



Engineering in Medicine & Biology

Designing a Career in Biomedical Engineering



Robot-assisted surgery. Photo courtesy The Acrobot Company, Ltd. (www.acrobot.co.uk)



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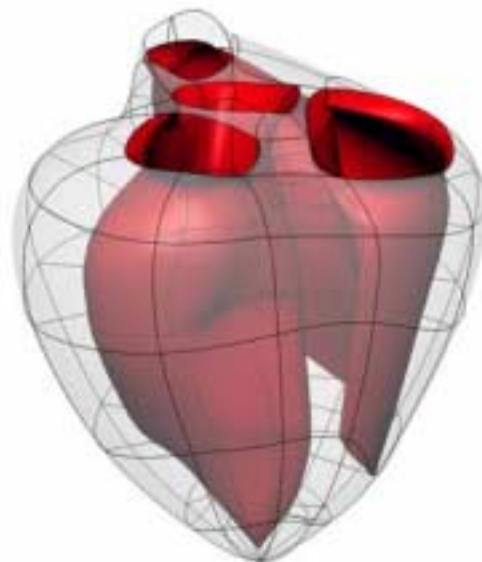
Is biomedical engineering right for you?

What kind of career do you imagine for yourself? Doctor? Lawyer? Scientist? Engineer? Teacher? CEO? Manager? Salesperson?

A university degree in biomedical engineering will prepare you for *all* of these professions and more. Biomedical engineers use their expertise in biology, medicine, physics, mathematics, engineering science and communication to make the world a healthier place. The challenges created by the diversity and complexity of living systems require creative, knowledgeable, and imaginative people working in teams of physicians, scientists, engineers, and even business folk to monitor, restore and enhance normal body function. The biomedical engineer is ideally trained to work at the intersection of science, medicine and mathematics to solve biological and medical problems.

What do biomedical engineers do?

Perhaps a simpler question to answer is *what don't biomedical engineers do?* Biomedical engineers work in industry, academic institutions, hospitals and government agencies. Biomedical engineers may spend their days designing electrical circuits and computer software for medical instrumentation. These instruments may range from large imaging systems such as conventional x-ray, computerized tomography (a sort of computer-enhanced three-dimensional x-ray) and magnetic resonance imaging, to small implantable devices, such as pacemakers, cochlear implants and drug infusion pumps. Biomedical engineers may use chemistry,



Bioengineers help translate human organs such as the heart into thousands of mathematical equations and millions of data points which then run as computer simulations. The result is a visual simulation that looks and behaves much like the real heart it mimics. Image courtesy Peter Hunter, Bioengineering Institute, Auckland, New Zealand.



Wearable computers can play a role in making health care delivery possible for anyone, anyplace, anytime. Photo courtesy Faustina Hwang.

physics, mathematical models and computer simulation to develop new drug therapy. Indeed a considerable number of the advances in understanding how the body functions and how biological systems work have been made by biomedical engineers. They may use mathematical models and statistics to study many of the signals generated by organs such as the brain, heart and skeletal muscle. Some biomedical engineers build artificial organs, limbs, knees, hips, heart valves and dental implants to replace lost func-

tion; others are growing living tissues to replace failing organs. The development of artificial body parts requires that biomedical engineers use chemistry and physics to develop durable materials that are compatible with a biological environment.

