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Biomedical Engineering +
Leonard Gelfand Center

Biomedical Engineering: An Introduction

Created and edited by:
Olivia Olshevski, BME, MS 2021
Renee Morton, BME, MS 2020

Some material provided by Professor Rosalyn Abbott, BME, PhD

This educational resource for middle and high school audiences was developed as a project by Carnegie Mellon student, Renee Morton, for the course *Experiential Learning through Projects*, taught by Dr. Conrad Zapanta and Dr. Judith Hallinen during the summer of 2020.

The content was edited and additional content was added by Olivia Olshevski for the course *Directed Study* during the fall of 2021.

NOTICE: If you are attempting an experiment, it is important to make sure that you are following all safety steps. All experiments should be completed with supervision of a adult. Weather permitting, we recommend taking messy experiments outside. Remember to wear safety gear like gloves, aprons, and goggles, especially for experiments with chemical reactions!

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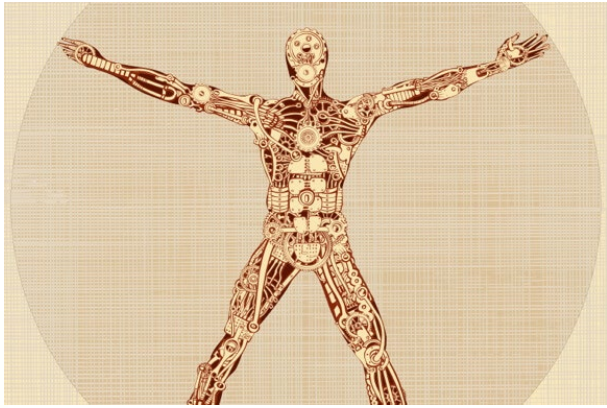
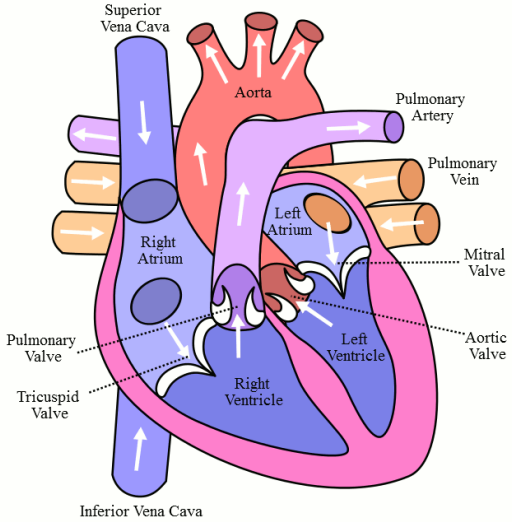
Be SAFE and enjoy the module!

Sources for content and for images that are included in these slides can be found in the accompanying script and on the slides at the end of the file.

The Body is the “Ultimate Machine”

- The body is the “ultimate machine”
  - 650 skeletal muscles and 206 bones
- Powered by the ultimate pump
  - Heart circulates fluids and beats ~2.5 billion times in a lifetime
  - Anticipates when you’ll be active, capable of speeding up / slowing down to give you fuel you need





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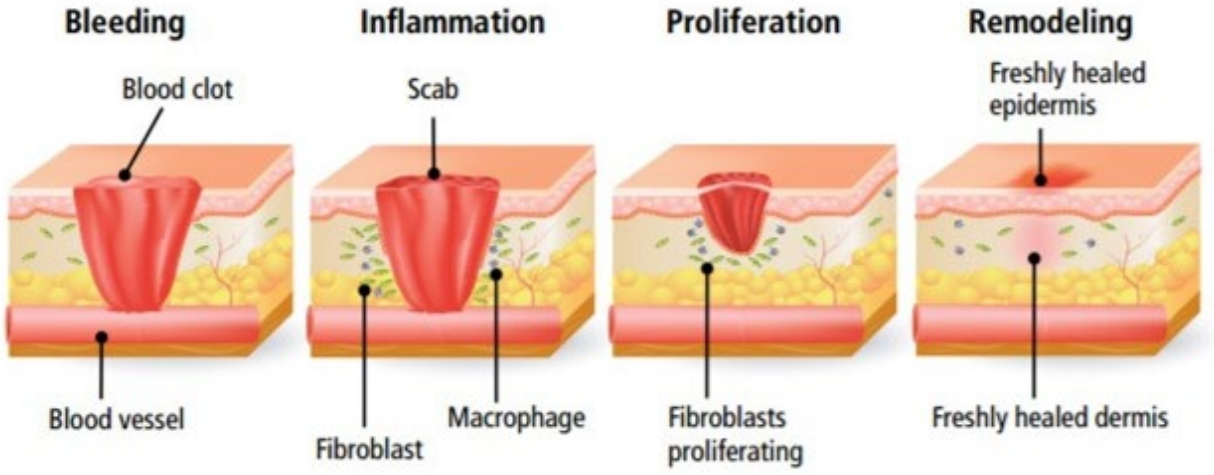
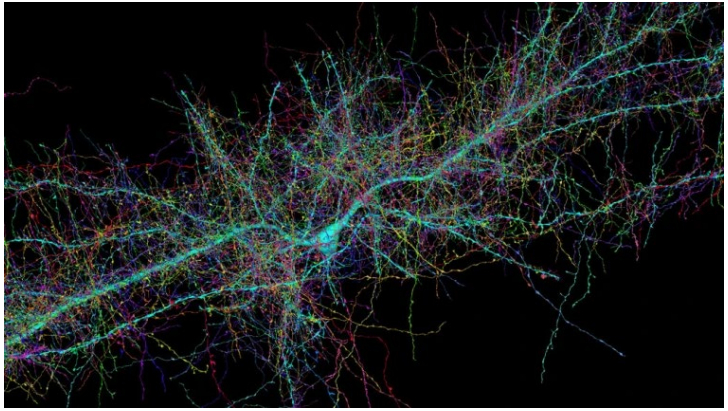
The Body is the “Ultimate Machine”

