Texas Higher Education Coordinating Board

Making Opportunity Affordable in Texas:

A Student-Centered Approach

Tuning of Biomedical Engineering

Texas Higher Education Coordinating Board

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Tuning Oversight Council
for Engineering and Science

Biomedical Engineering Committee

John C. Criscione, M.D., Ph.D. (Chair) Associate Professor of Biomedical Engineering Department of Biomedical Engineering Texas A&M University 3120 TAMUS College Station, TX 77843-3131 JCCriscione@tamu.edu	**Lennine Bashiri (Co-Chair)** Instructor South Texas College 3201 W. Pecan Blvd. McAllen, TX 78502 lsbashiri@southtexascollege.edu
Leonidas Bleris, Ph.D. Assistant Professor Department of Bioengineering The University of Texas at Dallas 800 W. Campbell Rd Richardson, TX 75080 Bleris@utdallas.edu	**Ting Chen, Ph.D.** Instructional Assistant Professor,Research Assistant Professor, Academic Advising Coordinator Department of Biomedical Engineering Cullen College of Engineering University of Houston 3605 Cullen Blvd, Room 2018 Houston, TX 77204-5060 tchen23@central.uh.edu
Cheng-Jen "Charles" Chuong, Ph.D. Professor The University of Texas at Arlington Arlington, TX 76019-0019 chuong@uta.edu	**Charlene Cole** Chair, Department of Life Sciences Tarrant County Community College NE Department of Life Sciences Hurst, TX 78054 charlene.cole@tccd.edu
Harvinder Singh Gill, Ph.D. Assistant Professor Department of Chemical Engineering Texas Tech University Lubbock, TX 79409-3121 Harvinder.gill@ttu.edu	**Joo L. Ong, Ph.D.** UTSA Distinguished Professor and Chair The University of Texas at San Antonio Department of Biomedical Engineering San Antonio, TX 78249 anson.ong@utsa.edu
Patrice Parsons, Ph.D. Professor Grayson Community College Denison, TX 75020 parsonsp@grayson.edu	**Chandeshwar Sharma, Ph.D.** Instructor, Coleman College for Health Sciences Houston Community College Houston, TX 77030 chandeshwar.sharma@hccs.edu
James Tunnell, Ph.D. Associate Professor, Undergraduate Advisor The University of Texas at Austin Biomedical Engineering, Cockrell School of Engineering Austin, TX 78712 jtunnell@mail.utexas.edu	**Reinold R. Cornelius, Ph.D.** THECB Liaison to Biomedical Engineering Program Director, Workforce, Academic Affairs and Research Texas Higher Education Coordinating Board Austin, Texas 78752 reinold.cornelius@thecb.state.tx.us

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Definition of Tuning

"Tuning" is a faculty-led pilot project designed to define what students must know, understand, and be able to demonstrate after completing a degree in a specific field, and to provide an indication of the knowledge, skills, and abilities students should achieve prior to graduation at different levels along the educational pipeline – in other words, a body of knowledge and skills for an academic discipline in terms of outcomes and levels of achievement of its graduates.

Tuning provides an expected level of competency achievement at each step along the process of becoming a professional: expectations at the beginning of pre-professional study, at the beginning of professional study, and at the transition to practice. It involves seeking input from students, recent graduates, and employers to establish criterion-referenced learning outcomes and competencies by degree level and subject area. Through Tuning, students have a clear "picture" of what is expected and can efficiently plan their educational experience to achieve those expectations. The objective is not to standardize programs offered by different institutions, but to better establish the quality and relevance of degrees in various academic disciplines.

An overview of Lumina Foundation for Education's "Tuning USA" Initiative is available at: http://www.tuningusa.org/; an overview of Tuning work to date in Texas is available at: http://www.thecb.state.tx.us/tuningtexas.

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Definition of Biomedical Engineering

The biomedical engineering profession is devoted to improving human health and well-being by using engineering principles and technologies. It develops fundamental theories, systems, and products to support medical industries, health care providers, governmental agencies, and academic entities. (Adapted from the vision and mission statements of the Biomedical Engineering Society, http://www.bmes.org/aws/BMES/pt/sp/mission.)

Source

This report is one in a series of reports for the Lumina Foundation for Education initiative "*Making Opportunity Affordable in Texas: A Student-Centered Approach*." Wording and concepts in this report were aligned, where appropriate, with wording and concepts of reports for other disciplines. Therefore, tuning reports were aligned not only with words and concepts of the disciplines' particular professional organizations, such as the Biomedical Engineering Society or the Regulatory Affairs Professional Society, but may have also been informed and aligned with ideas, concepts, and wording of other professional societies, such as the American Society of Civil Engineers (ASCE) 2025 Vision for Civil Engineering Body of Knowledge 2nd Edition (BOK2E).

