Biomedical Engineering: An Introduction

*Olivia Olshevski, Renee Morton, *Rosalyn Abbott*

The Body is the "Ultimate Machine" (Machine, Pump) [Slide 5]

You may not realize it, but your body is the most complex machine you'll ever use. With 650 skeletal muscles and 206 bones that control over 200 degrees of freedom, the human body far outpaces cars or even jet fighters in terms of complexity. These degrees of freedom are all of the factors that can influence how our bodies interact with the world around them, and each is important to proper everyday functioning. The human body is a marvel of engineering, with a design that is unmatched by anything we humans have built, produced, or manufactured to date.

Few machines are complete without a force generator, and neither is your body: the heart serves as a pump capable of circulating fluids throughout your body. This pump works nonstop, beating approximately once per second, every second, for around 80 years. That's about 2.5 billion beats! Your heart is capable of pumping quickly or slowly depending on your body's needs: while it can reach almost 200 beats per minute during intense exercise, it's also capable of dropping as low as around 40 beats per minute during moments of energy preservation. Interestingly, your heart is also able to look into the future: it can anticipate when you'll be active and speed up before you start moving in order to give you the fuel you need to accomplish the task at hand.

Image Citations

1. Dorrier, Jason. "If the Body Is a Machine, Can It Be Maintained Indefinitely?" *Singularity Hub*, Singularity Education Group, 3 Aug. 2014, https://singularityhub.com/2014/08/03/on-the-road-to-the-fountain-of-youth/.
2. Wapcaplet. "File:Diagram of the Human Heart (Cropped).Svg." *Wikimedia Commons*, 2 June 2006, https://commons.wikimedia.org/wiki/File:Diagram_of_the_human_heart_(cropped).svg.

The Body is the "Ultimate Machine" (Self-repair) [Slide 6]

But the body is more than just a functioning machine -- it's also capable of repairing itself, ensuring that this machine is always working optimally. For example, your skin cells have a lifespan of between 2-3 weeks, meaning that many cuts and injuries heal over time. Some cells really ramp up their healing rate, in order to make sure they get back to their job as quickly as possible. For example, colon cells have a lifespan of only 4 days, which allows them to work hard removing water, nutrients, and electrolytes from the foods you consume.

 Note: This educational resource was developed as a project by Carnegie Mellon student, Renee Morton, MS Biomedical Engineering 2020, for the course *Experiential Learning through Projects*, taught by Dr. Conrad Zapanta and Dr. Judith Hallinen in Summer 2020. Some slides were created by Dr. Rosalyn Abbott for the course *Introduction to Biomedical Engineering* at Carnegie Mellon University. The content was edited and additional content was added by Olivia Olshevski, MS Biomedical Engineering, 2021, for the course *Directed Study* during the fall of 2021, taught by Dr. Conrad Zapanta and co-advised by Dr. Judith Hallinen.

Citations links active as of December 2021.

Image Citation

1. InovaNewsroom. "Wound Healing Center at Inova Loudoun Treats Complex Wound and Ostomy Cases." *Inova Newsroom*, Inova Health System, 19 May 2017, https://www.inovanewsroom.org/ilh/2017/05/wound-healing-center-at-inova-loudoun-treats-complex-wound-and-ostomy-cases/.

The Body is the "Ultimate Machine" (Neurons) [Slide 7]

Your body is often intelligent, controlled by a brain with around 86 million neurons. Each of these neurons is capable of sending pulses of electricity to other neurons, and each neuron can receive information, integrate it, and send information to other neurons when conditions are right. In this way, your brain can establish a quick and efficient process for communicating with and understanding the world around you. On average, each neuron makes about 1000 connections with other neurons, meaning that you've got about 100 trillion connections in your brain right now. To put that into perspective, that's slightly more than the number of connections between all web pages currently on the internet. Talk about cramming lots of information into one small place!

Image Citation

1. Metcalfe, Tom. "This Is Your Brain, in Glorious Color." *NBCNews.com*, NBCUniversal News Group, 15 June 2021, https://www.nbcnews.com/science/science-news/brain-glorious-color-rcna1192.

The Body is the "Ultimate Machine" (Food) [Slide 8]

And as mentioned before, your body does all of this, using whatever food you decide to give it as fuel. While some food choices may be smarter than others, just about anything you ingest can be broken down and used to help support every activity you work on throughout the day. In particular, food can be broken down into proteins, polysaccharides, and lipids, which can themselves be broken down into amino acids, sugars, and fatty acids and glycerol, respectively. These smaller molecules ultimately generate the energy your body needs to keep up with everyday functions.

Image Citation

1. Inspiring. "Good and Bad Food. Thumbs Silhouette with Healthy and Junk Food." *Shutterstock*, Shutterstock, Inc., https://www.shutterstock.com/image-vector/good-bad-food-thumbs-silhouette-healthy-1069892234.