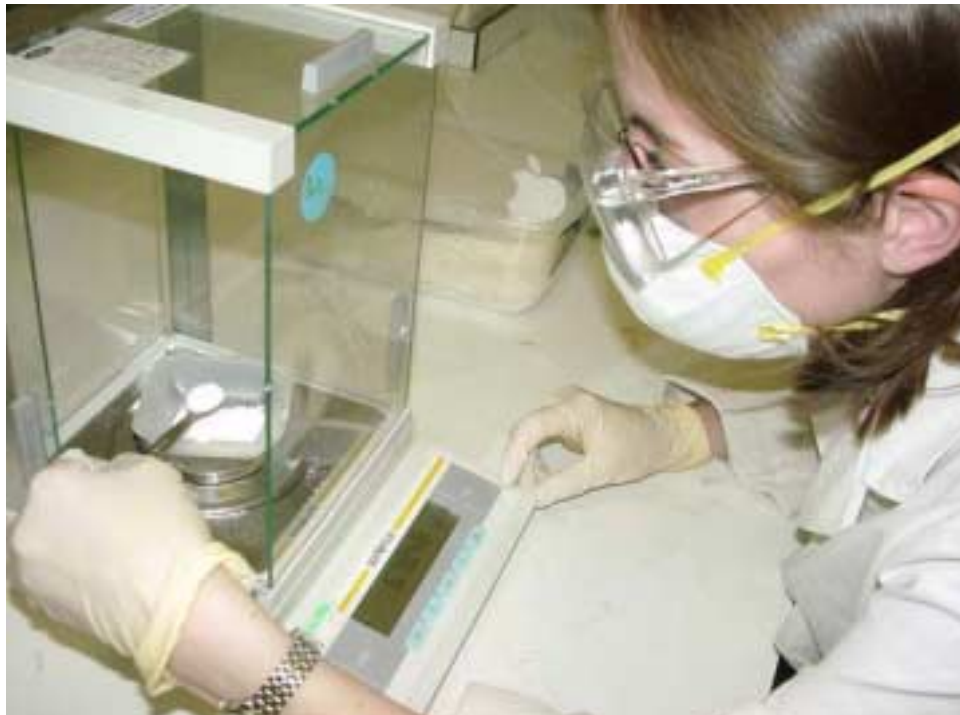
Biomedical engineers are also working to develop wireless technology that will allow patients and doctors to communicate over long distances. Many biomedical engineers are involved in rehabilitation—designing better walkers, exercise equipment, robots and therapeutic devices to improve human performance. They are also solving problems at the cellular and molecular level, developing nanotechnology and micro-machines to repair damage inside the cell and alter gene function. Biomedical engineers are also working to develop three-dimensional simulations that apply physical laws to the movements of tissues and fluids. The resulting models can be invaluable in understanding how tissue works, and how a prosthetic replacement, for example, might work under the same conditions.

Some biomedical engineers solve biomedical problems as physicians, business managers, patent attorneys, physical therapists, professors, research scientists, teachers and technical writers. While these careers

often require additional training beyond the bachelor's degree in biomedical engineering, they are all appropriate careers for the person trained in biomedical engineering. Sometimes electrical, mechanical, computer, or other types of engineers may find themselves working on bioengineering-related problems. After a few years, they may have so much biomedical-related expertise that they can be considered biomedical engineers.

How do biomedical engineers differ from other engineers?

Biomedical engineers must integrate biology and medicine with engineering to solve problems related to living systems. Thus, biomedical engineers are required to have a solid foundation in a more traditional engineering discipline, such as electrical, mechanical or chemical engineering. Most undergraduate biomedical engineering programs require students to take a core curriculum of traditional engineering courses. However, biomedical engineers are expected to integrate their engineering skills with their understanding of the complexity of biological systems in order to improve medical practice. Thus, biomedical engineers must be trained in the life sciences as well.



Courses in biology, chemistry, and physics will help prepare you to become a biomedical engineer. Photo courtesy Faustina Hwang.



Defibrillator for in-hospital use, designed by IDEO London for Artema, 1998. Photo courtesy IDEO.

How much education does a biomedical engineer require?

A biomedical engineering degree typically requires a minimum of four years of university education. Following this, the biomedical engineer may assume an entry level engineering position in a medical device or pharmaceutical company, a clinical engineering position in a hospital, or even a sales position for a biomaterials or biotechnology company. Many biomedical engineers will seek graduate level training in biomedical engineering or a related engineering field. A Master's or Doctoral degree offers the biomedical engineer greater opportunities in research and development, whether such work resides in an industrial, academic or government setting. Some biomedical engineers choose to enhance their education by pursuing a graduate degree in business, eventually to help run a business or manage health care technology for a hospital.

Many biomedical engineers go on to medical school and dental school following completion of their bachelor's degree. A fraction of biomedical engineers even choose to enter law school, planning to work with patent law and intellectual property related to biomedical inventions. What better training than biomedical engineering for our future physicians, dentists and patent lawyers?

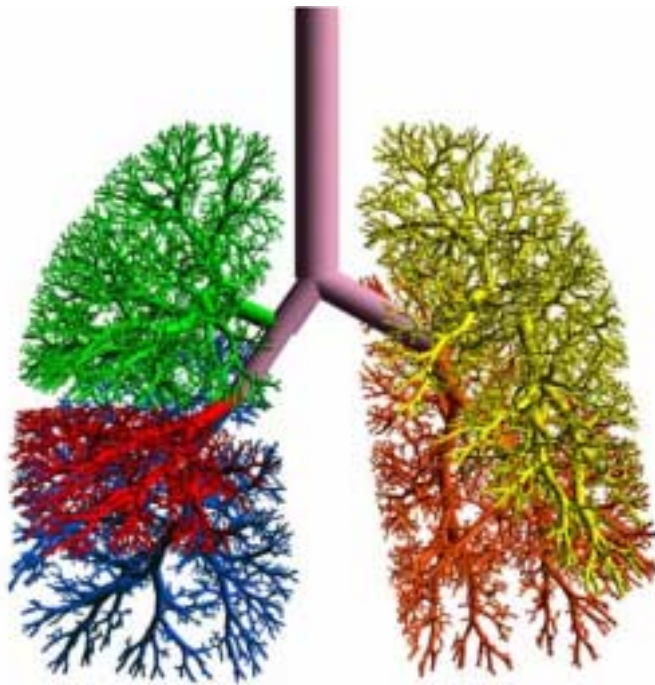
How can a high school education prepare me for studies in biomedical engineering?