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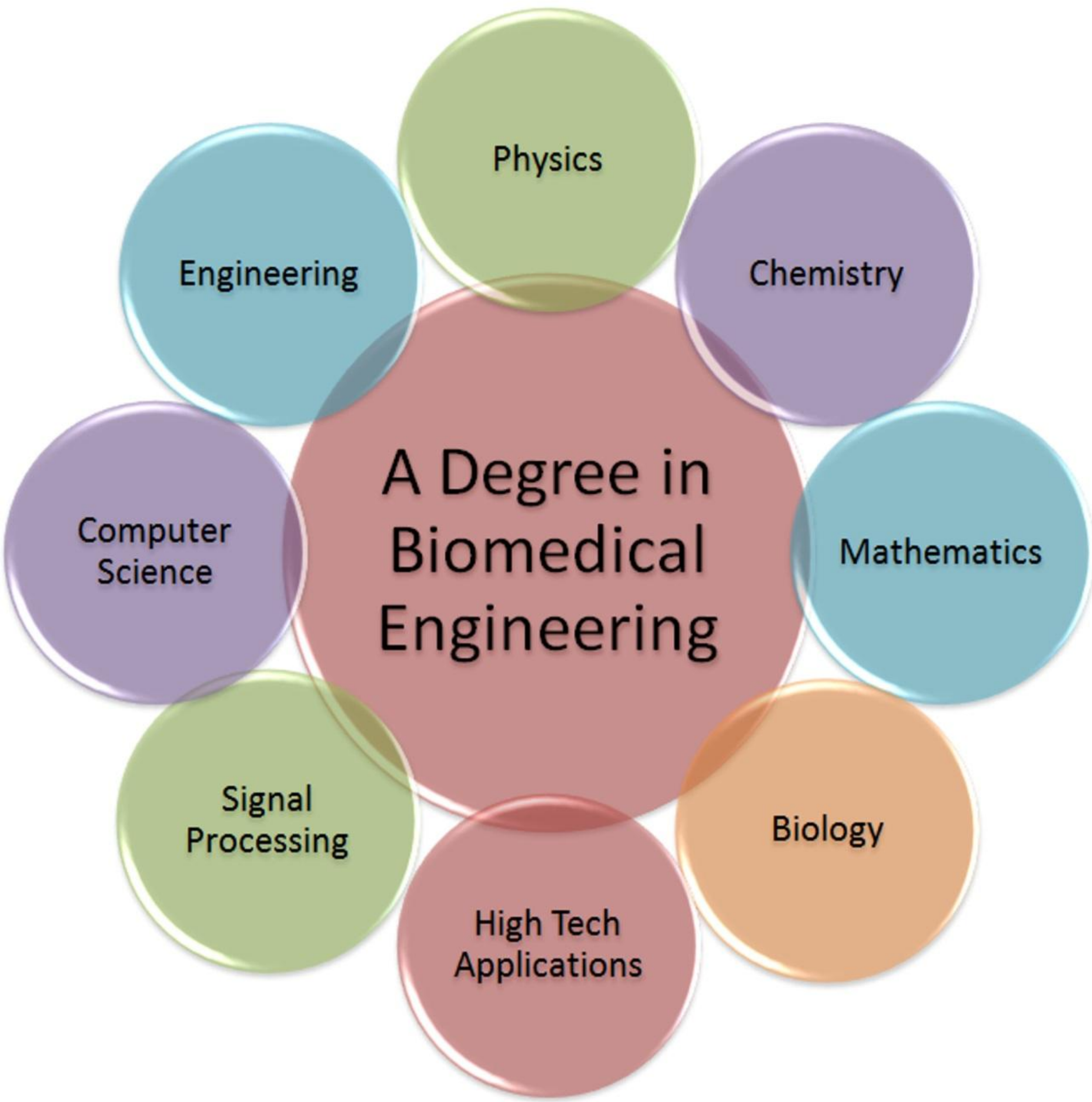
Biomedical Engineering Expertise Profile

The expertise profile lists types of course topics included in typical baccalaureate degrees in biomedical engineering. Note: General undergraduate degree requirements (e.g., the core curriculum) are not considered for the purpose of tuning biomedical engineering and this report.

Any broad topic of interest shown here may have specializations that are important for biomedical engineering. Specializations may be overlapping between topics of interest, because of the interdisciplinary nature of the field.



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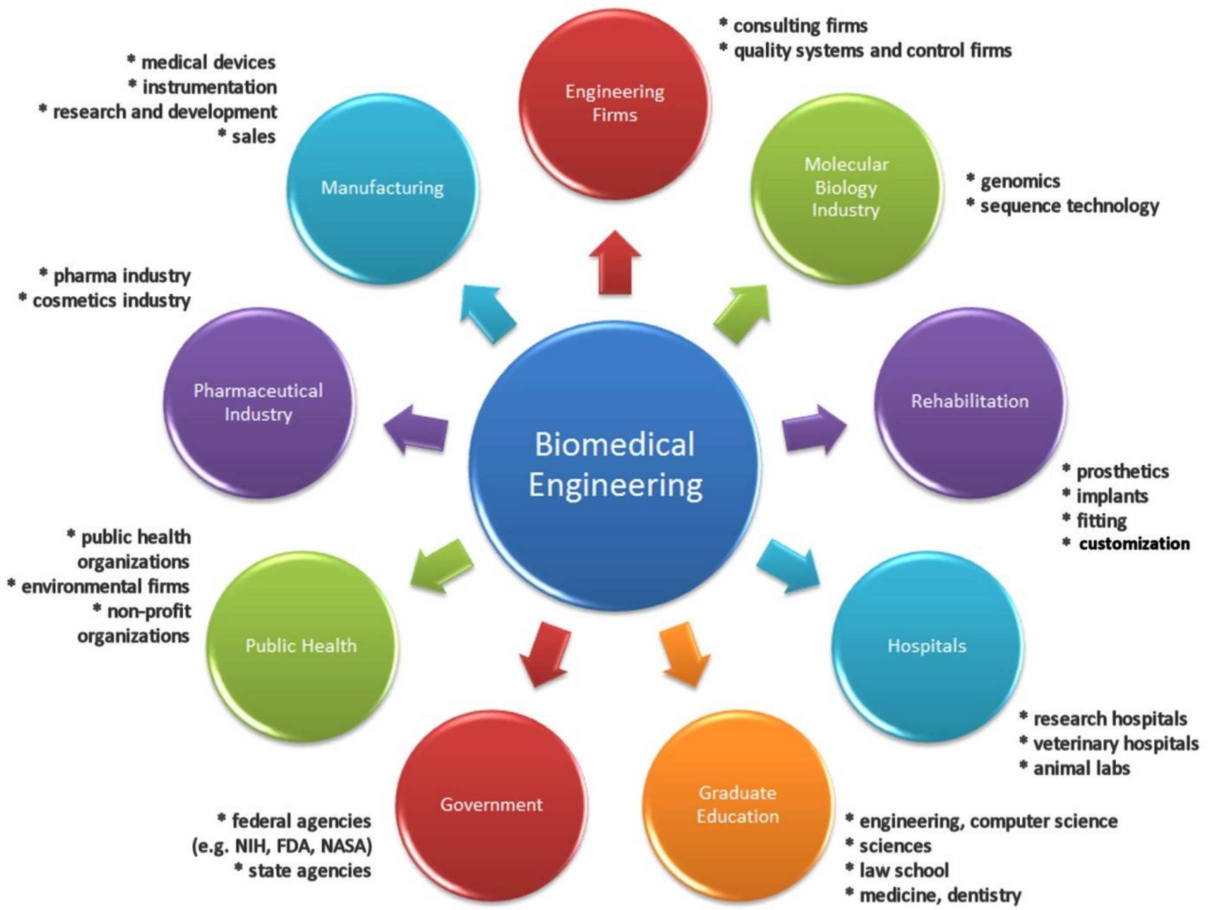
Biomedical Engineering Employment Profile

The employment profile lists the employment pathways available for graduates of biomedical engineering programs.

