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The School of Biomedical Engineering, Science and Health Systems
Graduate Programs

The School of Biomedical Engineering, Science and Health Systems

The School of Biomedical Engineering, Science, and Health Systems (formerly the Biomedical Engineering and Science Institute, founded in 1961) is a leader in biomedical engineering and biomedical science research and education. The undergraduate program was inaugurated in September 1998 and has steadily grown to attract the highest ability students at the University. The program has received accreditation by the Accreditation Board of Engineering Technology (ABET) in 2002 and again in 2008.

Our academic thrust areas, both in research and education, are at the forefront of biosensing, bioimaging, bioinformation engineering and integrated bioinformatics, drug delivery, biomedical ultrasound & optics, bionanotechnology, cellular tissue engineering, neuroengineering and human performance. Emerging initiatives include skin bioengineering, pediatric engineering and homeland security technologies. Various departments at Drexel University offer courses that are suited for students in biomedical engineering and biomedical science. Our curriculum complements the strengths of the Colleges of Arts & Sciences, Business, Engineering, Information Science, Law and Medicine. As a whole, our curriculum offers the advanced knowledge needed for industrial careers, health professions, graduate research or careers in highly specialized fields such as pre-professional health (medical, dental, and veterinary) and pre-law.

The marriage of technology with biology and medicine drives the 21st Century industrial enterprise. Consistent with this mission, we strive for clinical and industrial relevance in our academic pursuits. We enjoy a strong entrepreneurship program in biomedical technologies. Our alliance with regional economic development agencies and corporations together with our advisors from business development, legal, and investment communities sustains the growth of this program. The students and faculty of the School are committed to move their discoveries from our laboratories to clinical practice or home use. The success of our Translational Research in Biomedical Technologies Program has been recognized and funded regionally as well as nationally.

Our School has experienced remarkable growth in recent years thanks to our outstanding research portfolio, high quality and innovative undergraduate program, and our multidisciplinary approach to education and research. Another competitive advantage of our School is the unique free-standing university-level administrative structure with its own tenure-track faculty lines, budget and space. This helps us transcend the traditional organizational boundaries of engineering, sciences and medicine. Our independence allows us to pursue growth and collaborations in various disciplines. Our small size gives us agility to reconfigure and reorganize in response to emerging opportunities. The University Strategic Plan recognizes our School of Biomedical Engineering, Science and Health Systems as “Drexel’s prototype of academic integration. ”

Metropolitan Philadelphia has one of the nation’s highest concentrations of medical institutions and pharmaceutical, biotechnology, medical device and systems industry. The School has forged strategic partnerships with select universities, research institutes, health care institutions and industries in the region. We enjoy a

close working relationship with our Drexel College of Medicine as well as alliances with prominent medical institutions in the region to develop joint research and educational programs. These include University of Pennsylvania, Thomas Jefferson University, the Fox Chase Cancer Center and the Wistar Institute. These collaborative initiatives provide students with ample opportunities in basic and clinical research as well as innovative academic programs.

Applicants to the graduate program must meet the requirements for admission to graduate studies at Drexel University. Candidates for degrees in the School of Biomedical Engineering, Science and Health Systems are required to maintain academics standards applicable to all graduate students at Drexel University.

The School of Biomedical Engineering, Science, and Health Systems

Program Objectives
The overall objective of the graduate programs offered by the School of Biomedical Engineering, Science, and Health Systems is to provide multidisciplinary curricula with an instructional core and research opportunities for students. Graduate biomedical engineering students are typically individuals with undergraduate degrees in engineering, physical sciences, or mathematics. The core curriculum provides the necessary training in life and medical sciences, modeling and simulation, and biomedical engineering applications to allow students to apply their engineering skills and perspective to solve current problems in biology and medicine. Areas in which students may focus their advanced studies and research attention include biomechanics and biomaterials, cellular and tissue engineering, biomedical sensing and imaging, human factors and performance engineering, neuroengineering, and bioinformatics. Students without an academic background in engineering or physical science who wish to enter the biomedical engineering program may enroll in the Crossover Program.