The Body is the "Ultimate Machine" (Sight, Smell) [Slide 9]

A big appeal of your body's machinery is its ability to sense the environment around it. Two of these senses are sight and smell, both of which give you a better understanding of your physical context. Your eyes are capable of detecting single photons of light, with 3 color sensitive photoreceptors that give you the ability to distinguish around 10 million different colors. Your eyes are also highly sensitive to changes in light across a wide sensitivity range, with the ability to dilate or constrict your pupils in order to control the amount of light that comes into your eye at any moment. This makes it possible for you to see both during the day and at night and is why the lights may seem a little weird when you come inside after recess - your pupils are changing size to better accommodate the lower light source after observing objects in the bright sunlight.

Your nose is also pretty impressive, as it can detect around 100 different chemical compounds that translate into about 10,000 different odors depending on the combination and concentration of these compounds.

Image Citations

1. Sudowoodo. "Senses Icon Set Stock Illustration." *IStock*, 17 Oct. 2017, https://www.istockphoto.com/vector/senses-icon-set-gm862112534-142884135.
2. "Full Visible Spectrum." *Orca Grow Film*, California Grow Films LLC, https://www.orcagrowfilm.com/Articles.asp?ID=145.
3. "Sense of Smell." *Nature Scent*, Nature Scent of the Ozarks Inc., 2018, https://naturescent.com/sense-of-smell/.

The Body is the "Ultimate Machine" (Hearing, Touch) [Slide 10]

Other important senses include your hearing and touch. Your ears serve to detect vibrations that move through the air at various magnitudes and frequencies: for example, you're able to hear sounds at both 20 Hz (the lowest pedal on a pipe organ) and 20,000 Hz (like the ringtone that only people under 20 can hear). More than hearing sounds, your ears are also able to track the effect of gravity and motion on your body via the fluid-filled loops in your inner ear. This makes your ears important not just for listening to the sounds around you but also for keeping yourself stable and balanced.

Your body is also embedded with pressure, vibration, and texture sensors over every square inch of skin. Thanks to these sensors, you can tell where your limbs are in space, detect the gravitational forces around you, and perceive even minute changes in temperature. Your body can even use these touch sensors to infer the passage of time, with stronger vibrations perceived as lasting longer than weaker ones.

Image Citations

1. Sudowoodo. “Senses Icon Set Stock Illustration.” *IStock*, 17 Oct. 2017, https://www.istockphoto.com/vector/senses-icon-set-gm862112534-142884135.
2. “Ears and hearing.” *DK Find Out!*, Dorling Kindersley Limited, 2021, https://www.dkfindout.com/us/human-body/senses/ears-and-hearing/.
3. Dragon Images, Dragon. “Female Hand Touching Prickly Cactus.” *Shutterstock*, Shutterstock, Inc., https://www.shutterstock.com/image-photo/female-hand-touching-prickly-cactus-260096384.

But it’s not perfect… [Slide 11]

However, for all of its benefits, there are some drawbacks to your body’s machinery -- mainly, that it will eventually break down. Sometimes, the source of the breakdown can be identified: viruses and bacteria can give us diseases that our bodies can’t quite repair, genetic mutations may provide too much or not enough of a protein needed for regulation of daily activities, and we may just injure ourselves when interacting with the world around us. Other times, breakdown is just a result of aging. For reasons that we don’t quite understand, the body gives up on repairing itself over time, and it's this cessation of activity that leads to physical problems, illness and death.

But that’s where biomedical engineers come in, to save the day!

Image Citations

1. Barreto, Daniela. “Set of Different Bacteria and Viruses, for Medical Info Graphics. Hand Drawn Line Art Cartoon Vector Illustration.” *Shutterstock*, Shutterstock, Inc., https://www.shutterstock.com/image-vector/set-different-bacteria-viruses-medical-info-560228722.
2. Cluett, Jonathan. “Materials Used to Make a Cast.” *Verywell Health*, Verywell Health, 7 June 2020, https://www.verywellhealth.com/what-is-a-cast-for-broken-bones-made-out-of-2549317.
3. Smith, Irene. “Massage Therapy's Role in the Growing Hospice Movement.” *MASSAGE Magazine*, 12 Oct. 2016, https://www.massagemag.com/massage-therapys-role-in-the-growing-hospice-movement-40833/.
4. Genome Research Limited. “What Types of Mutation Are There?” *Your Genome*, https://www.yourgenome.org/facts/what-types-of-mutation-are-there.

What is biomedical engineering? [Slide 12]

So what is biomedical engineering? While many definitions exist, they all boil down to the application of engineering principles to medicine and biology in order to further someone’s health. By studying our biological systems and either improving or recreating them, biomedical engineers try to keep people healthier for longer. Depending on the context, the field of biomedical engineering may also be referred to simply as bioengineering: in both cases, we're applying biology to medicine from an engineering perspective.

Image Citation

1. bsd555. "Biomedical Engineering Word Concepts Banner." *IStock*, Getty Images, 23 Apr. 2020, https://www.istockphoto.com/vector/biomedical-engineering-word-concepts-banner-biotechnology-for-health-healthcare-gm1220302093-357262972.

BME = Medicine + Engineering [Slide 13]

Put simply, biomedical engineering is the combination of medicine and engineering. Both of these fields are focused on problems and solutions related to health, with medicine centered around diagnosis (identifying the issue and cause at hand), prognosis (describing the likely progression of the issue), treatment (providing a solution to counter the problem), and prevention (introducing new technology to detect and prevent issues from arising). While specific to the health field, these pillars of medicine are related to the engineering design process which features six steps that together identify the problem and systematically develop a solution. Biomedical engineering focuses on this overlap to provide *engineering* solutions to *medical* problems.