Biomedical employment opportunities are listed by industry. Examples of industries or types of industries are listed as bullets. On page 4, the broad and diverse biomedical engineering field is subdivided into different tracks of specialization, which overlay the employment opportunities listed here.



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Biomedical Engineering Professional Tracks

Biomedical Engineering is a broad and diverse discipline, and the field is subdivided into different tracks of specialization. Each track requires a different emphasis on skills that make up the biomedical engineering expertise profile. The ability to specialize helps to bring focus to the engineer's learning and training.

The 14 broad skill sets, called Outcome Titles, of the biomedical engineering competency table (page 8) were used to characterize 14 professional tracks open to biomedical engineering graduates:

1. Design and Prototyping Engineer
2. Project Manager in Medical Industry
3. Federal Inspector
4. Experimentalist or Testing Technician
5. Technical Sales Personnel
6. Regulatory Affairs Professional
7. Consultant in Medical Industry
8. Dental Student/Dentist
9. Medical Student/Medical Doctor
10. Law Student/Lawyer (Patent Attorney)
11. Graduate Student/Scientist
12. Pharmacy Student/Pharmacist
13. Veterinary Student/Veterinarian
14. Clinical Engineer, Instrumentation Engineer

In the description below, "math" means mathematics; "engineering" means engineering skills, tools, and techniques; "high tech" means high tech know-how and applications; and "impact" means impact of engineering solutions on society. Skills listed are not in order of importance, and only skills that are generally of high importance for a professional track are listed.

<u>Design and Prototyping Engineer</u>

Skills needed most highly: engineering, design, teamwork, high tech, physiology, modeling, biocompatibility, lifelong learning, and regulatory affairs.

The design and prototyping engineer needs a strong interest in product development and product management together with critical thinking skills, open mindedness, and a willingness to learn.

<u>Project Manager in Medical Industry</u>

Skills needed most highly: teamwork, ethics, communication, impact, lifelong learning, quantitative biology, high tech, and regulatory affairs.

A project manager in the medical industry needs a good foundation in quantitative biology, such as physiology, biochemistry, and immunology. Medical devices applications require

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knowledge in circuits and packaging of devices, as well as 3D design modeling. Knowledge of local, state, and federal codes is important, which includes the need for skills in risk assessment and design evaluation. Academic leadership training is required.

Federal Inspector

Skills needed most highly: engineering, design, chemistry, biology, physiology, math, teamwork, ethics, impact, contemporary issues, and regulatory affairs.

The federal inspector needs a strong foundation in basic sciences, physiology, patho-physiology and the ability to understand the underlying working principles of medical devices. The inspector needs to ask the right scientific, engineering, and clinically-relevant questions to challenge the issues. The work requires team work for consensus building, strong skills for oral and written communication, and objectivity and fair mindedness in documentation.

Experimentalist or Testing Technician

Skills needed most highly: experimentation, chemistry, biostatistics, ethics, communication, team work, and impact.

Experimentalist or testing technician must have strong verbal, analytical, and interpersonal skills. Since this job warrants practitioners to communicate data, information, and knowledge using information technology, candidates should have a strong understanding of statistics, clinical knowledge, and technical proficiency.

Technical Sales Personnel

Skills needed most highly: teamwork, ethics, communication, impact, contemporary issues, physiology, and biology.

Technical sales personnel should foremost have skills in team work and communication, together with excellent analytical skills for data analysis and a broad scientific knowledge. Practitioners need to be able to relay complex technical information to their clients. Knowledge of contemporary issues has to be kept current through willingness for lifelong learning, for example through conferences and professional meetings.

Regulatory Affairs Professional

Skills needed most highly: teamwork, ethics, communication, high tech, biostatistics, impact, contemporary issues, lifelong learning, and regulatory affairs.

The regulatory affairs professional needs to have a good understanding of statistics and statistical software tools. Experience with clinical trials is important. Regulatory affairs requires familiarity with audit procedures.

Consultant in Medical Industry

Skills needed most highly: teamwork, ethics, communication, design, biostatistics, impact, contemporary issues, lifelong learning, and regulatory affairs.

The consultant in the medical industry needs to have a strong background in engineering

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design as well as product development and product commercialization. Knowledge in regulatory affairs is mandatory.

Dental Student/Dentist

Skills needed most highly: physics, anatomy, ethics, communication, impact, and lifelong learning.

The biomedical engineer specializing in dentistry must have a firm grasp of anatomy. In addition to functionality, design aspects in dentistry mostly include cosmetics or aesthetics.

Medical Student/Medical Doctor

Skills needed most highly: biology, physical sciences, experimentation, teamwork, ethics, communication, contemporary issues, impact, physiology, biostatistics, and lifelong learning.

Biomedical engineering students who intend to pursue a degree in medicine must have strong verbal communication, motor skills, intellectual skills, excellent analytical skills, observation, and an ability to understand complex medical problems and to use engineering methods to solve them. In addition, the student must have a strong undergraduate understanding and knowledge in biology, chemistry, and physics. The graduate would apply knowledge of engineering and biomedical principles to the design, development, and evaluation of biological and health systems.

Law Student/Lawyer (Patent Attorney)

Skills needed most highly: ethics, communication, lifelong learning, regulatory affairs, engineering design, and contemporary issues.

The attorney must have a strong background in basic sciences, technology, and the engineering design process leading to the understanding of the technical issues involved in intellectual property protection and litigation. Of major importance in litigation of technical cases are written communication, regulatory issues and ethics. Patent attorneys interpret and analyze the basic science and technology surrounding novel design concepts.

Graduate Student/Scientist

Skills needed most highly: math, biology, engineering design, experimentation, ethics, communication, team work, contemporary issues, impact, high tech, physiology, modeling, biocompatibility, and lifelong learning.