Biomedical engineers require education and training in several sciences, as well as in mathematics, engineering design, communication, teamwork and problem-solving. To best prepare for a college program in biomedical engineering, one should take a well-rounded course of study in high school. The minimum such study should include a year each of biology, chemistry and physics. Advanced courses in any of these sciences are a plus. High school algebra, geometry, advanced algebra, trigonometry and pre-calculus are a must. A course in calculus is also typical of students entering biomedical engineering programs. A computer programming course gives students a definite advantage in their college program. One might also consider a drafting or mechanical drawing course as an elective.

The humanities and social sciences are also important to the biomedical engineer. High school preparation should include four years of English and composition, a speech course, several years of history and social studies and even study of a foreign language. As biomedical engineers work to improve healthcare worldwide, the ability to communicate in another language is a valuable skill.



Rehabilitation engineers work to improve the quality of life for people with a range of capabilities. Photo courtesy Faustina Hwang.



Engineers and mathematical modelers combine their skills to study the flow of air through the lungs. This research helps people to better understand and treat diseases of the lung. Image courtesy Merryn Tawhai, Bioengineering Institute, Auckland, New Zealand.

What types of university courses will prepare me to become a biomedical engineer?

Design is crucial to most biomedical engineering activities. To design, biomedical engineers must have a solid foundation in biology, chemistry, physics, mathematics, engineering, and the humanities. Although the biomedical engineering curriculum varies from university to university, most programs require courses in biology and

physiology, biochemistry, inorganic and organic chemistry, general physics, electronic circuits and instrumentation design, statics and dynamics, signals and systems, biomaterials, thermodynamics and transport phenomenon, and engineering design. Students also take a number of advanced science and engineering courses related to their specialty in biomedical engineering. Typical specialties include bioelectronics, biomechanics, biomaterials, physiologic systems, biological signal processing, rehabilitation engineering, telemedicine, virtual reality, robotic aided surgery, and clinical engineering. Newer specialties include cellular and tissue engineering, neural engineering, biocomputing and bioinformatics. Many engineering and science courses incorporate laboratory experience to provide students with hands-on, real-world applications.

In addition to science and engineering courses, the biomedical engineering student must take courses in English, technical writing, ethics, and humanities (such as history, political science, philosophy, sociology, anthropology, psychology, and literature). Some students continue studies of a foreign language in hopes of securing internships or permanent engineering positions in a foreign country. Business courses are also pop-

ular for students interested in engineering management.

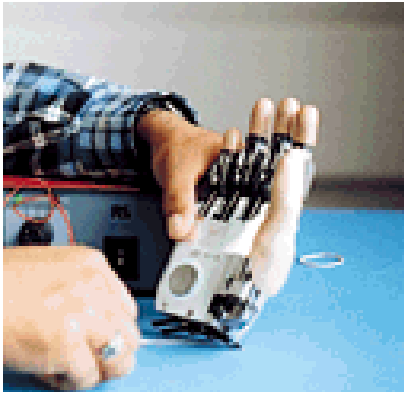
Many universities actively encourage six month overseas exchange programs where a component of the biomedical engineering curriculum is taught by a university in another country.



A biomedical engineer adjusts a monitor in Managua, Nicaragua. Photo courtesy Engineering World Health.

What kind of practical experience can I expect to gain while training to be a biomedical engineer?

Many undergraduate training programs in biomedical engineering offer students an opportunity to gain real-world experience prior to graduation. Summer internships with medical device and pharmaceutical



New devices with the latest technology can make a dramatic difference in people's lives.

companies are popular, as are summer research experiences at academic institutions and government agencies, including the National Institutes of Health (NIH) and regulatory approval bodies such as the FDA (Food and Drug Administration) in the USA. Some universities offer formal cooperative training programs in biomedical engineering whereby the student spends several semesters working at a biomedical company or hospital, earning academic credit as well as a salary. Such real-world experiences allow a student to explore career options and better define his or her role in the biomedical engineering community.

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What are some of the key areas of biomedical engineering?