The core courses in the Biomedical Science program are designed to educate life-science students in quantitative analysis, mathematical modeling, systems analysis, and fundamental computational and informatics skills. Students are then encouraged to combine their knowledge of the life sciences with their newly acquired analytical skills to focus in such areas as tissue engineering and/or bioinformatics.

A recent agreement with the Interdepartmental Medical Science Program at the Drexel College of Medicine allows students to spend one year taking courses at the College of Medicine and their second year at the School of Biomedical Engineering, Science and Health Systems—leading to a Master's degree in Biomedical Science.

A non-thesis MS degree is available to non-traditional students seeking advanced studies in biomedical engineering and biomedical science to enhance their careers.

Admission Requirements

Acceptance for graduate study at Drexel's School of Biomedical Engineering, Science and Health Systems requires a four-year bachelor's degree from an accredited institution in the United States or equivalent international institution. Regular acceptance requires a minimal cumulative grade point average of 3.0 (B) on a 4.0 scale for the last two years of undergraduate work, and for any graduate level work undertaken.

Drexel's School of Biomedical Engineering, Science and Health Systems normally requires a TOEFL score of at least 260. Verbal, analytical, and quantitative scores on the GRE General Test are recommended for admission and are required for financial assistantship consideration.

The School practices a rolling admissions policy--students are able to apply at any term during the year, but students are encouraged to matriculate in the fall to ensure proper sequence of coursework.

In addition to the School's requirements, students must satisfy the requirements of the Office of Research and Graduate Studies in matters such as academic standing, thesis, examinations, and time limits.

Students without an academic background in engineering or physical science should review information about the Crossover Program.

Crossover Program

Students without an academic background in engineering or physical science who wish to enter the biomedical engineering program will be enrolled in the Crossover Program, an accelerated curriculum designed to fulfill the requirements for admission to a Drexel graduate engineering program. Classes in the program do not count toward the MS. degree, and they may entail one to two years of additional full-time study. For specific course requirements, students should contact Dr. Rami Seliktar, the graduate advisor for biomedical engineering.

Applicants to the graduate program must meet the requirements for admission to graduate studies at Drexel University. Candidates for degrees in the School of Biomedical Engineering, Science, and Health Systems are required to maintain academic standards applicable to all graduate students at Drexel University.

Graduate Co-op Program (GCP)

Drexel University's long tradition in the field of experiential learning has now been extended into many of its master's programs in science, business, and engineering.

This option, called Graduate Co-op, provides students with the opportunity to gain work experience directly related to their career goals while earning academic credit. Students who have earned a minimum of 24 credits with a GPA of at least 3.0 are eligible to participate. Employment typically lasts six months, during which students enroll in a special 3 credit GCP course coinciding with their term of employment. Students gain work experience while earning salaries. It is important to note that the GCP program does not guarantee a job. It is a market-driven process for the candidates as well as employers. GCP provides the tools and contacts; the student must qualify for the job on the basis of merit, qualifications, and skills.

Further information on the GCP program is available at the Drexel Steinbright Career Development Center.

Biomedical Engineering

General Information
Biomedical engineering is concerned with the application of engineering and science methodologies to the analysis of biological and physiological problems and to the delivery of health care. The biomedical engineer requires the analytical tools and broad physical knowledge of modern engineering and science, fundamental understanding of the biological or physiological system, and familiarity with recent technological breakthroughs.

The biomedical engineer serves as an interface between traditional engineering disciplines and living systems and may work in either direction, applying the patterns of living organisms to engineering design or engineering new approaches to human health. The biomedical engineer may use his/her knowledge of physiological systems to reverse engineer nature, creating, for example, artificial tissues and neural networks. On the other hand, a biomedical engineer may use his/her knowledge of engineering to create new equipment or environments for such purposes as maximizing human performance, accelerating wound healing, or providing non-invasive diagnostic tools.