- Capable of self-repair
  - Skin cells have lifespan of 2-3 weeks
  - Colon cells: 4 days



The Body is the “Ultimate Machine”

- Is intelligent
  - ~86 billion neurons (each capable of sending pulses of electricity to other neurons)
  - Each neuron makes ~1000 connections with other neurons (100 trillion connections in total)

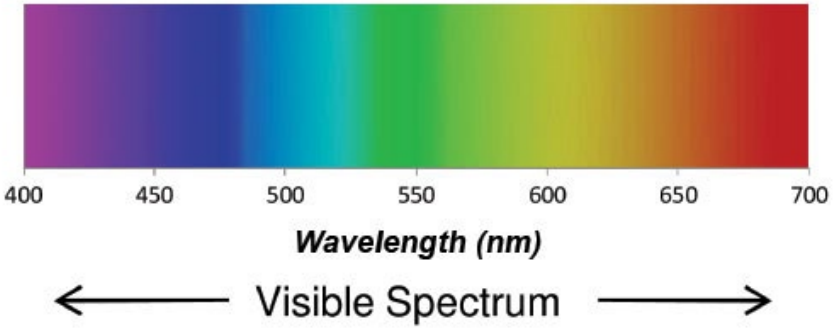


The Body is the “Ultimate Machine”

- Powered by food
- Food broken down into smaller molecules:
  - Proteins → amino acids
  - Polysaccharides → sugars
  - Lipids → fatty acids and glycerol
- Smaller molecules generate energy for your body

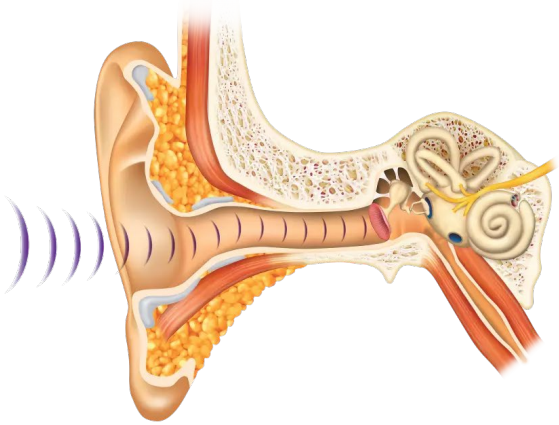
The Body is the “Ultimate Machine”

- Can sense its environment
  - **Sight**: eyes detect single photons of light
    - Dilate to let more light in
    - High sensitivity range
    - 3 different color sensitive photoreceptors (we can distinguish ~10 million colors)
  - **Smell**: nose detects ~1000 different chemical compounds → 10,000 different odors



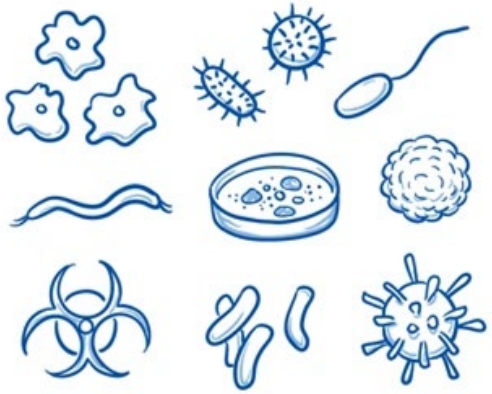
The Body is the “Ultimate Machine”

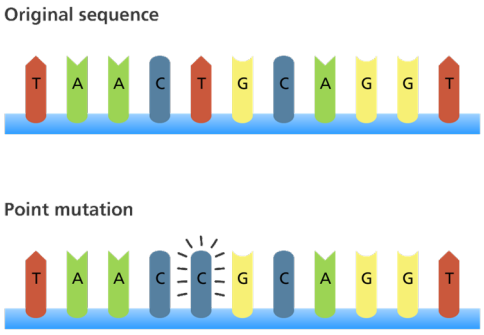
- Can sense its environment
  - **Hearing**: ears sense vibrations in the air over a large range of amplitude
    - Frequencies between 20 and 20,000 Hz
  - **Sensors**: fingers and skin detect heat, pressure, vibration, and texture
    - Knows where its limbs are in space
    - Can infer the passage of time



But it's not perfect...

- Susceptible to disease
  - Viruses
  - Bacteria
- Injuries
- Key genetic mutations
- Age