If we compare the fields of medicine and engineering, we see that the difference between a doctor and an engineer is primarily the scale and outlook of the problem. While doctors use the design process to treat an illness or injury, engineers use the design process to improve all aspects of medicine. Biomedical engineering applies engineering concepts to the field of medicine; however, their roles go beyond the treatment of an individual patient. While a doctor utilizes the engineering design process for the treatment of an illness or injury, a biomedical engineer can use the engineering design process to improve all four pillars of medicine. This involves the diagnosis, prognosis, treatment, and prevention stages.

Image Citation

1. "10 Science Clipart Images." *KindPNG.com*, Shenzhen BestAI Internet Co., https://www.kindpng.com/imgv/TwxRmxx_10-science-clipart-images-download-for-free-hd/.
2. "Bot Gears - Mechanical Engineering Clipart." *PngKit.com*, https://www.pngkit.com/view/u2q8a9q8w7o0u2e6_bot-gears-mechanical-engineering-clipart/.

Historical Perspective [Slide 14]

In terms of STEM, biomedical engineering is one of the more recent disciplines; in fact, it is the only engineering discipline that developed after the Second World War. With that said, innovation within the field has been rapid, and this slide lists only some of the most important biomedical contributions. For example, in 1943, German medical student Willem Kolff created the first artificial kidney dialysis machine, which helps filter and clean your blood after kidney failure. Later in the 40s and into the 50s, the first polio vaccine was created by American physician Jonas Salk. This vaccine was incredibly important, as increasingly severe polio outbreaks were affecting both Europe and the United States in the early 1900s, causing paralysis to many of the individuals contracting the virus. This vaccine brought the incidence of polio down from 13.9 cases per 100,000 to less than 0.8 within 6 years of its widespread adaptation. The 1950s also saw the creation of the first artificial heart valve by Charles A. Hufnagel, which can be implanted to replace failed heart valves and helps keep blood flowing properly through the heart. In the late 1950s, the biomedical engineering field also saw the development of the first external cardiac pacemaker, which uses electrodes to help the heart contract at the right heart rate. This ensures that the right cardiac output is maintained.

Content Citation

1. "History." *Navigate the Circuit*, American Institute for Medical and Biological Engineering (AIMBE), https://navigate.aimbe.org/why-bioengineering/history/.
2. Baicus, Anda. "History of polio vaccination." *World journal of virology* vol. 1,4 (2012): 108-14. doi:10.5501/wjv.v1.i4.108.

Image Citations

1. "End Chronic Kidney Disease Neglect." *Nature*, Springer Nature Limited, 11 Mar. 2020, https://www.nature.com/articles/d41586-020-00691-4.
2. Turina, Marko. "File:First Pacemaker (Siemens-Elema 1958).Jpg." *Wikimedia Commons*, University Hospital, Zurich, 9 Apr. 2009, https://commons.wikimedia.org/wiki/File:First_pacemaker_(Siemens-Elema_1958).jpg.
3. Hawk, Alan. "File:Hufnagel Heart Valve15111214-Photos 309.Jpg." *Wikimedia Commons*, 23 Aug. 2010, https://commons.wikimedia.org/wiki/File:Hufnagel_heart_Valve15111214-photos_309.jpg.
4. Davis, Charles Patrick. "What Is Polio? Symptoms and Vaccine." Edited by Jerry R Balentine, *MedicineNet*, WebMD, https://www.medicinenet.com/polio_facts/article.htm.

Historical Perspective, Continued [Slide 15]

While biomedical engineering was established as a professional field in the 1940s, it entered the academic world in the late 1960s, with the first biomedical engineering departments appearing in colleges such as the University of Virginia, Case Western Reserve University, Johns Hopkins, and Duke. With academic training, innovations continued to soar, and by the 1970s, a big focus was placed on recombinant DNA technology. During this time period, recombinant DNA molecules were first created by joining DNA from different species and inserting them into a host cell. This allowed scientists to introduce new genetic combinations to the host which helped in science, medicine, agriculture, and industry. A final big shift was seen in the late 20th century, when the international community set the goal of fully sequencing human DNA through a project called the Human Genome Project. During this time, numerous scientists and research facilities identified, mapped, and determined the base pairs of all of the genes within the human genome. While the project was created in 1990, the full genome wasn't completed until May of 2021 (although the project was "completed" in April of 2003). The Human Genome Project has been the largest collaborative effort within the biological field to date and illustrates just how important teamwork is within the sciences.

Content Citations

1. "History." *Navigate the Circuit*, American Institute for Medical and Biological Engineering (AIMBE), https://navigate.aimbe.org/why-bioengineering/history/.
2. "1972: First Recombinant DNA." *Genome.gov*, National Human Genome Research Institute, 26 Apr. 2013, https://www.genome.gov/25520302/online-education-kit-1972-first-recombinant-dna#:~:text=The%20first%20production%20of%20recombinant,host%20cell%2C%20often%20a%20bacterium.