The scientist must be well versed in analytical experimentation and tools for biochemistry or bio-processing. Knowledge about laboratory operations is critical. Other important skills are usage of computational software for math, fluid flow, and biostatistics. Biology expertise should be geared towards cell and molecular biology. Analytical chemistry is a needed background.

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Pharmacy Student/Pharmacist

Skills needed most highly: math, chemistry, biology, microbiology, physiology, anatomy, ethics, team work, communication, impact, contemporary issues, biostatistics, and lifelong learning.

For the pharmacist it is important to have a good undergraduate studies background in physiology, anatomy, microbiology, and math. The ability to work on teams is also important.

Veterinary Student/Veterinarian

Skills needed most highly: math, physics, chemistry, biology, ethics, physiology, communication, impact, lifelong learning.

Experimentation skills may be important as well, for the veterinarian, depending on the future goals of the graduate. Knowledge of contemporary issues has to be kept current through willingness for lifelong learning.

Clinical Engineer, Instrumentation Engineer

Skills needed most highly: engineering, teamwork, ethics, communication, lifelong learning.

Clinical engineering is responsible for applying and implementing medical technology to optimize healthcare delivery. Clinical engineers must understand human anatomy and physiology, microbiology, and patho-physiology. They should have good technical knowledge of medical design, clinical instrumentation, life science, and engineering techniques. The instrumentation engineer applies the principles of physics, chemistry, and mathematics to design and model a product for its compatibility to human physiology and anatomy. The profession requires good interpersonal and communication skills, excellent electronics aptitude, and a thorough understanding of medical machinery.

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Biomedical Engineering Key Competency Tables and Learning Outcome Descriptions

The Biomedical Engineering competency table has 14 learning outcome titles, one for each learning outcome description:

1. Mathematics
2. Physical Sciences (Chemistry, Physics)
3. Life Sciences (Biology, Physiology, and Anatomy)
4. Experimentation
5. Design (Structural and Aesthetic Design)
6. Teamwork
7. Problem Solving
8. Engineering Skills, Tools, and Techniques
9. Ethics
10. Communication
11. Lifelong Learning
12. Contemporary Issues and Impact of Engineering Solutions
13. Specializations (Biomaterials, Tissue Engineering, Bioinformatics, Biomechanics, Bioimaging, Biosensors, Bioinstrumentations, and Modeling)
14. Regulatory Affairs

The competency table has four learning outcome categories (columns from left to right):

1. core competencies needed to enter higher education in biomedical engineering (HS),
2. pre-engineering competencies gained during first two years of study (CC),
3. baccalaureate-level engineering competencies (BS), and,
4. graduate-level engineering competencies (G)

Learning outcome descriptions for each of the outcome titles of the competency table explain the knowledge, skills, and attitudes that should be achieved by the graduates.

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Mathematics:

Mathematics deals with the science of structure, order, and relation that has evolved from counting, measuring, and describing the shapes of objects. It uses logical reasoning and quantitative calculation and is considered the underlying language of science and engineering. The principal branches of mathematics relevant to biomedical engineering include algebra, geometry, trigonometry, calculus, optimization, probability, statistics, and numerical methods.

Biomedical engineers apply mathematics to formulate and solve problems in biology or clinically relevant applications, and interpret the solutions to further understand or to advance technology development in the health care delivery system. The mathematics required for biomedical engineering practice must be learned at the undergraduate level and should prepare students for subsequent challenges through their career development.

MATHEMATICS			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension" and "Application"**	**"Analysis"**	**"Synthesis"**
Solve problems in mathematics in algebra, plane geometry, trigonometry, and analytical geometry (or pre-calculus), and apply this knowledge to the solution of science and technology problems. Students should be ready to complete Calculus I in their first college semester.	Explain key concepts and problem-solving processes in mathematics through calculus and differential equations; apply math concepts to solve basic engineering problems.	Formulate and solve problems in biology or clinically relevant applications; interpret the solution to address the biology problems or medical applications.	Analyze a complex problem to identify the key mathematical principles, formulate the problem in mathematics, and solve it for quantitative solution, and apply advanced mathematic concepts as necessary for complex biological systems.

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Physical Sciences (Chemistry, Physics):

Physics and chemistry are two disciplines of the natural sciences that have historically served as basic foundations shaping the advancement of our modern technology. Physics is concerned with understanding the structure of the natural world and interactions in terms of fundamental principles and laws. Chemistry is the science that deals with the properties, composition, and structure of substances in the material world and in living things. Chemistry further describes the reactions and transformations these substances undergo and the energy released or absorbed during those processes. Virtually all applications in biomedical engineering are based on the fundamental laws in physics and working principles in chemistry.

Biomedical engineers should have solid foundations in physics and chemistry which enable them to solve complex problems in biology and to further the advancement in health care delivery technology.

PHYSICAL SCIENCES			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension"**	**"Application"**	**"Analysis" and "Synthesis"**
Define factual information and explain key concepts related to fundamental laws in physics and working principles in chemistry.	Describe and solve calculus-based physics and chemistry problems; apply the same techniques to simple problems in biomedical engineering to appreciate its interdisciplinary nature and approach.	Analyze, formulate, and solve complex problems in physics and chemistry using multiple tools, techniques, and skills in an accurate manner. Use scientific methods to analyze biomedical problems, apply engineering techniques to design experiments, followed by data collection, results analysis, and interpretation.	Resolve complex problems in physics and chemistry that arise in biology and in health care delivery. Develop an engineering goal with working hypothesis, design experiments to test the hypothesis and to achieve the engineering goal with the right technology and tools. Be able to challenge the status quo with new thinking and adopt newly emerging technology.

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Life Sciences (Biology, Physiology, and Anatomy):

Among the wide spectrum of life science disciplines, biology, human physiology, and anatomy are among the most important to biomedical engineers. Biology studies the fundamental principles of how living things work by examining the structure-function relationships of life's building blocks from molecular, cellular, and organ levels to the organism level. Human physiology studies how the complex organ systems of the body work in a coordinated way to accomplish physiological functions essential for life. It also studies how the organism maintains the dynamic equilibrium or constancy of its internal environment as well as how it defends and repairs itself in the face of different challenges through the life cycle. Physiology and anatomy are intrinsically related fields, often studied in tandem: The former is the study of function and the latter is the study of form.