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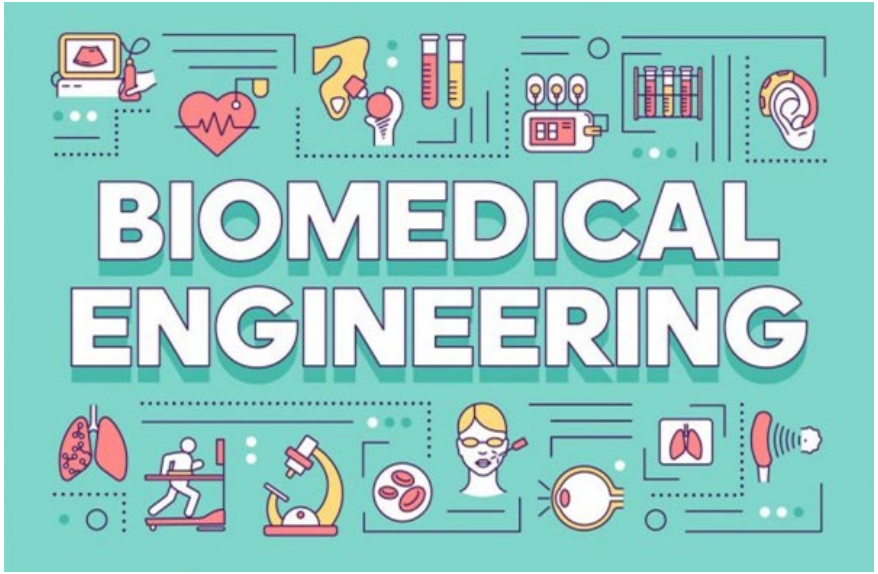
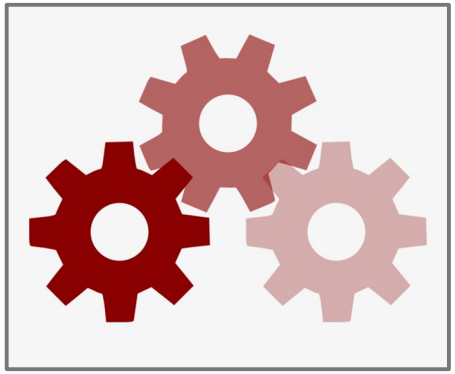
What is biomedical engineering?

The application of engineering principles to medicine and biology for health purposes. It is the study of biological systems.



BME = Medicine + Engineering



Medicine

- Diagnosis
- Prognosis
- Treatment
- Prevention

Engineering

- Identify the problem
- Define the constraints
- Generate ideas
- Select approach
- Develop design
- Test solution

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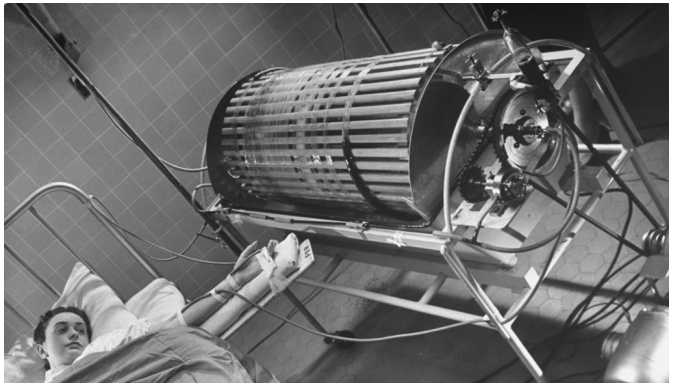
Historical Perspective

- Only engineering discipline developed post-WWII
- Kidney dialysis -Willem Kolff (1940s)
- Polio vaccines - Jonas Salk (1940s and 50s)
- Artificial heart valve -Charles A. Hufnagel (1952)
- First external cardiac pacemaker (1958)



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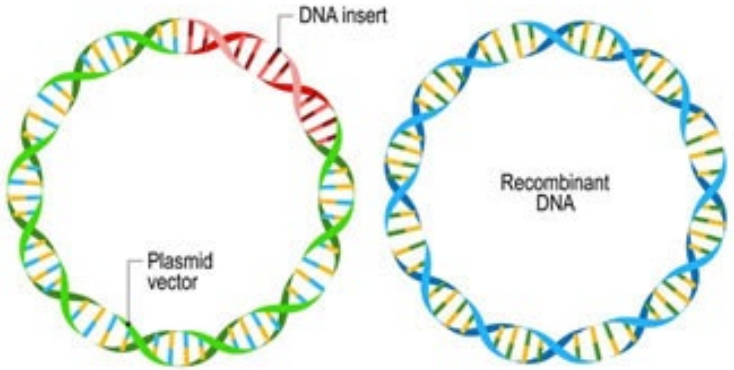
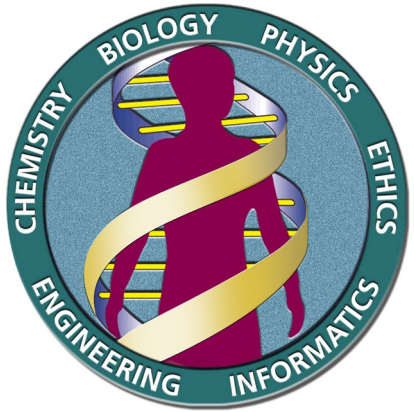
Historical Perspective

- First biomedical engineering departments formed (late 1960s)
  - University of Virginia
  - Case Western Reserve University
  - Johns Hopkins University
  - Duke University
- Recombinant DNA technology (1970s)
- Human Genome Project (later 20th century)





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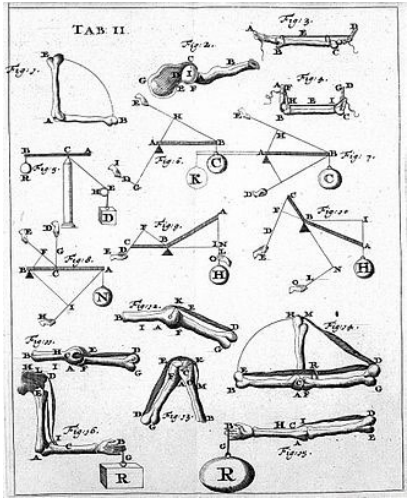
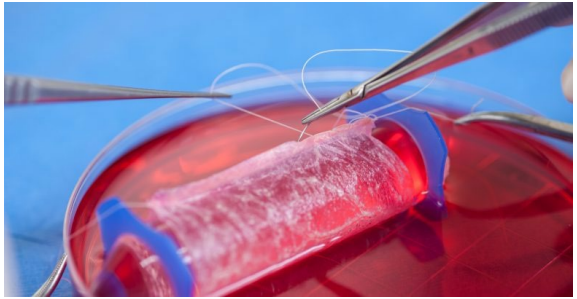
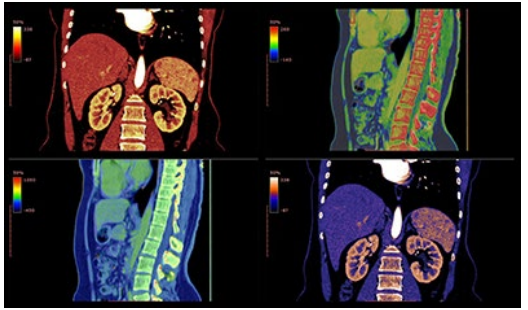
What do biomedical engineers do?
BME Focus Areas