Bioinformatics involves developing and using computer tools to collect and analyze data related to medicine and biology. Work in bioinformatics could involve using sophisticated techniques to manage and search databases of gene sequences that contain many millions of entries.

BioMEMS Microelectromechanical systems (MEMS) are the integration of mechanical elements, sensors, actuators, and electronics on a silicon chip. BioMEMS are the development and application of MEMS in medicine and biology. Examples of BioMEMS work include the development of microrobots that may one day perform surgery inside the body, and the manufacture of tiny devices that could be implanted inside the body to deliver drugs on the body's demand.

Biomaterials are substances that are engineered for use in devices or implants that must interact with living tissue. Examples of advances in this field include the development of coatings that fight infection common in artificial joint implants, materials that can aid in controlled drug delivery, and "scaffolds" that support tissue and organ reconstruction.

Biomechanics is mechanics applied to biology. This includes the study of motion, material deformation, and fluid flow. For example, studies of the fluid dynamics involved in blood circulation have contributed to the development of artificial hearts, while an understanding of joint mechanics has contributed to the design of prosthetic limbs.

Biosignal Processing involves extracting useful information from biological signals for diagnostics and therapeutics purposes. This could mean studying cardiac signals to determine whether or not a patient will be susceptible to sudden cardiac death, developing speech recognition systems that can cope with background noise, or detecting features of brain signals that can be used to control a computer.



Researchers in biomaterials work to develop substances that are better suited to interact with living tissue. Photo courtesy Faustina Hwang.



Young child using a prosthetic arm. Photo courtesy the Institute of Biomedical Engineering, University of New Brunswick, Canada.

Biotechnology is a set of powerful tools that employ living organisms (or parts of organisms) to make or modify products, improve plants or animals, or develop microorganisms for specific uses. Some of the earliest efforts in biotechnology involved traditional animal and plant breeding techniques, and the use of yeast in making bread, beer, wine and cheese. Modern biotechnology involves the industrial use of recombinant DNA, cell fusion, novel bioprocessing techniques, which can all be used to help correct genetic defects in humans. It also involves bioremediation—degradation of hazardous contaminants with the help of living organisms.

Clinical Engineering Clinical engineers support and advance patient care by applying engineering and managerial skills to healthcare technology. Clinical engineers can be based in hospitals, where responsibilities can include managing the hospital's medical equipment systems, ensuring that all medical equipment is safe and effective, and working with physicians to adapt instrumentation to meet the specific needs of the physician and the hospital. In industry, clinical engineers can work in medical product development, from product design to sales and support, to ensure that new products meet the demands of medical practice.

Genomics is a new discipline that involves the mapping, sequencing, and analyzing of genomes—the set of all the DNA in an organism. A full understanding how genes function in normal and/or diseased states can lead to improved detection, diagnosis, and treatment of disease.

Imaging and Image Processing X-rays, ultrasound, magnetic resonance imaging (MRI), and computerized tomography (CT) are among the imaging methods that are used to let us “see” inside the human body. Work in this area includes developing low-cost image acquisition systems, image processing algorithms, image/video compression algorithms and standards, and applying advances in multimedia computing systems in a biomedical context.



TransCyte artificial skin growth chamber, designed by IDEO London for Advanced Tissue Sciences, 1997. Photo courtesy IDEO.



Standing frame for children with severe disabilities, designed by Triplicate Isis with Leckey. Photo courtesy James Leckey Design, Ltd.

Information Technology in biomedicine covers a diverse range of applications and technologies, including the use of virtual reality in medical applications (e.g. diagnostic procedures), the application of wireless and mobile technologies in health care settings, artificial intelligence to aid diagnostics, and addressing security issues associated with making health care information available on the world wide web.

Instrumentation, Sensors, and Measurement involves the hardware and software design of devices and systems used to measure biological signals. This ranges from developing sensors that can capture a biological signal of interest, to applying methods of amplifying and filtering the signal so that it can be further studied, to dealing with sources of interference that can corrupt a signal, to building a complete instrumentation system such as an x-ray machine or a heart monitoring system.

Micro and Nanotechnology Microtechnology involves development and use of devices on the scale of a micrometer (one thousandth of a millimeter, or about 1/50 of the diameter of a human hair), while nanotechnology involves devices on the order of a nanometer (about 1/50 000 of the diameter of a human hair, or ten times the diameter of a hydrogen atom). These fields include the development of microscopic force sensors that can identify changing tissue properties as a way to help surgeons remove only unhealthy tissue, and nanometer length cantilever beams that bend with cardiac protein levels in ways that can help doctors in the early and rapid diagnosis of heart attacks.