Image Citations

1. U.S. Department of Energy, Human Genome Project. "File:Logo HGP.jpg." Wikimedia *Commons*, 19 June 2006, https://commons.wikimedia.org/wiki/File:Logo_HGP.jpg.
2. Designua. "Plasmid and Recombinant DNA. Bacterial DNA in Which a Foreign DNA Fragment Is Inserted into a Plasmid Vector. ." *Shutterstock*, Shutterstock, Inc., https://www.shutterstock.com/image-vector/plasmid-recombinant-dna-bacterial-which-foreign-794366641.

What do biomedical engineers do? BME Focus Areas [Slide 16]

The field of medicine is big, so it follows that the field of biomedical engineering is also big. With such complex machinery, your body can fail in a number of ways, and each of these failures requires a different solution. To narrow the scope, BME is often split into focus areas. Example focus areas (and the ones that Carnegie Mellon University faculty tend to focus on) are biomechanics, biomaterials & tissue engineering, biomedical devices, machine learning & bioinformatics, bioimaging & signal processing, cellular & molecular biotechnology, and neuroengineering. While these focus areas can be useful for identifying specific parts of the field that you're interested in, any one BME solution often incorporates techniques from multiple focus areas. Don't be surprised if more than one of these fields sounds interesting to you; BME is notoriously multidisciplinary, with lots of passionate people coming together to improve health.

Image Citations

1. Borelli, Giovanni Alfonso. "File:Giovanni Borelli - Lim Joints (De Motu Animalium).Jpg." *Wikimedia Commons*, 1 Jan. 1980, https://commons.wikimedia.org/wiki/File:Giovanni_Borelli_-_lim_joints_(De_Motu_Animalium).jpg.
2. Kandola, Aaron. "What to Know about Heart Pacemakers." *Medical News Today*, Healthline Media, 11 Mar. 2019, https://www.medicalnewstoday.com/articles/324662#outlook.
3. Tontonoz Wednesday, Matthew. "Genetic 'Scars' Provide Clues for Tailoring Cancer Treatment." *Memorial Sloan Kettering Cancer Center*, Memorial Sloan Kettering Cancer Center, 11 Oct. 2017, https://www.mskcc.org/news/genetic-scars-provide-clues-tailoring-cancer-treatment.
4. Vision Online Marketing Team. "UC Berkeley Announces Advanced Bioimaging Center, Aims to Promote Imaging Technology in Life Sciences." *Automate*, A3 Association for Advancing Automation, 31 Mar. 2020, https://www.automate.org/blogs/uc-berkeley-announces-advanced-bioimaging-center-aims-to-promote-imaging-technology-in-life-sciences.
5. Market Research Future. "Tissue Engineering Market to Garner USD 53,424.00 Million by 2024, with a CAGR of 17.84% ." *Medgadget*, Medgadget, Inc., 20 June 2019, https://www.medgadget.com/2019/06/tissue-engineering-market-to-garner-usd-53424-00-million-by-2024-with-a-cagr-of-17-84-global-industry-size-share-new-technology-trends-business-growth-opportunities.html.

Focus Area: Biomechanics [Slide 17]

Biomechanics is focused on the mechanics of living structures. In this field, students will primarily study the mechanical properties of tissues, both on the macro and microscopic levels. Common classes in this area include micromechanics, solid mechanics, viscoelasticity, fluid mechanics, and the study of entropy, diffusion, and osmosis in force generation.

Image Citations

1. "Biomechanics." McCormick School of Engineering, Northwestern University, https://www.mccormick.northwestern.edu/biomedical/research/areas/biomechanics.html.
2. Goldin, Ian, and Chris Kutarna. "Our Michelangelo Moment: How to Protect the Legacy of Our Own Renaissance." *The Irish Times*, The Irish Times, 3 June 2016, https://www.irishtimes.com/culture/books/our-michelangelo-moment-how-to-protect-the-legacy-of-our-own-renaissance-1.2671635.

Applications: Biomechanics [Slide 18]

Biomechanics has several applications to the medical field. For example, biomechanics is responsible for learning how the cardiovascular system pumps fluid through your body, as well as understanding the mechanics of cells and biological materials. Biomechanics may also look at the way different biological solids and fluids act when under stress.

Image Citations

1. "Studying Blood Flow Dynamics to Identify the Heart of Vessel Failure." *DAIC*, Diagnostic and Interventional Cardiology, 16 Aug. 2016, https://www.dicardiology.com/content/studying-blood-flow-dynamics-identify-heart-vessel-failure.
2. Arizona State University. "New Study Explores Cell Mechanics at Work." *Phys.org*, Science X, 19 June 2018, https://phys.org/news/2018-06-explores-cell-mechanics.html.
3. Sasaki, Naoki. "Viscoelastic Properties of Biological Materials." *IntechOpen*, IntechOpen, 7 Nov. 2012, https://www.intechopen.com/chapters/40738.