Collectively, molecular and cellular biology, human physiology, and anatomy provide the foundations for the understanding of the working and maintenance of the human body throughout the life cycle. With such understanding, biomedical engineers can apply their expertise on multiple scales (molecular biology to modeling entire organ systems) using physical sciences, mathematics and engineering methodologies, techniques, and skills to develop innovations that enhance the quality of life and health care. Examples of their contributions include the development of medical devices, instrumentation, surgical robotics, functional imaging for disease diagnosis and treatment as well as tissue-engineered replacements and pharmaceutical products. Life sciences are critical to current trends in regenerative, molecular, and personalized medicine.

LIFE SCIENCES			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension"**	**"Application" and "Analysis"**	**"Synthesis" and "Evaluation"**
Identify the levels of organization of life. State basic concepts of cellular and molecular biology. Have a broad knowledge and understanding of the function of DNA and its importance for biological systems and gene regulations.	Explain the structure and function of genes, proteins, and other biomolecules. Explain the concept of homeostasis, and the mechanisms relevant to cell cycle. Identify the organ systems of humans with an emphasis on the relationship of structure and function.	Illustrate the relationship of the structure and function at all levels: molecular, cellular, and organismal. Manipulate and model, in the lab, molecular and cellular processes and analyze findings using scientific method.	Produce an original hypothesis regarding molecular and cellular problems relevant to human, organismal, and ecological health. Determine the value of the models and experiments conducted that address problems relevant to human health.

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Experimentation:

Experiments are conducted to test hypotheses developed regarding the causal relationship of factors and mechanisms which govern processes in the natural world. This work not only addresses unknown or poorly understood relationships but also is done to clarify previous experimental data. Biomedical engineers must be able to determine the relevance, importance, and societal benefits of the experimental outcomes concerning the medical community.

Biomedical engineers are required to design the protocols, establish the conditions, and gather the data regarding their proposed models. They will need to analyze and evaluate the results and be able to suggest alternate approaches or additional experiments to support their findings. They will need to be familiar with the purpose and protocols commonly used in basic and clinical research. They should be familiar with the safety issues, limitations, and operation of equipment used to conduct the experiments. They should be able to conduct experiments, report results, and analyze them in accordance with the applicable standards of the field. They should be able to understand the boundaries of reliability in the data and determine the limitations of their findings.

EXPERIMENTATION			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension"**	**"Application" and "Analysis"**	**"Synthesis" and "Evaluation"**
Identify equipment and understand safety issues relevant to conducting engineering experiments, report results, and determine the accuracy of the results.	Explain purpose and procedures relevant to performance of scientific experiments and communication of results.	Conduct experiments according to established protocols. Analyze and interpret experimental results by applying the scientific method. Formulate and solve problems related to experimentation relevant to biomedicine.	Design experiments to address specific needs, conduct experiments, and analyze and interpret results. Evaluate and defend experimental procedures and methods.

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Design (Structural and Aesthetic Design):

Design is an iterative process that is often creative and involves discovery and the acquisition of knowledge. Such activities as problem definition, the selection or development of design options, analysis, detailed design, performance prediction, implementation, observation, and testing are parts of the engineering design process.

Design problems are often ill-defined, so defining the scope and design objectives and identifying the constraints governing a particular problem are essential to the design process. The design process is open-ended and involves a number of likely correct solutions, including innovative approaches. Successful design requires critical thinking, an appreciation of the uncertainties involved, and the use of engineering judgment. Consideration of risk assessment, societal and environmental impact, standards, codes, FDA regulations, safety, security, sustainability, constructability, and operability are integrated at various stages of the design process.

The biomedical engineering graduate designs a system or process to meet desired needs within such realistic constraints as economic, environmental, social, political, ethical, health and safety, constructability, and sustainability.

DESIGN			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
No Competencies Needed	**"Knowledge" and "Comprehension"**	**"Application," "Analysis," and "Synthesis"**	**"Evaluation"**
	Define and identify the steps of an iterative design.	Apply the design process to create a solution to a biomedical need, while meeting constraints of cost and U.S. Food and Drug Administration (FDA) regulations.	Develop and evaluate the design of sophisticated systems. Assess compliance of systems with safety standards and FDA regulations.

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Teamwork:

Multidisciplinary engineering teams are groups of persons engaged in engineering who represent a spectrum of engineering and technical specialties. Students must be able to identify distinctions between the various disciplines and functions within engineering. To contribute successfully is to take an active, participatory, and productive role in the accomplishment of the tasks of a team. They must possess effective leadership, management, and communications skills. They should demonstrate knowledge of the importance of planning and organizing tasks to accomplish project goals; know the importance of effectively utilizing resources; know the techniques used to run effective meetings; know the techniques used to promote team harmony; and, know the techniques used to foster high levels of performance, creativity, and professionalism. Students must also be able to define, specify, and successfully complete a major engineering design project as part of a multi-disciplinary design team.

At the time a student completes the undergraduate degree requirements, the student must have the ability to function successfully on interdisciplinary teams. In the work place and in graduate school, biomedical engineers need to function effectively on multi-disciplinary teams.

TEAMWORK			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension"**	**"Application"**	**"Analysis" and "Synthesis"**
Have experience in collaborative learning and teamwork by participation in class projects.	Understand what makes a team function well, and how teamwork leads to a reduction in errors and design flaws.	Function effectively as a member of an interdisciplinary team.	Function effectively as a member of a multidisciplinary team. Characterize and decide what makes a good team. Ability to lead teams.

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Problem Solving:

Problem solving in biomedical engineering consists of identifying engineering problems: understanding technological, biological, and medical requirements and/or constraints; reviewing available information and literature; proposing and implementing solutions; and, finally, performing evaluation of the results. Problem solving involves not only the ability to identify the problems but also to rationally select the appropriate solution strategies. The techniques and tools required to solve biomedical engineering problems include information technology, device and circuit engineering, basic biology, and physiology.

