduce advanced undergraduate and graduate students in mechanical engineering and related disciplines to the core concepts of modern biotechnology and therapeutic engineering, and to clarify how physical, mechanical, and systems considerations shape real-world therapies and devices.

The course is particularly well suited to mechanical engineering students because many of today's most important biomedical advances require expertise in transport, mechanics, materials, sensing, actuation, and scalable manufacturing. It is also shaped by an instructor perspective that began in the mechanical engineering discipline and transitioned into biomedical engineering, reflecting the intellectual bridge between physical engineering principles and modern therapeutic technologies.

Prior coursework in physiology or molecular biology is helpful but not required. We will begin with an overview of the biotech landscape and biomaterials/biofabrication, then build up to stem-cell and organoid technologies, gene and synthetic tools, neuromodulation and sensor–motor interfaces, cell-based immunotherapies, biopharmaceuticals, and integrative future directions in digital twins and precision biomanufacturing.

Schedule:

Day 1. Biotech Landscape and Biomaterials/ Stem Cells, Organoids

Lecture 1: Onboarding & course logistics, overview of modern biotech (1 hour)

- Biotech modalities: small molecules, biologics, cell and gene therapies, synthetic biology, and immunotherapies
- Roles of mechanical engineers in devices, bioreactors, organoids, and biomanufacturing
- Course roadmap and translational case studies

Lecture 2: Biomaterials and Biofabrication Fundamentals (1 hour)

- Biomaterials classes: metals, ceramics, polymers, hydrogels; structure–property relationships
- Biofabrication: 3D bioprinting, scaffolds, and microfabricated platforms
- Mechanical design parameters including stiffness, porosity, geometry, and degradation

Lecture 3: Stem Cells, Organoids, and Engineered Tissues (1 hour)

- Stem-cell basics: embryonic stem cells, adult stem cells, and induced pluripotent stem cells
- Organoids, organs-on-chips, and engineered tissues for disease modeling and therapeutic testing
- Mechanical control of tissue maturation through perfusion, shear, and matrix properties

Day 2. Gene editing, Synthetic Biology, and Electrophysiology

Lecture 4: CRISPR and Gene Editing for Therapy and Modeling (1 hour)

- Gene-editing platforms: ZFNs, TALENs, CRISPR-Cas systems, base editing, and prime editing
- Delivery strategies: viral vectors, nanoparticles, and physical delivery methods
- Therapeutic applications, disease modeling, and engineering constraints

Lecture 5: Synthetic Biology and Biohybrid Machines (1 hour)

- Synthetic gene circuits: sensing, logic, actuation, and feedback control in living cells
- Mechano-responsive and optogenetic circuits
- Biohybrid soft robots and living actuators based on muscle or cardiomyocytes

Lecture 6: Sensor–Motor Systems and Electrophysiology (Brain & Muscle Focus) (2 hours)

- Membrane potentials, action potentials, synaptic transmission, and excitation–contraction coupling
- Brain, nerve, skeletal muscle, and cardiac electrophysiology
- Recording and stimulation technologies: EEG, EMG, multielectrode arrays, pacing, and neural interfaces

Day 3. Neuromodulation and Cell Therapies

Lecture 7: Optogenetics, Neuromodulation, and Closed-Loop Therapeutic Interfaces (1 hour)

- Optogenetic tools for controlling neural, muscle, and immune cell function
- Light-delivery systems: fiber optics, micro-LEDs, and implantable devices
- Closed-loop therapeutic systems integrating sensing, stimulation, and control

Lecture 8: CAR-T Cells and Advanced Cell Therapies (1 hour)

- CAR-T design principles and manufacturing workflow
- Ex vivo engineering, expansion, and quality control of therapeutic cells
- Engineering roles in bioreactors, microfluidic testing, and tumor microenvironment modeling

Day 4. Biopharma Technology and Future Directions

Lecture 9: Antibody–Drug Conjugates (ADCs) and Biopharma Technology (1 hour)

- ADC design: antibodies, linkers, payloads, and pharmacologic design principles
- Manufacturing and scale-up of biologics and ADCs
- Process engineering challenges in purification, formulation, and quality assurance

Lecture 10: Future Therapeutic Engineering: AI, Digital Twins, and Precision Biomanufacturing (1 hour)

- Digital twins for organs, patients, and manufacturing systems
- AI-enabled therapeutic design and automated experiment planning
- Precision biomanufacturing, robotic platforms, and integrative future opportunities for mechanical engineers

Instructor Information:

Prof. Sung Jin Park, Ph.D.
Assistant Professor
Wallace H. Coulter Department of Biomedical Engineering
Georgia Institute of Technology & Emory University
Email: sung.jin.park@gatech.edu ; sung.jin.park@emory.edu
Website: GT/Emory Biohybrid Lab: https://www.biohybridlab.org/