- Biomechanics
- Biomaterials and Tissue Engineering
- Biomedical Devices
- Bioimaging and Signal Processing
- Cellular and Molecular Biotechnology
- Neuroengineering







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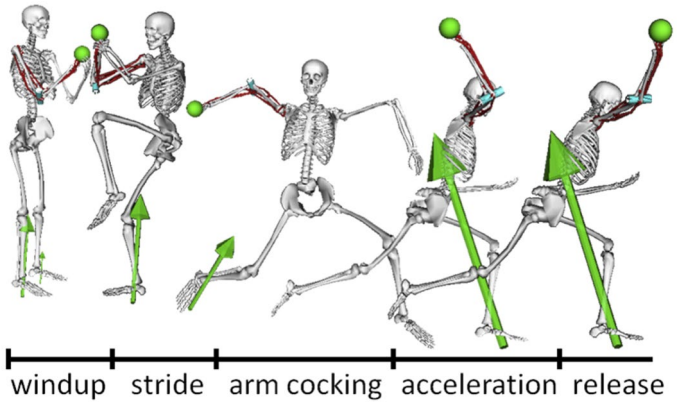
Focus Area: Biomechanics

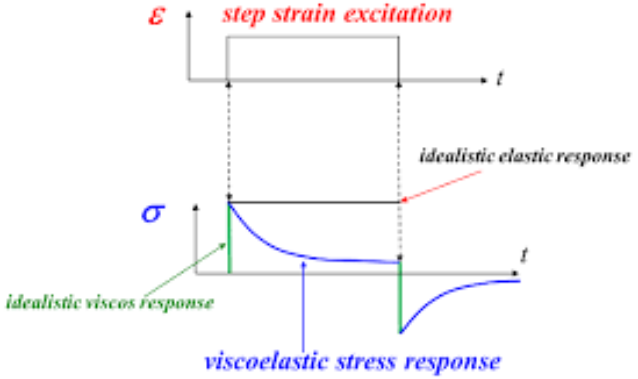
The scientific study of the mechanics of living structures (or of structures produced by organisms) -*Nature* definition

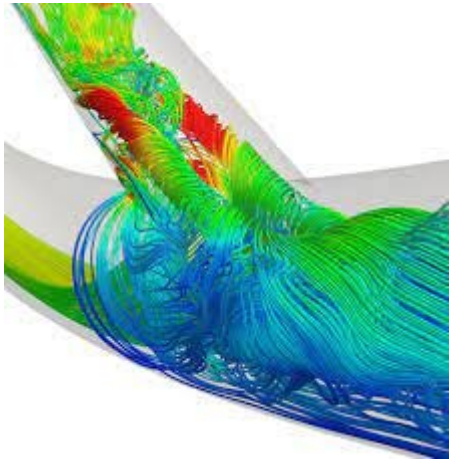
- What you study
  - Mechanical properties of tissues (macro and micro)
    - Micromechanics
    - Solid mechanics
    - Viscoelasticity
    - Fluid mechanics
    - Entropic force, diffusive force, osmotic force

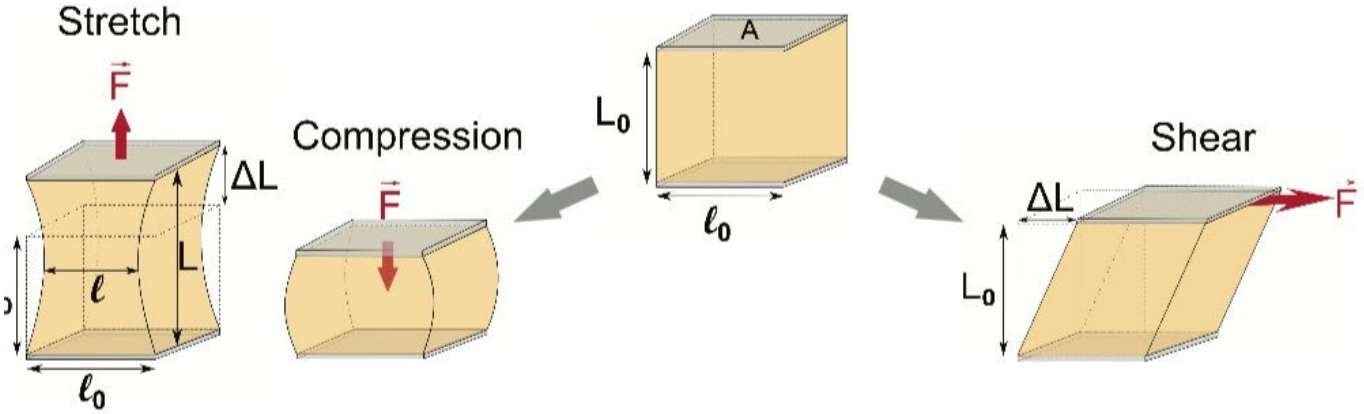


Applications: Biomechanics

- Cardiovascular fluid mechanics and dynamics
- Cell mechanics
- Solid mechanics of biological materials
- Biological viscoelastic solids and fluids