Neural Systems and Engineering This emerging interdisciplinary field involves study of the brain and nervous system and encompasses areas such as the replacement or restoration of lost sensory and motor abilities (for example, retinal implants to partially restore sight or electrical stimulation of paralyzed muscles to assist a person in standing), the study of the complexities of neural systems in nature, the development of neuro-robots (robot arms that are controlled by signals from the motor cortex in the brain) and neuro-electronics (e.g. developing brain-implantable micro-electronics with high computing power).

Physiological Systems Modeling Many recently improved medical diagnostic techniques and therapeutic innovations have been a result of physiological systems modeling. In this field, models of physiological processes (e.g. the control of limb movements, the biochemistry of metabolism) are developed to gain a better understanding of the function of living organisms.

Proteomics A proteome is the set of all proteins produced by a species, in the same way the genome is the entire set of genes. Proteomics is the study of proteomes – the location, interactions, structure, and function of proteins. Advances in proteomics have included



Mini-infusion pump transdermal medicine-delivery device, designed by IDEO for Pharmetrix. Photo courtesy IDEO.

the discovery of a new cellular process that explains how infections occur in humans – an advance that is leading to new treatments for infectious diseases. Additionally, these advances have led to discovery of a method to detect protein patterns in the blood for early diagnosis of ovarian cancer. Work in proteomics can also involve the development of hardware devices that provide accurate and rapid measurements of protein levels.

Radiology refers to the use of radioactive substances such as x-ray, magnetic fields as in magnetic resonance imaging, and ultrasound to create images of the body, its organs and structures. These images can be used in the diagnosis and treatment of disease, as well as to guide doctors in image-guided surgery.

Rehabilitation Engineering is the application of science and technology to improve the quality of life for people with disabilities. This can include designing augmentative and alternative communication systems for people who cannot communicate in traditional ways, making computers more accessible for people with disabilities, developing new materials and designs for wheelchairs, and making prosthetic legs for runners in the Paralympics.

Robotics in Surgery includes the use of robotic and image processing systems to interactively assist a medical team both in planning and executing a surgery. These new techniques can minimize the side effects of surgery by providing smaller incisions, less trauma, and more precision, while also decreasing costs.

Telemedicine, sometimes called “telehealth” or “e-health,” involves the transfer of electronic medical data from one location to another for the evaluation, diagnosis, and treatment of patients in remote locations. This usually involves the use of “connected” medical devices, advanced telecommunications technology, video-conferencing systems, and networked computing. Telemedicine can also refer to the use of these technologies in health-related distance learning.

Where do I get more information about biomedical engineering programs?

You can find more information about biomedical engineering degree programs through your high school guidance counselors, at your local library and through the internet. Most universities provide program descriptions, curriculum requirements and admission requirements on their web pages. In addition, most of these programs provide application forms on line. You may also find information on biomedical engineering programs at www.embs.org or www.bmenet.org. There is also worthwhile information available through the National Institute of Biomedical Imaging and Bioengineering and its website (www.nibib.nih.gov). The *IEEE Engineering in Medicine and Biology Magazine* and journals such as the *IEEE Transactions on Biomedical Engineering* can also be very useful, as well as books such as the *Introduction to Biomedical Engineering, Medical Instrumentation: Application and Design*, and the *Biomedical Engineering Handbook* series. Also, there are educator resources available from the Educator's Toolbox on the main page of the IEEE Engineering in Medicine and Biology Society website at www.embs.org.

The field of biomedical engineering now enjoys the services of many organizations collaborating to improve the lives of people around the world. These societies include the IEEE Engineering in Medicine and Biology (IEEE-EMBS), the Biomedical Engineering Society (BMES), the European Alliance for Medical and Biological Engineering and Science (EAMBES), and the world umbrella organization for all biomedical engineering societies – the International Federation for Medical and Biological Engineering (IFMBE). Wherever you are living, you should be able to find a biomedical engineering organization to help you reach your goals.



A bioengineering student with her tiny patient. Photo courtesy Engineering World Health.

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The **Engineering in Medicine and Biology Society** of the IEEE advances the application of engineering sciences and technology to medicine and biology, promotes the profession, and provides global leadership for the benefit of its members and humanity by disseminating knowledge, setting standards, fostering professional development, and recognizing excellence.

The field of interest of the IEEE Engineering in Medicine and Biology Society is the application of the concepts and methods of the physical and engineering sciences in biology and medicine. This covers a very broad spectrum ranging from formalized mathematical theory through experimental science and technological development to practical clinical applications. It includes support of scientific, technological and educational activities.

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IEEE EMBS Special Topic Conference on Neural Engineering
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