Focus Area: Biomaterials and Tissue Engineering [Slide 19]

Biomaterials and tissue engineering is the area of study that creates man-made materials for medical treatment and produces living functional tissue. These materials and tissues can be used both as disease models and as replacements for damaged tissue in the body. A biomedical engineer focuses on biomaterials and tissue engineering is likely to study the interactions between materials, cells, and tissues and how these interactions can affect both the body and the materials involved. They also study the major responses of the body, including wound healing, the immune response, and the foreign body response; all of these can help you determine how to best design a material depending on how it needs to be incorporated into the body. Biomaterials engineers also characterize different types of biomaterials, such as metals, ceramics and polymers, and natural and synthetic materials. Finally, they are likely to spend time culturing cells and determining the biocompatibility of a material.

Content Citation

1. Kasemo, Bengt. "Biomaterials vs Tissue Engineering - What Is the Difference?" *Biolin Scientific*, Biolin Scientific, 5 May 2020, https://www.biolinscientific.com/blog/biomaterials-vs-tissue-engineering-what-is-the-difference.

Image Citations

1. Science Museum, London. "Hip Joint Replacement, United States, 1998." *Wellcome Collection*, Wellcome Collection, https://wellcomecollection.org/works/fpnvsmum.

2. Zia, Sonia & Mozafari, Masoud & G., Natasha & Tan, Aaron & Cui, Zhanfeng & Seifalian, Alexander. (2015). Hearts beating through decellularized scaffolds: whole-organ engineering for cardiac regeneration and transplantation. Critical reviews in biotechnology. 36. 1-11. 10.3109/07388551.2015.1007495.
3. "Bioprinting." *Advanced BioMatrix*, Advanced BioMatrix, https://advancedbiomatrix.com/bioprinting/.

Applications: Biomaterials and Tissue Engineering [Slide 20]

Applications of this focus area include the development of artificial organs and bioscaffolds, and improving the wound healing process. Researchers in this area may also create collagen substitutes or study how implants fail and how materials react in different environments.

Image Citations

1. Business Industry Reports. "Outstanding Growth of Artificial Organs Market Is Estimated to Reach US$ 25030 Million by 2023." *OpenPR.com*, OpenPR, 6 Dec. 2019, https://www.openpr.com/news/1876594/outstanding-growth-of-artificial-organs-market-is-estimated.
2. Whelan D, Caplice NM, Clover AJ. Fibrin as a delivery system in wound healing tissue engineering applications. *J Control Release*. 2014;196:1-8. doi:10.1016/j.jconrel.2014.09.023.
3. Max Planck- Gesselschaft. "Scientists Use Silk from the Tasar Silkworm as a Scaffold for Heart Tissue." *Phys.org*, Science X, 30 Jan. 2012, https://phys.org/news/2012-01-scientists-silk-tasar-silkworm-scaffold.html.

Focus Areas: Biomedical Devices [Slide 21]

Another focus area is biomedical devices, which creates the instruments, machines, implants, and other tools needed for the prevention, diagnosis, treatment, and rehabilitation of illness and disease for humans. Experts in this field learn how to use various research instruments, particularly for taking accurate images and measurements. They focus on the difference between diagnostic and therapeutic devices, depending on whether you're helping to identify a disease or get better from it. These experts also learn how to fabricate these devices and look into how the devices will interact with cells, tissues, and organs. Finally, they must consider how to combine multiple systems together into a single device. Common applications include the creation of sensors and actuators, as well as both diagnostic and therapeutic devices.

Content Citation

1. Lam R.H.W., Chen W. (2019) Introduction to Biomedical Devices. In: Biomedical Devices. Springer, Cham. https://doi.org/10.1007/978-3-030-24237-4_1.

Image Citations

1. Foran, Jared R.H., and Michael B. Cross. "Revision Total Knee Replacement - Orthoinfo - Aaos." *OrthoInfo*, American Academy of Orthopaedic Surgeons, May 2021, https://orthoinfo.aaos.org/en/treatment/revision-total-knee-replacement/.
2. "Mechanical Prosthesis." *CThSurgery.com*, Cardiothoracic Surgery, https://www.cthsurgery.com/mechanical-prosthesis.html.
3. "First Insulin Pump That Acts like an Artificial Pancreas Launched for People with Type 1 Diabetes." *Diabetes Research & Wellness Foundation*, Diabetes Research & Wellness Foundation, 16 Apr. 2015, https://www.drwf.org.uk/news-and-events/news/first-insulin-pump-acts-artificial-pancreas-launched-people-type-1-diabetes.
4. Biggers, Alana. "What Is Dialysis, and How Can It Help?" *Medical News Today*, MediLexicon International, 17 July 2018, https://www.medicalnewstoday.com/articles/152902.
5. "X-Ray Machine." *CGAxis*, CGAxis, https://cgaxis.com/product/x-ray-machine/.

Applications: Biomedical Devices [Slide 22]

This focus area is responsible for the development of new medical instruments and systems, as well as the software behind each of the devices. As seen in the pictures, some well-known biomedical devices include artificial heart values, insulin pumps, imaging machines, joint replacements, and dialysis machines.

Image Citations

1. Aliverti, Andrea. (2017). Wearable technology: Role in respiratory health and disease. Breathe. 13. e27-e36. 10.1183/20734735.008417.
2. *Model 7800*, Ivy Biomedical Systems, https://www.ivybiomedical.com/model-7800.html.
3. Hemalatha, R.J., et al. "Biomedical Instrument and Automation: Automatic Instrumentation in Biomedical Engineering." *Handbook of Data Science Approaches for Biomedical Engineering*, 2020, pp. 69–101., https://doi.org/10.1016/b978-0-12-818318-2.00003-9.
4. Gordon, W.J., Stern, A.D. Challenges and opportunities in software-driven medical devices. *Nat Biomed Eng* 3, 493–497 (2019). https://doi.org/10.1038/s41551-019-0426-z.