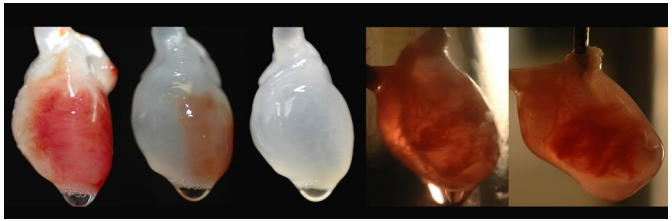




Focus Area: Biomaterials and Tissue Engineering

The field of study in which man-made materials are developed for medical treatments (biomaterials) and living functional tissue is produced (tissue engineering)

- What you study
  - Interactions between materials and cells or tissues (and their effects)
  - Major body responses (wound healing, immune response, foreign body response)
  - Characterizing biomaterials (metals, ceramics, polymers)
  - Natural and synthetic materials
  - Cell culture
  - Material biocompatibility



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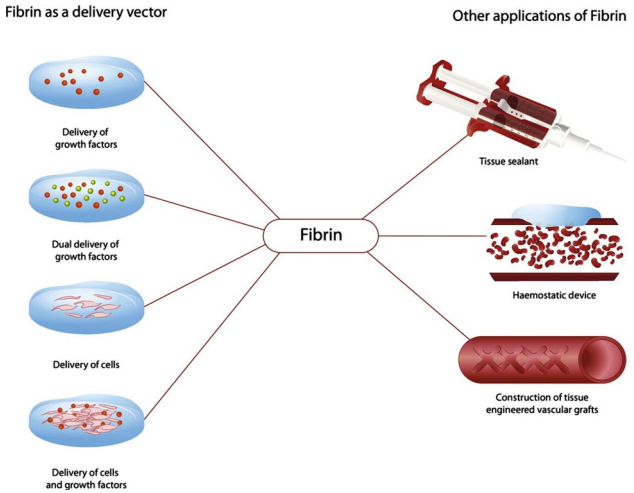
Applications: Biomaterials and Tissue Engineering

- Artificial organs
- Wound healing
- Bioscaffolds
- Collagen biomaterials
- Implant failure and material reactions



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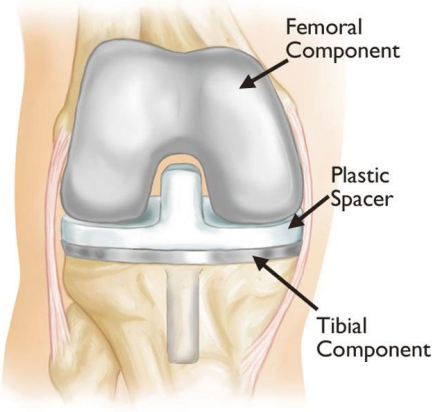
Focus Area: Biomedical Devices

The field of study that produces instruments, machines, implants, in vitro reagents, software, materials, and other related articles for the safe and effective prevention, diagnosis, treatment, and rehabilitation of illness and disease for human beings

- What you study
  - Instrumentation and measurement
  - Diagnostic vs. therapeutic devices
  - Integrated Systems technology
  - Device fabrication
  - Interaction with cells, tissues, organs



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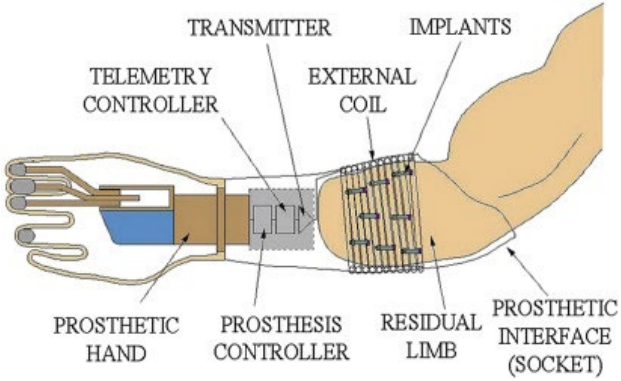
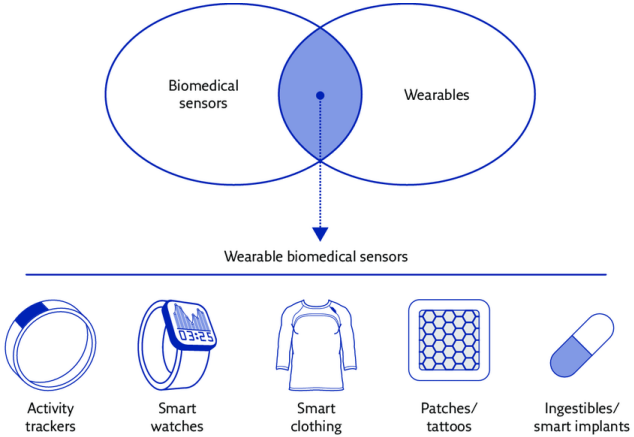
Applications: Biomedical Devices

- Sensors
- Actuators
- Diagnostic devices
- Therapeutic devices
- Instruments
- Systems
- Software





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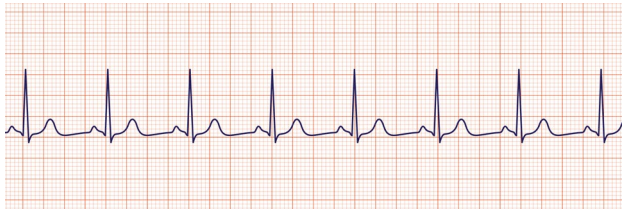
Focus Area: Bioimaging and Signal Processing

The field of study centered on methods and instruments used to acquire, process, and visualize structural or functional images of living objects or systems at desired spatial and temporal scales



- What you study
  - Medical imaging
    - Methods
    - Types
  - Signal processing
  - Image analysis
  - Neural engineering
  - Electrical signals of brain and heart