For more information, visit the The School of Biomedical Engineering, Science, and Health Systems' web site.

Master of Science Program in Biomedical Engineering

The core requirements for the master's in biomedical engineering encompass approximately 45.0 course credits. (Most courses carry three credits each.) A thesis is highly recommended. A non-thesis option is also offered. Students who choose the non-thesis option must take 51.0 credits of coursework and cannot register for thesis or research credits.

The curriculum includes room for specialization in several focus areas of Biomedical Engineering, as well as a Concentration in Biomedical Technology Development.

Curriculum

Core Courses		
BMES 501	**Medical Sciences I: Cellular and Tissue Biology**	3.0
BMES 502	**Medical Sciences II: Organ-Level Physiology**	3.0
BMES 503	**Medical Sciences III: Neural and Endocrine Control Systems**	3.0
BMES 672	**Biosimulation I**	3.0
BMES 673	**Biosimulation II**	3.0
BMES 864	**Seminar**	0.0

Electives

The sum of electives, core credits, and/or thesis credits must total 45.0 for thesis students and and 51.0 for non-thesis students. Elective choices would depend upon the student's area(s) of focus or concentration.

Thesis	
BMES 897	**Research**
BMES 898	**Master's Thesis***

*The research for the thesis may include work carried out during an internship.

Biomedical Technology Development Concentration

Students enrolled in this concentration will develop an understanding of critical regulatory, economic, and legal issues in addition to the project management skills that facilitate the development of new medical devices and positive working relationships with intellectual property lawyers, insurance companies, and the federal government.

Biomedical Technology Development Core Courses		**15.0 Credits**
BMES 509	**Entrepreneurship for Biomedical Engineering**	3.0
BMES 534	**Design Thinking for BMEs**	3.0
BMES 538	**Biomedical Ethics and Law**	3.0
BMES 588	**Medical Device Development**	3.0
BMES 590	**Clinical Rotation**	3.0

Biomedical Engineering: Areas of Focus

Students can plan their own focus area that will give them strength in a particular sub-discipline. Alternatively, the student can specialize by conducting research and writing a thesis.

The focus areas of the School's faculty from which students can learn and participate in research include:

Biomaterials and Tissue Engineering
Biomaterials and tissue Engineering is designed to provide students with advanced training in cellular and molecular biology relevant to tissue engineering and behavior of materials used in biomedical applications.

Biomechanics and Human Performance Engineering
Biomechanics and human performance engineering is designed to meet two objectives: to acquaint students with the responses of biological tissues to mechanical loads as well as with the mechanical properties of living systems and to provides the students with the background and skills needed to create work and living environments which improve human health and enhance performance. Biomechanics and Human Performance also involves the study of orthopedic appliances and the broader aspect of Rehabilitation Engineering and the Management of Disability.

Biomedical Systems and Imaging
Biomedical systems and imaging focuses on the theoretical and practical issues related to machine vision, image processing and analysis, and signal processing associated with such medical applications as well biomedical instrumentation and product development.

Biomedical Technology Development Concentration
Students pursuing the concentration will develop an understanding of critical regulatory, economic, and legal issues in addition to the project management skills that facilitate the development of new medical devices and positive working relationships with intellectual property lawyers, insurance companies, and the federal government. (This is a formal concentration with specific course requirements.)

Bioinformatics
Bioinformatics emphasizes a systems engineering approach to provide a foundation in systems biology and pathology informatics. Students are provided with hands-on experience in the application of genomic, proteomic, and other large-scale information to biomedical engineering as well as experience in advanced computational methods used in systems biology: pathway and circuitry, feedback and control, cellular automata, sets of partial differential equations, stochastic analysis, and biostatistics.