Focus Area: Bioimaging and Signal Processing [Slide 23]

Bioimaging and Signal Processing study the methods and instruments that we use to acquire, process, and visualize both structural and functional images of living objects or systems both in space and in time. These engineers study different types and methods of medical imaging, as well as how to process and interpret the signals received from the body. They analyze the images you obtain, as well as the electrical signals from both the brain and heart.

Content Citation

1. "BioImaging." *Georgia Tech: Bioengineering Interdisciplinary Graduate Program*, Parker H Petit Institute for Bioengineering & Bioscience, https://bioengineering.gatech.edu/node/5335#:~:text=Bioimaging%20refers%20to%20methods%20and,used%20visualize%20fixed%20biological%20samples.

Image Citations

1. "Brain-Computer Interfaces and Neural Engineering." *University of Essex*, University of Essex, https://www.essex.ac.uk/departments/computer-science-and-electronic-engineering/research/brain-computer-interfaces-and-neural-engineering.
2. Mayo Clinic Staff. "Fetal Ultrasound." *Mayo Clinic*, Mayo Foundation for Medical Education and Research, https://www.mayoclinic.org/tests-procedures/fetal-ultrasound/about/pac-20394149.
3. "Rhythm Recognition." *ACLS Medical Training*, ACLS Medical Training, https://www.aclsmedicaltraining.com/rhythm-recognition/.

Applications: Bioimaging and Signal Processing [Slide 24]

Common applications of bioimaging and signal processing include electrocardiograms (which characterize your heart beat over time), imaging modalities (such as x-ray, ultrasound, CT, PET, or MRI scans), and looking at both neuron and heart functions in the body. There are also applications in identifying different imaging qualities, such as the contrast, signal, and spatial resolution of an image.

Image Citations

1. "Rhythm Recognition." *ACLS Medical Training*, ACLS Medical Training, https://www.aclsmedicaltraining.com/rhythm-recognition/.
2. Pamies, Pep. "Ultrafast Ultrasound Microscopy of Deep Brain Vessels." *Nature News*, Nature Publishing Group, 16 Mar. 2021, https://bioengineeringcommunity.nature.com/documents/mar-21.
3. Mikhael, Alexandra, and Christian Nasr. "Chest X-Ray Prior to Thyroidectomy: Is It Really Needed?" *Consult QD*, Cleveland Clinic, 16 Apr. 2018, https://consultqd.clevelandclinic.org/chest-x-ray-prior-to-thyroidectomy-is-it-really-needed/.
4. "Signal-to-Noise Ratio (SNR) and Image Quality." *MRIMaster*, MRIMaster, https://mrimaster.com/technique%20SNR.html.

Focus Area: Cellular and Molecular Biotechnology [Slide 25]

Cellular and molecular biotechnology focuses on the practical application of both cellular and molecular knowledge, and aims to enhance and improve the production of cells and molecules in both cell cultures and microorganisms. These researchers study biological regulation at the body, organ, and system level. They must learn how to culture cells to create different cell types, as well as seeing how changing different culture conditions influences the size and shape of the cells that grow. They may also look into the impacts of genetics on cell development, as well as the diffusion, transport, and delivery of cells and molecules to the body for different medications.

Content Citation

1. "Specialisation Cellular and Molecular Biotechnology." *WUR*, Wageningen University & Research, https://www.wur.nl/en/education-programmes/master/msc-programmes/msc-biotechnology/specialisations-of-biotechnology/cellular-and-molecular-biotechnology.htm#:~:text=Focus%20on%20the%20practical%20application,micro%2Dorganisms%20or%20cell%20cultures.

Image Citations

1. "Pharma Fermenters." *GEA*, GEA Group, https://www.gea.com/en/products/distillation-fermentation/fermenters/pharma-fermenters.jsp.
2. "What Is Plasmid Design?" *GenoFAB*, GenoFAB, 22 Aug. 2019, https://blog.genofab.com/plasmid-design.
3. nextmsc. "Microfluidics Market Research Report and Forecast 2021." *The Manomet Current*, The Manomet Current, 29 June 2021, https://manometcurrent.com/microfluidics-market-research-report-and-forecast-2021-fluidigm-corporation-agilent-technologies-bio-rad-laboratories-inc/.
4. Center for Biologics Evaluation and Research. "Vaccines." *FDA*, U.S. Food and Drug Administration, 27 Jan. 2021, https://www.fda.gov/vaccines-blood-biologics/vaccines.

Applications: Cellular and Molecular Biotechnology [Slide 26]

Common applications of this field include the manufacturing of proteins and viruses, as well as the development of pharmaceuticals. Cellular and molecular biotechnology has an influence on the study of genetic engineering to help create vaccines, bioreactors, and microfluidic devices.