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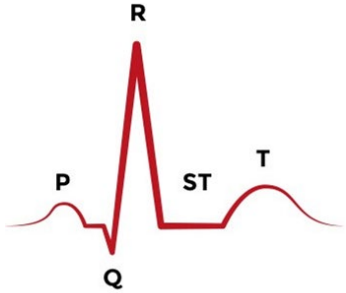
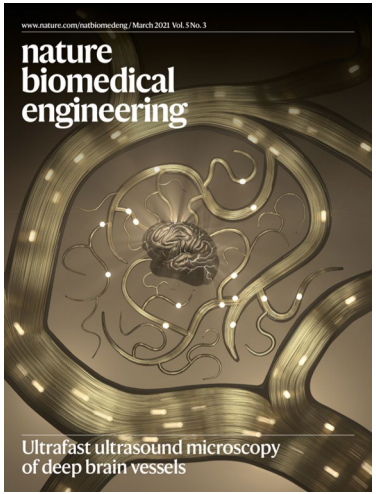
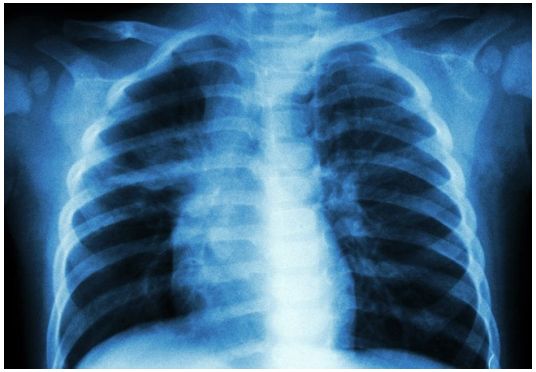
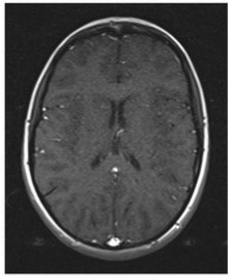
Applications: Bioimaging and Signal Processing

- Electrocardiograms
- Neuron functions
- Heart functions
- Imaging modalities (microscopy, ultrasound, X-ray, CT, PET, MRI, etc.)
- Image qualities (contrast, signal, spatial resolution)

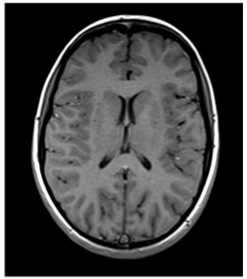




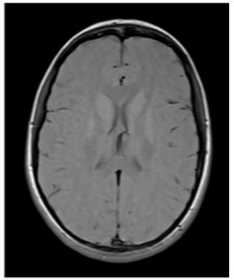




TR 200
TE 15
Low tissue contrast
Low SNR



TR 500
TE 15
High tissue contrast
High SNR



TR 1000
TE 15
Low tissue contrast
High SNR

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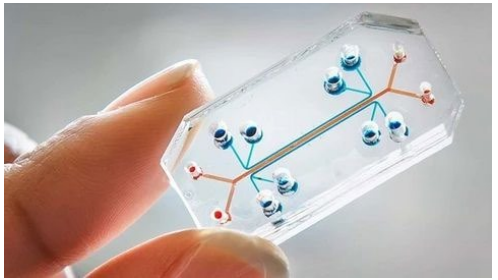
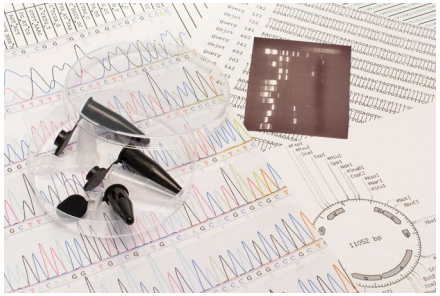
Focus Area: Cellular and Molecular Biotechnology

The field of study focused on the practical application of cellular and molecular knowledge with the aim of enhancing or improving production in microorganisms or cell cultures

- What you study
  - Biological regulation (signaling, endocrine system, hormones)
  - Cell culture
  - Cell morphology
  - Genetics
  - Diffusion, transport, and delivery
  - Binding kinetics





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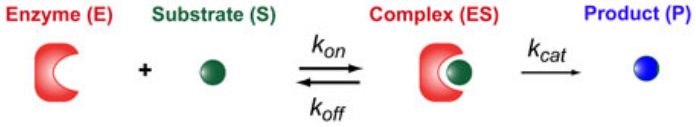
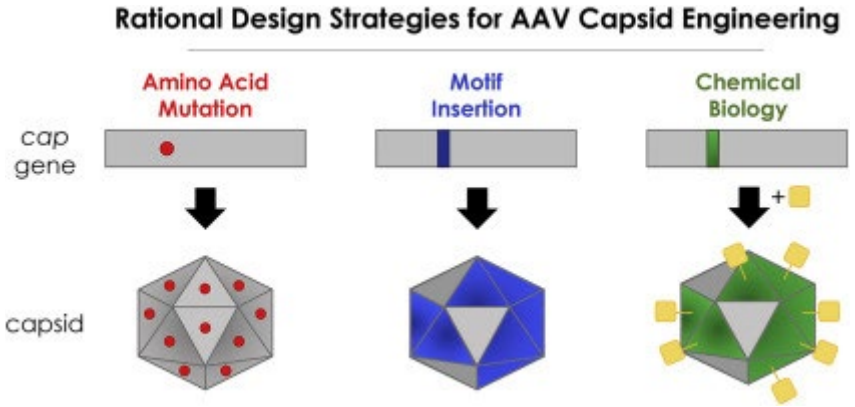
Applications: Cellular and Molecular Biotechnology

