Educational Improvements around Biomedical Engineering Teaching Modules

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Abstract

Biomedical Engineering is one of the most pursued streams of engineering today. Biomedical engineering is taught as a highly interdisciplinary field of study integrating core concepts in science and engineering and advanced concepts in the different engineering disciplines. Universities have provided different blend of core courses and advanced courses for students to improve their learning outcomes and provide better job prospects as biomedical engineers. Biomedical engineering has always faced the challenge and benefit of striking the right balance of core concepts and advanced concepts, which eventually will help build the next generation workforce that is creative, bold, and ready to face the new challenges in healthcare. In this review article, our team discusses the scope of biomedical engineering education at universities, the course curriculum, and challenges in implementing this curriculum at universities. The importance of industrial experience through internships is recommended as an effective way to develop soft skills for students besides the experience of working around professional individuals.

Introduction

The discipline of biomedical engineering is an emerging area that is highly multidisciplinary in nature and applies principles and techniques from all fields of engineering, chemistry, physics, biology, medicine, and other sciences to solve problems in healthcare of humans, animals, and plants [1-15]. The goal of biomedical engineering is to develop new technologies, sensor and actuator devices, and integrated systems that strive to improve patient care, refine the best practices, and advance our reasoning and understanding of natural processes [1-7].

Scope of Biomedical Engineering

Biomedical engineering focusses on a large variety of topics, and some of them can be categorized here [5-12]. Medical devices and instrumentation focus on the design, development, and testing of devices such as pacemakers, imaging machines (MRI, CT scans), and diagnostic equipment. Biomaterials focus on creating materials that interact with biological systems, such as implants, prosthetics, and tissue-engineered products. Biomechanics focus on studying the mechanics of the human body to design artificial limbs, joints, and other assistive devices, as well as to understand movement and physical function. Bioinformatics and computational biology employ computational tools and techniques to analyze biological data, which can aid in understanding genetic information, protein structures, and disease patterns. Medical imaging focus on developing technologies for visualizing the inside of the body for diagnostic and treatment purposes, including MRI, ultrasound, and X-ray technologies. Tissue engineering and regenerative medicine develops methods to repair or replace damaged tissues and organs using cells, scaffolds, and biologically active molecules. Neural engineering develops technologies that interface and communicate with the nervous system, including brain-computer interfaces, neuroprosthetics, and systems for monitoring and treating neurological disorders. Rehabilitation engineering focus on creating devices and systems that help individuals recover physical or cognitive function lost due to injury or illness, such as prosthetics, orthotics, and assistive technologies.

Course Curriculum in Biomedical Engineering Education

Within universities, biomedical engineering education typically involves a blend of courses in engineering, life sciences, and medical sciences [17-30]. Every university has its own blend of core courses and academic courses focused on biomedical engineering depending on the student needs and desires, enrollment, local economy, and job prospects.

Core Foundational Courses

The core courses are generally in Mathematics, statistics, general chemistry, physics, and introduction of engineering that may cover courses in thermodynamics, fluid flow, or core engineering design based on fundamental principles. In addition, there are subsequent courses in biomaterials, biomechanics, medical imaging, physiology, biomedical instrumentation, biomolecular engineering, and cell and tissue engineering [28-40].

Intermediate-level Courses

The course on biomaterials can study the properties of materials used in medical applications, including biocompatibility and material properties [40-48]. The course on biomechanics can study the analysis of the mechanics of the human body, including the design of prosthetics and orthopedic devices. The course on medical imaging focusses on the principles and applications of imaging technologies such as MRI, CT, ultrasound, and X-rays. The course on bioinstrumentation can focus on the design and use of devices that measure physiological data, such as ECG and EEG. The course on human physiology can study and develop an understanding of physiological systems and how they interact, often with a focus on quantitative analysis. Similarly, the course on biomedical signals and systems can study the signal processing techniques applied to biomedical data. The course on Cell and Tissue Engineering can build an understanding of techniques for developing and manipulating biological tissues for medical applications. The course on biomolecular engineering can discuss the application of engineering principles to molecular and cellular systems, often including genetic engineering and biotechnology.