The baccalaureate-level BME graduate will be able to develop, incorporate and execute problem-solving strategies in biomedical engineering case studies. At the post-graduate level, the BME graduate will also have the ability to perform critical assessment of the problem-solving strategies and recommend alternative solutions. Developing problem-solving skills can be a critical factor for success independent of a BME graduate career path. The competencies gained in a BME curriculum are generally applicable and will prepare the graduates for dealing with a wide range of problems.

PROBLEM SOLVING			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
No Competencies Needed	**"Knowledge" and "Comprehension"**	**"Application," "Analysis," and "Synthesis"**	**"Evaluation"**
	Identify, list, and interpret scientific problems and solve conventional problems in physics, chemistry, and mathematics.	Demonstrate capacity to develop appropriate strategies and anticipate solutions for particular problems in BME. Develop, revise, incorporate, and execute problem solving strategies.	Evaluate, compare, and justify problem-solving strategies. Perform critical assessment of solutions, be able to make decisions, and recommend alternative problem-solving strategies. Develop novel strategies for yet-unsolved problems.

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Engineering Skills, Tools, and Techniques:

Students graduating with an undergraduate degree in biomedical engineering will have the ability to use modern engineering tools, techniques, and processes in the practice of biomedical engineering. Modern engineering tools and techniques include equipment, assays, and electrical circuits. They include also numerical methods, programming, statistics, and graphics. These skills provide the means to model, modify, and verify known biomedical systems and device behavior. Skill sets may include technical expertise in the areas of tissue engineering, biomedical imaging, biomechanics, biomaterials, and biomedical instrumentation.

ENGINEERING SKILLS, TOOLS, AND TECHNIQUES			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
No Competencies Needed	**"Knowledge" and "Comprehension"**	**"Application" and "Analysis"**	**"Synthesis" and "Evaluation"**
	Identify and solve basic mathematical problems. Know how engineering tools are applied at a basic level.	Apply engineering tools to solve practical BME problems. Analyze and characterize solutions as appropriate to the tasks and tools learned.	Develop and assess modern biomedical engineering tools and processes.

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Ethics:

Ethical issues are a key component of biomedical engineering today. Ethics relies on the ability to apply moral principles in real-life situations, and it is context-dependent. There is no universal agreement on definitive approaches. Particularly today, in the era of genomics and the associated technologies and applications, it is critical that the biomedical engineering curriculum incorporates ethics training from the early baccalaureate stages throughout graduate school.

Technologies and products directly influence costs, quality, and access to medical treatments, and thereby, often ethical issues arise that need to be resolved in consultation with clinicians, regulators, and ethics experts.

Frontier areas for ethical consideration, which are important for students to learn, are related to genomics, stem cells, personalized medicine, and synthetic biology. As the cost of DNA sequencing drops rapidly, sequencing individual genomes will become regular medical practice. The use and access of this data and associated implications are heavily debated, and the ethical issues will be central to any regulatory or policy decision. Stem cells, including embryonic stem cells and induced pluripotent stem (iPS) cells, are a group of cells that can self-renew and differentiate into multiple cell types. Clearly there are several ethical issues related to their source and use. Both stem cells and sequencing belong to the realm of personalized medicine and will redefine biomedical engineering. Finally, synthetic biology is a rapidly evolving research area that combines science and engineering to design, synthesize, and analyze novel biological functions and systems. Concerns related to the ethical issues of synthetic biology are gathering equivalent momentum.

ETHICS			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension" and "Application"**	**"Analysis" and "Synthesis"**	**"Evaluation"**
The high-school experience should introduce and illustrate the impact of professional work on society and the environment. Students should have an appreciation of the need for ethical behavior.	Describe and discuss ethical concepts and identify and explain ethical issues. Demonstrate capacity to implement the professional code of ethics in example cases.	Analyze, compare, and differentiate a wide range of ethical concepts in cases and technologies related to BME. Develop strategies and solutions to address ethical challenges and dilemmas in BME.	Evaluate and assess ethical issues. Compare risks and burdens to foreseeable benefits and recommend appropriate new or refined ethical guidelines.

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Communication:

The biomedical engineer must communicate effectively with technical and non-technical individuals and audiences in a variety of settings. Proficiency in communication includes skills related to listening, observing, reading, speaking, writing, and preparing graphics. Use of these means of communication requires an understanding of communication within professional practice. Within the scope of their practice, biomedical engineers prepare and/or use calculations, spreadsheets, equations, computer models, graphics, and drawings—all of which are integral to a typically complex analysis and design process. Fundamentals of communication should be acquired during formal education, and pre-licensure experience should build on these fundamentals to refine the biomedical engineer's communication skills.

COMMUNICATION			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge" and "Comprehension"	**"Application" and "Analysis"**	**"Synthesis"**	**"Evaluation"**
Demonstrate basic writing, reading, listening, and oral communication skills by the effective usage of grammar, punctuation, sentence structure, and content organization in formulating written documents and oral presentations. Distinguish facts from opinion. Identify the role of technology in document development.	Demonstrate effective communication skills exhibited in content, organization, logical reasoning, writing, and oral delivery to a specific audience. Demonstrate the ability to interpret technical documents. Challenge and defend a position with supporting evidence and logical reasoning.	Compose a report or presentation using clear, logical, and correct prose adapted to a specific audience. Utilize technology and appropriate media to communicate concepts concisely. Use listening, writing, reading, and oral communication skills effectively in team-based collaborative projects. Conduct peer reviews.	Evaluate and review communication tools such as research proposals, scientific publications, and general methodologies. Assess teaching and communication instruments.

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Lifelong Learning:

Biomedical engineers are associated with a wide variety of responsibilities related to human health. While much is known about the human body, a significantly larger portion remains unknown. Thus, as biomedical discoveries are being made at a fast pace, it is critical for biomedical engineers to engage in a clear methodology to update their knowledge and learn new skills and tool sets.

The gain in new knowledge could span a wide spectrum, ranging from discoveries at the molecular to cellular to tissue to organ level, to new tools and techniques for detection, imaging and treatment of various diseases and abnormalities.