Protein manufacturing

- Pharmaceuticals
- Virus manufacturing
- Genetic engineering
- Vaccines
- Bioreactors
- Microfluidics





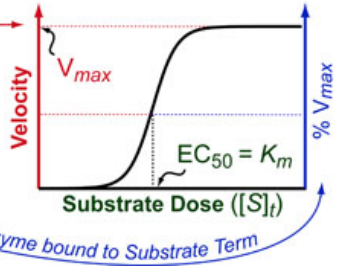
Michaelis-Menton Equation

$$\frac{d[P]}{dt} = k_{cat}[E]_t \cdot \frac{[S]_t}{K_m + [S]_t}$$

Maximum Velocity Term

Fraction of Enzyme bound to Substrate Term

Dose-Velocity Curve



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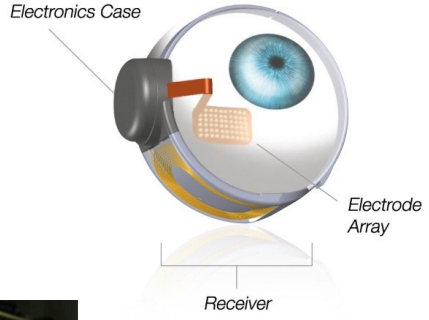
Focus Area: Neuroengineering

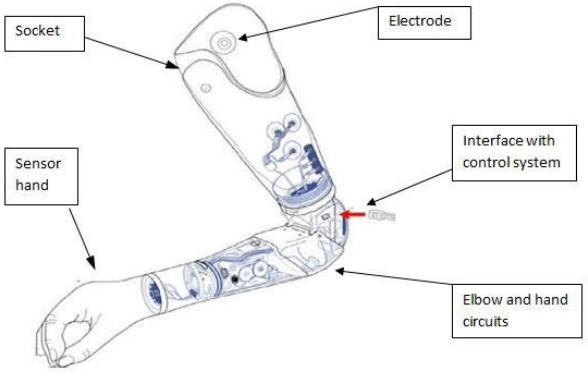
The field of study that involves the use of engineering technology to study the function of various neural systems

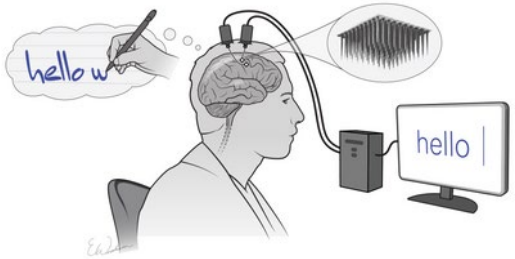
- What you study
  - Neuroimaging techniques
  - Neural anatomy
  - Action potentials
  - Nervous system modulation

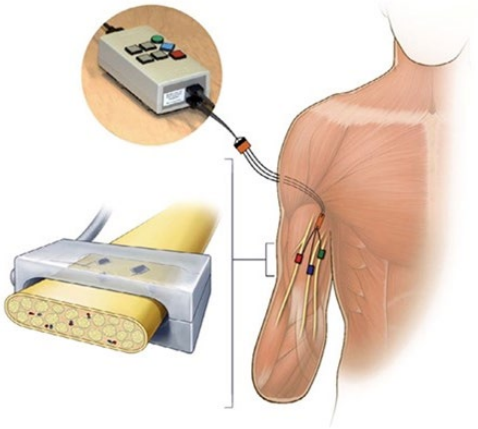


Applications: Neuroengineering

- Implantable technology and materials
- Neural prosthetics
  - Cochlear implants
  - Retinal implants
  - Touch restoration
  - Vestibular implants
  - bladder/bowel control
  - Brain-computer interfaces
- Sensor and motor prosthesis







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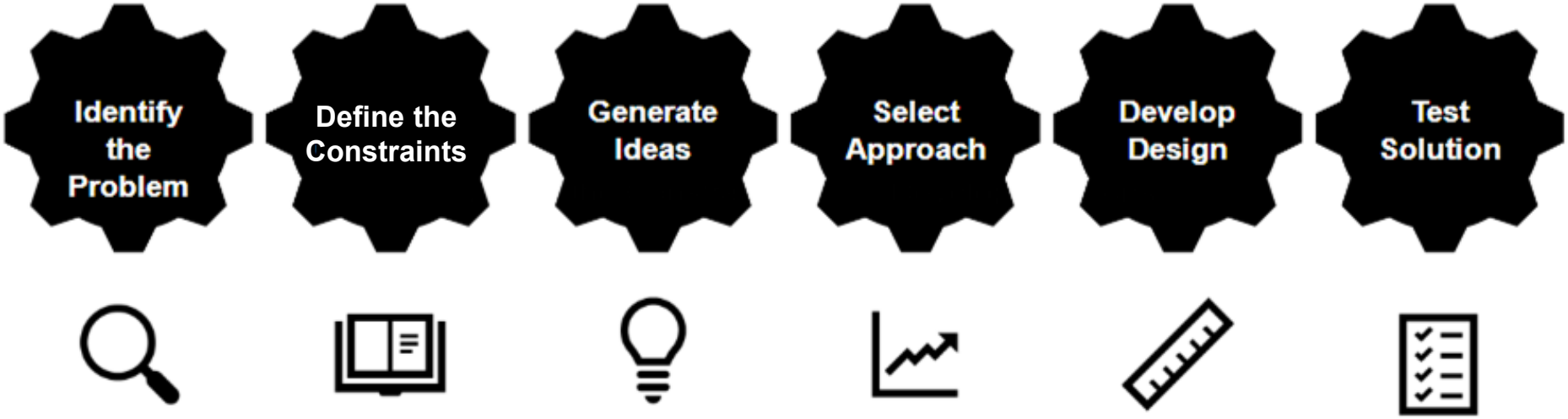
BME Design Process: How Biomedical Engineers Approach Problems