Advanced and Elective Courses

There are a number of advanced courses that could be taken as elective courses by students in universities. Neural engineering focusses on the study of technologies interfacing with the nervous system, including neuroprosthetics and brain-computer interfaces. Rehabilitation engineering studies the development of devices and systems to assist individuals with disabilities. Bioinformatics studies the use of computational tools to analyze biological data, such as genomics and proteomics. Clinical engineering studies the application of engineering principles in a healthcare setting, focusing on the management of medical equipment and technologies. Laboratory courses can provide hands-on experience with biomedical engineering tools and techniques, often including experimentation and data analysis [28-39]. A capstone project can be used for students to apply their knowledge to solve a real-world biomedical engineering problem, often in collaboration with industry or healthcare partners. In addition, there may be cross-cutting courses related to ethics and regulations. Ethics in Biomedical Engineering studies the understanding of the ethical considerations in biomedical research and medical device development. Regulatory Affairs and Quality Control courses focus on the regulatory environment, standards, and practices necessary for medical device approval and quality assurance.

Challenges in Implementation of Biomedical Engineering Curriculum

Biomedical engineering education presents several unique challenges due to the interdisciplinary nature of the field, the rapid pace of technological advancement, and the need for practical skills [11-27]. These challenges stem primarily from the highly interdisciplinary nature of the field of engineering when compared to more traditional streams of engineering such as mechanical or electrical engineering.

There are challenges to integrating the various fundamental concepts into packaged curriculum [5-20]. Biomedical engineering combines principles from engineering, biology, and medicine. Students must grasp concepts across these disciplines, which can be challenging due to the breadth and depth required. It is challenging to balance the core concepts and advanced skills in a curriculum that covers both fundamental engineering skills and specialized biomedical topics can be difficult. Students need a strong foundation in basic sciences and engineering, while also gaining specific knowledge in areas like biomaterials, medical imaging, and biomechanics.

As with most fields of engineering, the biomedical engineering field evolves quickly with new technologies, techniques, and regulations [32-41]. Educational programs and courses must continuously update their curriculum to reflect the latest developments, which can be resource-intensive and time-intensive. It is also challenging to integrate new technologies, such as machine learning and AI in medical diagnostics or advanced imaging techniques, into the curriculum requires updating equipment, retraining faculty, and developing new coursework [15-19]. Most of these computational techniques need project experience and advanced coding skills to be able to perform and execute the models.

Role of Industrial Experience and Internships in Biomedical Engineering Education

Universities need to provide students with hands-on experience in laboratories or with clinical equipment, which is crucial for their understanding and learning [5-12]. Maintaining such up-to-date teaching laboratories and securing advanced medical devices for student training can be a significant investment. This often requires endowments and industrial gifts to establish centers of excellence focused on certain thematic topics. Biomedical students eventually will work in healthcare settings or collaborate with medical professionals, for which they need experience working in industry settings. Facilitating internships, co-ops, or clinical placements is essential for universities by establishing long-term working relationships with local and regional industry partners. In addition, biomedical engineers must navigate complex regulatory landscapes, especially when developing medical devices or working with biological materials. Internships and industrial experience can help initiate this learning outcome [21-37]. Teaching students about regulatory requirements is critical but can be challenging due to the complexity and variability of regulations. This understanding of regulations is vital to the success of the students enrolled in biomedical engineering. Industry experience can further help students to understand and discuss the ethical concerns around testing and product development. Biomedical engineering raises numerous ethical issues, from patient privacy to the implications of genetic engineering. Incorporating robust ethical training into the curriculum and internships is necessary and critical to student success.

Teaching Interdisciplinary Collaboration in Diverse Work Settings

Universities must foster collaboration between different departments, such as engineering, biology, and medical schools, to provide comprehensive education [7-19]. Such experience can help students prepare for their future careers. Graduates in biomedical engineering can pursue careers in industry, academia, healthcare, or research, each requiring different skill sets. Preparing students for this diversity in career options is important while providing sufficient exposure to all potential career paths [21-30]. Besides technical skills, biomedical engineers also need strong communication, teamwork, and project management skills. Integrating these soft skills into a technically focused curriculum can be challenging but can be acquired through internships, industrial experience, and interdisciplinary collaboration on group projects. Effective biomedical engineers often work in interdisciplinary teams with medical professionals, biologists, and other engineers [5-14]. Developing strong collaboration skills in students is essential but challenging to teach in a traditional classroom setting.

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