Neuroengineering
Neuroengineering is broadly defined to include the modeling of neural and endocrine systems, neural networks, complexity in physiological systems, evolutionary influences in biological control systems, neurocontrol, and neurorobotics.

PhD in Biomedical Engineering

90.0 credits.

Degree Requirements

To be awarded the PhD degree, students must complete 90 credits and fulfill the one-year residency requirement. The following milestones have to be satisfied during the course of the program:

1. Students must successfully pass the candidacy examination;
2. Students must submit a PhD dissertation proposal and successfully defend it;
3. Students must write a dissertation and successfully pass final oral defense.

Post-Baccalaureate Requirements and Post-Master's Requirements

Both post-baccalaureate and post-master's students are admitted into the doctoral program in Biomedical Engineering, but have slightly differing sets of requirements.

For **post-master's students**, 45.0 of the credits that they earned toward their Master's degree may be applied toward the PhD. If coming from the Master's program in Biomedical Engineering at Drexel University, those courses they took would apply. For non-Drexel students who have completed their master's elsewhere, there may be exceptions made. If these students believe that they have covered the material of the required courses in another program, they must show evidence of such material and obtain a formal waiver of this requirement from the Graduate Advisor.

For **post-baccalaureate students**, students must complete a minimum of 90.0 credits of courses and a research thesis. These 90.0 credits of courses include the core courses required by Drexel's MS in Biomedical Engineering, as follows:

Core Courses		**15.0 Credits**
BMES 501	**Medical Sciences I: Cellular and Tissue Biology**	3.0
BMES 502	**Medical Sciences II: Organ-Level Physiology**	3.0
BMES 503	**Medical Sciences III: Neural and Endocrine Control Systems**	3.0
BMES 672	**Biosimulation I**	3.0
BMES 673	**Biosimulation II**	3.0
BMES 864	**Seminar**	0.0

In addition to the required courses, pos-baccalaureate PhD students must take at least 21.0 more credits in courses. This balance may be taken as research and/or thesis/dissertation credits.

Thesis Advisor/Plan of Study

During the first year of the program all Doctoral students are required to identify a Thesis Advisor and complete a plan of study. The student's Thesis Advisor and the Graduate Advisor will guide the student in developing this plan of study. Each plan of study is individually tailored to the student, and includes a combination of

research and course credits most beneficial and complimentary to the student’s chosen thesis topic.

The Candidacy Examination
Doctoral students must successfully pass a candidacy examination, preferably at the end of the first year of their study, but no later than the end of the second year.

The overall objective of the candidacy examination is to test the student's basic knowledge and preparedness to proceed toward a PhD in Biomedical Engineering. The candidacy examination contains two parts: a written portion and a pre-proposal. In the written portion of the candidacy examination, students are expected to demonstrate physical science aptitude and a preparation to formulate and model biomedical problems. The pre-proposal portion focuses on the formulation of a brief research protocol of a specific study, its presentation to a committee of five faculty members, an the student's ability to successfully answer relevant questions.
After a satisfactory performance on the candidacy examination the student is awarded the Doctoral Candidate status. Candidates must submit a Thesis Proposal by the end of the second year and defend it in an oral presentation to a committee of five faculty members.

Thesis Defense
After the student has successfully completed all the necessary research and composed a thesis manuscript, in accordance with the guidelines specified by the Office of Research and Graduate Studies, he or she then must formally defend their thesis. A formal thesis defense includes an oral presentation of research accomplishments in front of a committee of faculty members. The thesis defense is open to the general public.
Prospective PhD students are welcome to contact the school to discuss their research interests. For a more detailed description of the PhD requirements, please visit the School of Biomedical Engineering and Health Systems' Biomedical Engineering web site.

Biomedical Science

General Information
Biomedical science is a broad field concerned with the application of fundamental biological research and quantitative analysis to human health.
The overall objective of the School of Biomedical Engineering, Science and Health Systems is to provide multidisciplinary programs offering an instructional core curriculum and research in selected areas.