A number of different approaches could be used to engage in a continuous learning process, including reading research articles published in peer-reviewed journals, attending conferences related to biomedical engineering (e.g., the annual meeting of the Biomedical Engineering Society), attending short courses or workshops either online or in person, internet resources, newly updated and published professional and technical books, and popular media.

LIFELONG LEARNING			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension" and "Application"**	**"Analysis"**	**"Synthesis"**
Identify the need to engage in lifelong learning.	Demonstrate the ability to research scientific literature different from prescribed textbooks and apply the knowledge to better understand scientific material.	Distinguish between different options available to help engage in lifelong learning and identify the best course to obtain the required knowledge and skill sets. Be able to describe ways to research scientific peer-reviewed literature.	Develop courses, books, and other relevant specialized education material to enable lifelong learning by others.

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Contemporary Issues and Impact of Engineering Solutions:

Biomedical engineering education must impart engineers with the broad knowledge that allows them to weigh the effects of different engineering solutions on society to identify the most optimal solution. The societal impact could span a wide range of themes, including social, economic, political, ethical, and legal ramifications. Contemporary issues at local and global scales must be integrated into the design and implementation of biomedical solutions.

For example, the need for inexpensive diagnostic and treatment methodologies in developing countries is an important contemporary societal need. The biomedical engineers should be trained to consider such issues during the design and implementation of medical technologies.

With the high degree of globalization, it is also extremely important for biomedical engineers to assess health, sanitation, sustainability, development, supply chain, competitiveness, production, and environmental effects on a global scale to perform their functions effectively.

Obtaining such awareness skills involves continuous learning and interaction on a global scale. Some of the methods by which students can gain these skills include group problem solving of real medical challenges, study abroad and exchange-student options, and working trips to developing countries to obtain knowledge of contemporary issues, medical challenges, and needs of those countries.

ISSUES AND IMPACT OF ENGINEERING SOLUTIONS			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
"Knowledge"	**"Comprehension" and "Application"**	**"Analysis"**	**"Synthesis" and "Evaluation"**
Identify and describe contemporary issues on local and global scales.	Identify the impact of contemporary issues on engineering solutions.	Analyze and integrate the demands of local and global scale contemporary issues into the design and implementation of biomedical and related technologies.	Develop BME solutions that incorporate contemporary issues into the methodologies for design, development, and assessment.

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Specializations (Biomaterials, Tissue Engineering, Bioinformatics, Biomechanics, Bioimaging, Biosensors, Bioinstrumentations, and Modeling):

Since biomedical engineering is a broad and diverse discipline, the field is subdivided into different tracks or specializations. These common tracks or specializations include biomaterials, tissue engineering, bioinformatics, biostatistics, biomechanics, bioimaging, biosensors, bioinstrumentations, and modeling of biological phenomena. The ability to specialize helps to bring focus to the engineer's learning and training.

Biomedical engineers draw upon their engineering knowledge and training in a specific track or specialization to design, evaluate, analyze, solve, and/or develop solutions to a fundamental understanding of human health as well as enhancing diagnosis, monitoring, and therapy.

SPECIALIZATIONS			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
No Competencies Needed	**"Knowledge"**	**"Comprehension," "Application," and "Analysis"**	**"Synthesis" and "Evaluation"**
	Identify areas of specialization in biomedical and related industries.	Obtain specialization-specific knowledge and skills. Examine problems and apply appropriate solutions specific to an area of specialization.	Develop and evaluate new technologies related to an area of specialization.

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Regulatory Affairs:

Products for use of medicine are regulated by government agencies throughout the world, such as the Food and Drug Administration (FDA) in the United States.

Issues of regulatory affairs are critically important throughout the healthcare product lifecycle, from concept through product obsolescence. Biomedical engineers must consider strategic, tactical, and operational direction and support for working within regulations to expedite the development and delivery of safe and effective healthcare products to individuals around the world. Continuous evolution in science and changes in the regulatory environment, health sector and general economics shape the dynamic and expanding scope of regulatory demands. Biomedical engineers must continually grow their knowledge and skills to be effective and to advance in their profession. (Adapted from the Regulatory Affairs Professional Society's Whitepaper 2007, <http://www.raps.org/>.)

REGULATORY AFFAIRS			
Core Competencies Needed to Enter Higher Education in Biomedical Engineering (BME)	**Pre-BME Competencies Gained During First Two Years of Study**	**Baccalaureate-Level BME Competencies**	**Post-Graduate/ Work Experience BME Competencies**
No Competencies Needed	**No Competencies Needed**	**"Knowledge," "Comprehension," and "Application"**	**"Analysis" and "Synthesis"**
	Know that there are regulations for medical products and that there are regulatory entities like the FDA that monitor compliance.	Know and identify the appropriate regulatory pathways for specific medical technologies and utilize the correct framework for achieving regulatory compliance.	Create, analyze, and contrast regulatory strategies for bringing new medical technologies to market.

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Biomedical Engineering Key Competencies Profile

The key competencies profile (page 24) is a schematic diagram that is derived from the competency table (page 8). It lists for each learning outcome (columns) the required competency levels according to Bloom's taxonomy (rows) that must be gained at each of four educational levels:

1. secondary education competencies, marked "HS"
2. pre-engineering competencies, marked "CC"
3. baccalaureate-level competencies, marked "BS"
4. graduate-level competencies, marked "G"

The level of response for each of Bloom's taxonomy levels is described through active verbs; examples of verbs for each level can be found at:

http://www.teach-nology.com/worksheets/time_savers/bloom/

Biomedical Engineering Key Competencies Diagram

	Mathematics	Physical Sciences	Life Sciences	Experimentation	Design	Teamwork	Problem Solving	Engineering Skills, Tools, and Techniques	Ethics	Communication	Lifelong Learning	Contemporary Issues and Impact of Engineering Solutions	Specializations	Regulatory Affairs
Evaluation			G	G	G		G	G	G	G		G	G	
Synthesis	G	G	G	G	BS	G	BS	G	BS	BS	G	G	G	G
Analysis	BS	G	BS	BS	BS	G	BS	BS	BS	CC	BS	BS	BS	G
Application	CC	BS	BS	BS	BS	BS	BS	BS	CC	CC	CC	CC	BS	BS
Comprehension	CC	CC	CC	CC	CC	CC	CC	CC	CC	HS	CC	CC	BS	BS
Knowledge	HS	HS	HS	HS	CC	HS	CC	CC	HS	HS	HS	HS	CC	BS