Image Citations

1. Douglass, Eugene, and Chad Miller. "Binding #2: The Michaelis-Menton Equation." *Practically Science*, Practically Science, 18 May 2014, https://www.practicallyscience.com/binding-kinetics-101-2-the-michaelis-menton-equation/.
2. "What Can I Do with a Pharmaceutical Sciences Major?" *UCI School of Pharmacy and Pharmaceutical Sciences*, UCI School of Pharmacy and Pharmaceutical Sciences, 11 Aug. 2020, https://pharmsci.uci.edu/can-pharmaceutical-sciences-major/.

3. Lee, Esther J., et al. “Adeno-Associated Virus (AAV) Vectors: Rational Design Strategies for Capsid Engineering.” *Current Opinion in Biomedical Engineering*, vol. 7, Sept. 2018, pp. 58–63., https://doi.org/10.1016/j.cobme.2018.09.004.

Focus Area: Neuroengineering [Slide 27]

Finally, neuroengineering uses engineering technology to study the function of various neural systems. Neuroengineers learn different neuroimaging techniques in order to best visualize what’s going in the brain. They must understand the anatomy of the brain, both on the tissue and neuron level. Because brain activity is dependent on electrical activity, neuroengineers become more familiar with the action potentials to make it possible for brain cells to communicate with one another, and they also learn how to influence the nervous system to produce desired changes.

Content Citation

1. “Neuroengineering.” *College of Engineering - University of Wisconsin-Madison*, University of Wisconsin-Madison, https://www.engr.wisc.edu/department/biomedical-engineering/research/neuroengineering/.

Image Citations

1. Stone, Mark. “UW Bioengineering Advances Solutions to Neural Engineering Challenges with New Research Area.” *UW Bioengineering | University of Washington Department of Bioengineering*, Center for Sensorimotor Neural Engineering, 26 Oct. 2020, https://bioe.uw.edu/announcing-neural-engineering/.
2. “Cochlear Implant Surgery.” *Johns Hopkins Medicine*, The Johns Hopkins University, The Johns Hopkins Hospital, and Johns Hopkins Health System, https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/cochlear-implant-surgery.
3. Greenemeier , L. FDA Approves First Retinal Implant. *Nature* (2013). https://doi.org/10.1038/nature.2013.12439.

Applications: Neuroengineering [Slide 28]

Applications of neuroengineering include the creation of implantable technology and materials, as well as the development of neural prosthetic devices. Such devices include cochlear or vestibular implants (in the ear), retinal implants (in the eye), the restoration of touch, bladder or bowel control, and brain-computer interfaces that make it possible for engineers to interact directly with the brain. Sensor and motor prosthetic devices may also be developed.

Image Citations

1. Imran, Alishba. “Robotic Hand That Can See for Itself.” *The Knowledge Society*, TKS, https://tks.world/artificial-intelligence/robotic-hand-that-can-see-for-itself/.

2. Graczyk EL, Schiefer MA, Saal HP, Delhaye BP, Bensmaia SJ, Tyler DJ. The neural basis of perceived intensity in natural and artificial touch. *Sci Transl Med*. 2016;8(362):362ra142. doi:10.1126/scitranslmed.aaf5187.
3. Willett, F.R., Avansino, D.T., Hochberg, L.R. et al. High-performance brain-to-text communication via handwriting. *Nature* 593, 249–254 (2021). https://doi.org/10.1038/s41586-021-03506-2.

BME Design Process: How Biomedical Engineers Approach Problems [Slide 29]

As previously mentioned, the BME design process consists of 6 big steps. First, engineers identify the problem. Then they define the constraints of the problem so that they develop an idea of the exact criteria that need to be met. From there, engineers generate potential ideas for solutions: at this step, no solution is too goofy, and brainstorm sessions become second-nature. Once the main solution idea is selected, the engineers choose the best approach for creating the solution. With the approaches identified, engineers then set out to develop a design that addresses the problem at hand. Finally, they test the solution to ensure that their device actually does what it is advertised to do. Together, these steps give an outline for approaching (and hopefully solving) the medical problems that biomedical engineers are introduced to.

Identify the Problem [Slide 30]

The first step in the problem-solving process is to solve the problem. The engineering step relates to the diagnostic process in medicine, used by doctors to identify the symptoms. To determine the issue at hand, medical professionals may utilize diagnostic tests and assessments to define the problem: for example, imaging tests, physical exams, and patient histories. However, as a biomedical engineer, this engineering step can also apply to the other pillars of medicine. There could be issues with diagnostic machines, prognostic abilities, preventative measures, or treatment options. Identifying areas of improvement anywhere in the field of medicine can fall within this engineering step. Biomedical engineers create a problem statement by asking questions about the specific needs. For example, who has the problem? What is the problem? And why is it important?

Define the Constraints [Slide 31]

The second step is to define the constraints. For engineers, constraints for design are often based on physical limitations of the solution, such as cost, size, weight or material specifications. These constraints describe the conditions that must be met by the design in order to provide an adequate solution. For doctors, medical constraints are often involved in the prognosis (or progression) of a disease given that they determine whether a treatment option is appropriate. Limiting factors here may include cost, time, patient values, or medical expertise. Here, the constraints describe conditions that must be met by the treatment method in order to provide an adequate response to the health problem.