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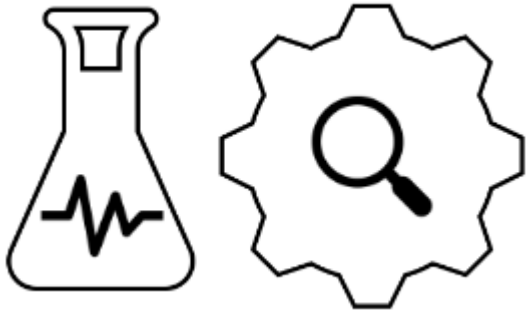
Identify the problem



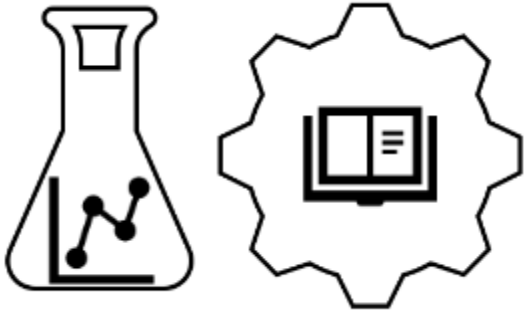
Engineering

- Identify the needs
- Create a problem statement
  - Who has the problem/need?
  - What is the problem/need?
  - Why is it important?

Medicine

- Identify the symptoms
- Utilize diagnostic tests and assessments to define the problem
  - Imaging tests
  - Physical exams
  - Patient histories

Define the constraints



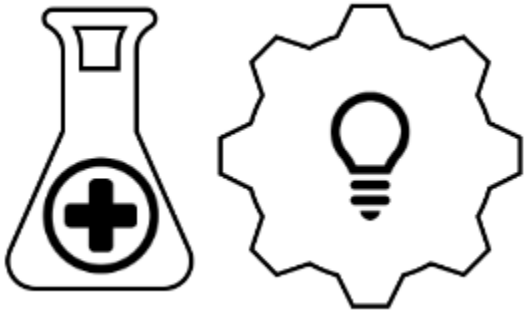
Engineering

- Describe conditions that must be met with design solution
- Limit design possibilities by excluding or requiring additional specifications
  - Cost
  - Size
  - Weight
  - Material

Medicine

- Describe conditions that must be met with treatment method
- Limit treatment options based on various factors
  - Cost
  - Time
  - Patient values
  - Medical expertise

Generate ideas



Engineering

- Brainstorm multiple solutions
- Study existing solutions
  - Identify aspects of existing solutions that can be utilized or improved
- Research

Medicine

- Consider alternative treatment methods
  - Surgery vs. medications
- Examine existing treatments
  - Determine current downfalls
- Research

Select approach

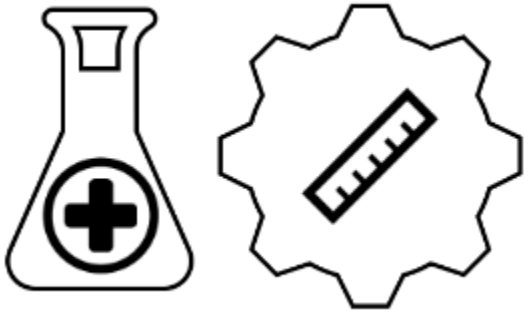
Engineering

- Describe advantages and disadvantages of all possible solutions
- Ensure that design criteria and constraints are satisfied
- Identify an optimal approach

Medicine

- Describe risks and benefits of each treatment option
- Ensure that treatment plan is appropriate for patient's diagnosis and prognosis
- Identify an optimal treatment plan

Develop design



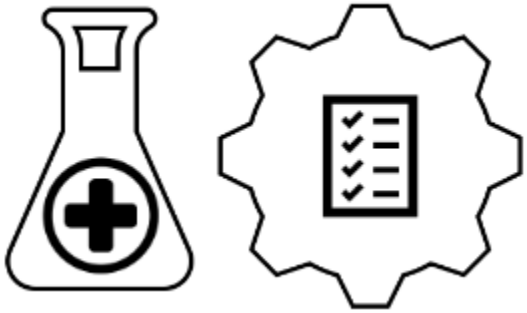
Engineering

- Refine approach based on problem specifics
- Establish design function and structure
  - Build prototype
  - Create simulations

Medicine

- Refine approach based on patient specifics
- Establish treatment component
  - Design device
  - Develop pharmaceutical

Test solution



Engineering

- Iterate design process to improve current work and identify any remaining flaws
- Continuously evaluate feedback and possible improvements or upgrades available for design

Medicine

- Clinical trials to identify any common flaws or dangers associated with a treatment
- Patient follow-ups post treatment to ensure successful individual therapy

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Ethics/Morals

From the *Biomedical Engineering Society (BMES) Code of Ethics*

Professional Obligations

- Use knowledge, skills, and abilities to enhance the safety, health, and welfare of the public
- Strive by action, example, and influence to increase the competence, prestige, and honor of the the BME profession

Health Care Obligations

- Regard responsibility toward and rights of patients, including those of confidentiality and privacy as their primary concern
- Consider the larger consequences of their work in regard to cost, availability, and delivery of healthcare

Ethics/Morals

Research Obligations

- Comply fully with legal, ethical, institutional, governmental, and other applicable research guidelines, respecting the rights of and exercising the responsibilities to colleagues, humans and animal subjects, and the scientific and general public
- Publish and/or present properly credited results of research accurately and clearly

Training Obligations

- Honor the responsibility not only to train BME students in proper professional conduction in performing research and publishing results, but also to model such conduct before them
- Keep training methods and content free from inappropriate influence from special interests

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