G	graduate-level competencies
BS	baccalaureate-level competencies
CC	pre-engineering competencies
HS	secondary education competencies

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Community College Program of Study for Transfer to a Biomedical Engineering Program

FRESHMAN YEAR

First Semester (Fall)		SCH	Second Semester (Spring)		SCH
MATH 2413	Calculus I	4	MATH 2414	Calculus II	4
CHEM 1311	General Chemistry I	3	PHYS 2325	University Physics I	3
CHEM 1111	General Chemistry I lab	1	PHYS 2125	University Physics I lab	1
ENGR 1201	Introduction to Engineering	2	BIOL 1406	Biology I with Lab	4
XXXX ####	Texas Core Curriculum	3	XXXX ####	Texas Core Curriculum	3
XXXX ####	Texas Core Curriculum	3	XXXX ####	Texas Core Curriculum	3
		16			**18**

SOPHOMORE YEAR

First Semester (Fall)		SCH	Second Semester (Spring)		SCH
MATH 2415	Multi-Variable Calculus III	4	MATH 2320	Differential Equations	3
CHEM 1312	General Chemistry II	3	ENGR 2305	[2]Electrical Circuits I	3
CHEM 1112	General Chemistry II lab	1	ENGR 2105	Electrical Circuits I lab	1
PHYS 2326	University Physics II	3	CHEM 2323	Organic Chemistry	3
PHYS 2126	University Physics II lab	1	CHEM 2123	Organic Chemistry lab	1
ENGR 2304	[1]Programming for Engineers	3	ENGR 2301	Engineering Mechanics: Statics	3
XXXX ####	Texas Core Curriculum	3	XXXX ####	Texas Core Curriculum	3
		18			**17**

[1]COSC 1436/1336, Programming Fundamentals, may be substituted for ENGR 2304, Programming for Engineers

[2]ENGR 1304, Engineering Graphics, may be substituted for ENGR 2305 and 2105, Electrical Circuits I and its accompanying lab

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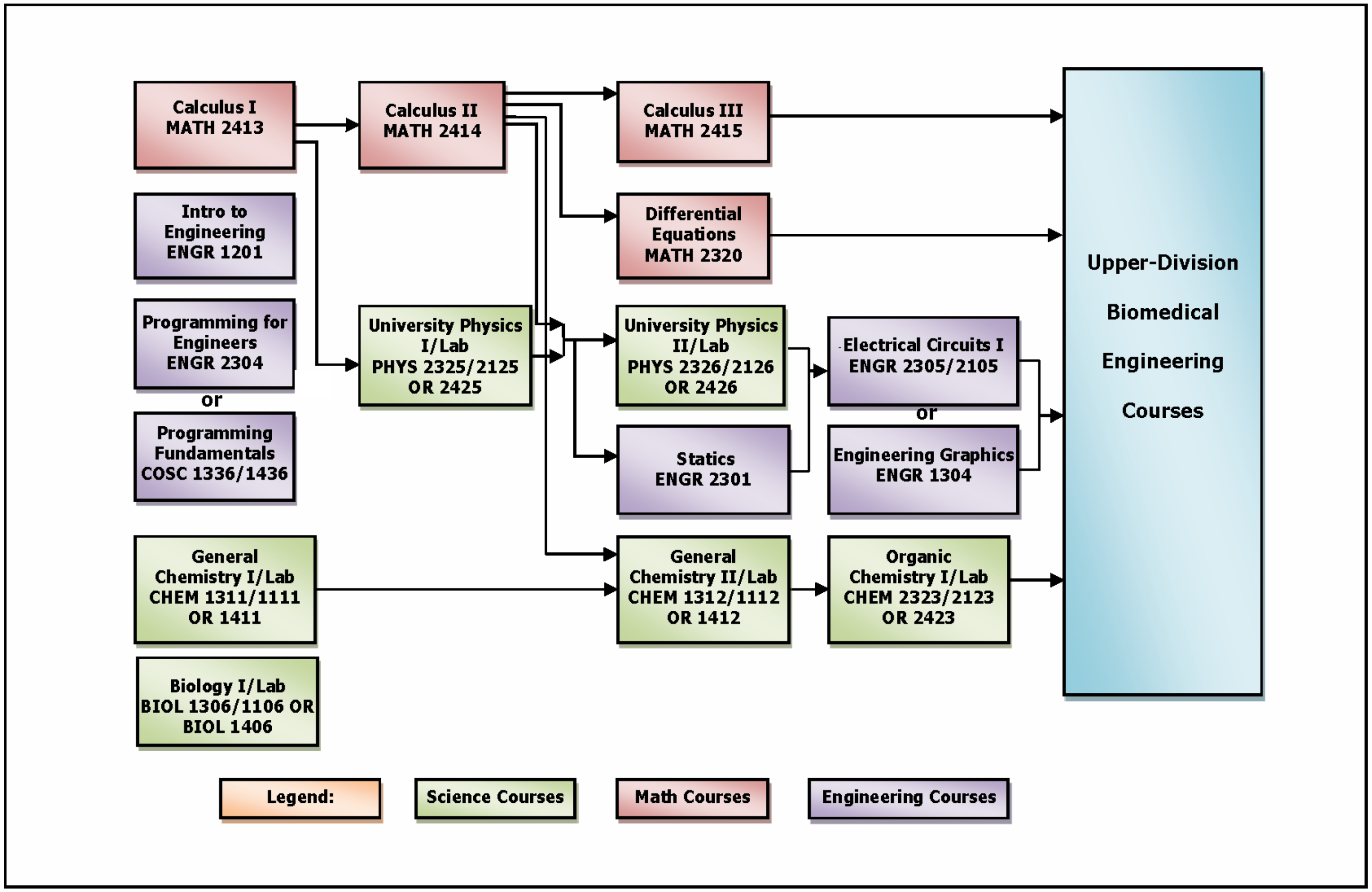
Prerequisite Flowchart for Transfer to a Biomedical Engineering Program



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