Generate Ideas [Slide 32]

Next up in the process is idea generation, which prevents people from zeroing in on one possibility and failing to consider other options. In engineering, this usually includes brainstorming multiple solutions, studying existing solutions (particularly to see where improvements can be made), and performing more research about the problem's context. In medicine, this includes considering all treatment methods, including surgery, medication, and potential alternative methods. Medical professionals also look at existing treatments in order to identify any drawbacks and perform research on both the identified problem and associated difficulties. In diagnostic cases, idea generation may refer to the diagnostic process, which requires that medical professionals consider multiple illnesses or injuries that might lead to similar problems.

Select Approach [Slide 33]

Once ideas have been generated, it's time to select an optimal approach. For both engineering and medicine, this selection process involves weighing the pros and cons of each option. For engineering, the design criteria and constraints are prioritized; for medicine, the patient diagnosis, prognosis, and treatment plan are centered. In medical treatments, this process may also include a risk-benefit analysis to help guide the patient's decision; in medical diagnostics, tests may be used to rule out various options and to identify the most likely cause of the problem.

Develop Design [Slide 34]

With an approach selected, the design can now be executed. For engineering, this involves matching up the approach methods with the specifics of the problem and establishing both the function and structure of the design. During this step, many prototypes or simulations are created, with each iteration providing valuable information to the engineers. For medicine, patient specifics are revisited in order to ensure the approach is best tailored to the individual's needs. In some cases, treatments must be personalized for different patients; in others, a standardized approach is used. The treatment is then developed, often in the form of either a device or a pharmaceutical.

Test Solution [Slide 35]

Now that the solution has been designed, it must undergo testing to ensure that it is appropriate for the problem statement and meets the required specifications and constraints. This testing--or validation-- process is often iterative for engineers, with each new prototype or product iteration improving on previous work and highlighting any flaws that remain. This process is also evaluation-heavy, with feedback (from testers or research results) considered. Finally, engineers may wish to stay up-to-date on current literature for relevant subfields, as there may be possible improvements or upgrades available for the design. For medicine, this testing process may entail clinical trials (which help identify flaws or dangers associated with the treatment) and patient follow ups (to ensure that the administered therapy was and remains to be successful).

Ethics/Morals (Professional, Health Care) [Slide 36]

Because of their roles in medical innovation, biomedical engineers have established their own list of morals and ethics. By defining exactly what biomedical engineers should and shouldn't do when working in the healthcare sector and identifying their primary goals and responsibilities, they are able to better understand the role that biomedical engineers will have in current and future medical innovations.

The Biomedical Engineering Society (BMES) created a Code of Ethics that lists a biomedical engineer's obligations to the professional, health care, research, and training fields. For example, an engineer's professional obligations are focused primarily on enhancing public safety, health, and welfare. Approaching an engineering problem with these three values, biomedical engineers can ensure that they remain positive contributors to every problem they face. Similar to medical codes of ethic such as the Hippocratic oath, a biomedical engineer's health care obligations are centered around taking responsibility for and prioritizing the rights of the patients, especially surrounding confidentiality and privacy. This ensures that both patients and health care professionals are comfortable working with biomedical engineers. Additionally, engineers have an obligation to consider how decisions around cost, availability, and delivery of healthcare may impact the medical field. By remembering that their contributions should be primarily benefiting patients, engineers can make informed decisions throughout the design process.

Content Citation

1. "Biomedical Engineering Society Code of Ethics - BMES." *BMES*, Biomedical Engineering Society, Feb. 2004, https://www.bmes.org/files/CodeEthics04.pdf.
2. Saha, S, and P S Saha. "Biomedical ethics and the biomedical engineer: a review." *Critical reviews in biomedical engineering* vol. 25,2 (1997): 163-201.

Ethics/Morals (Research, Training) [Slide 37]

Biomedical engineering revolves around research: almost every recent biomedical innovation has included research, either into new materials and technologies or current markets and clinical trials. Therefore, biomedical engineers are expected to follow and respect all research guidelines, especially those which keep colleagues, humans, animal subjects, and both the scientific and general public safe. They also have an obligation to be accurate and clear when publishing their results, which supports better and easier communication throughout the field.

Finally, biomedical engineers have training obligations, in order to ensure that future generations of biomedical engineers maintain the prestige and honor of the field. Therefore, incoming engineers must be trained on proper research and publishing etiquette and must be provided with positive role models who understand and follow these same rules. Finally, biomedical engineers must be trained and brought into the field in a way that excludes special interests. This ensures that the field remains unbiased and focused on the most pressing public health issues of the time.

Content Citation

1. "Biomedical Engineering Society Code of Ethics - BMES." *BMES*, Biomedical Engineering Society, Feb. 2004, https://www.bmes.org/files/CodeEthics04.pdf.
2. Saha, S, and P S Saha. "Biomedical ethics and the biomedical engineer: a review." *Critical reviews in biomedical engineering* vol. 25,2 (1997): 163-201.

Image Citation

1. "File:Scales of Justice.svg." *Wikipedia*, Wikimedia Foundation, 29 Sept. 2020, https://en.wikipedia.org/wiki/File:Scales_Of_Justice.svg.