The graduate program in biomedical science educates students whose undergraduate education is in basic life sciences (e.g. , biology or biochemistry) or paramedical disciplines (e.g. , nursing, physical therapy, or medical technology) in quantitative analysis, mathematical modeling, fundamental computing skills, and informatics.

For students entering with degrees in physics, mathematics, and/or computer science, the School, in close collaboration with the Department of Biology, provides the coursework needed to acquire proficiency in the life sciences. Students in biomedical science achieve depth in the modeling of living systems and biomedical information processing and display.

Students may choose to specialize in **Biomaterials and Tissue Engineering** or **Bioinformatics**. Students who graduate with a master's degree from the biomedical science program often continue clinical training in medicine, dentistry, or veterinary medicine; pursue further graduate study toward the PhD degree; or work in industry in such fields as health care, pharmaceuticals, biotechnology, medical devices, etc.

For more information, visit the The School of Biomedical Engineering, Science, and Health Systems' web site.

Master of Science Program in Biomedical Science

The core requirements for the master's in Biomedical science encompass approximately 45 course credits (most courses carry three credits each). A thesis is highly recommended. A Non-Thesis option is also offered. The School of Biomedical Engineering, Science and Health Systems has recently decided to eliminate the comprehensive exam as a part of the requirements for the Non-Thesis master's degree. This change is effective immediately for those students that commenced their studies in the Fall term of the 2006-2007 Academic Year. Students who began their studies prior to that date are subject to the original requirements. However, students will be allowed to appeal to the Graduate Advising Committee for a waiver of the exam. Appeal requests will be considered on an individual basis by a committee and will be based on academic performance.

A unique aspect of the School's Biomedical sciences program is its ability to integrate aspects of physiology and molecular biology with quantitative analysis, mathematical modeling, and computer processing to create a systems approach to biomedical research and applications. Elective courses such as Biological Control Systems; Applied Evolution; and Chronobioengineering reflect the School's emphasis on multidisciplinary approaches to the most current research in biology and medicine.

Curriculum

Courses		
BMES 505	**Mathematics for Biomedical Science I**	3.0
BMES 506	**Mathematics for Biomedical Science II**	3.0
BMES 507	**Mathematics for Biomedical Science III**	3.0
BMES 510	**Biomedical Statistics**	4.0
BMES 511	**Principles of Systems Analysis Applied to Biomedicine I**	3.0
BMES 512	**Principles of Systems Analysis Applied to Biomedicine II**	3.0
BMES 514	**Computer Applications for Biomedical Research**	3.0
BMES 515	**Experimental Design in Biomedical Research**	4.0
BMES 538	**Biomedical Ethics and Law**	3.0

Electives		**18.0**
BMES 897	**Research**	variable
BMES 898	**Master's Thesis**	variable

Areas of Specialization
Two concentrations are currently offered within the Biomedical Science graduate program:

- **Biomaterials and Tissue Engineering**
- **Bioinformatics**

Additional Courses in Biomaterials and Tissue Engineering

BMES 631	**Tissue Engineering I**	4.0
BMES 632	**Tissue Engineering II**	4.0
BMES 660	**Biomaterials I**	4.0
BMES 661	**Biomaterials II**	4.0
BMES 675	**Biomaterials and Tissue Engineering III**	4.0

Additional Courses in Bioinformatics

BMES 543	**Quantitative Systems Biology**	4.5
BMES 544	**Genome Information Engineering**	4.5
BMES 545	**Biocomputational Languages**	4.5
BMES 546	**Biosystems Modeling**	4.5
BMES 551	**Biomedical Signal Processing**	3.0
BMES 604	**Pharmacogenomics**	3.0

Biomedical Science Areas of Specialization

Two concentrations are currently offered within the Biomedical Science graduate program:

Biomaterials and Tissue Engineering
Biomaterials and Tissue Engineering is designed to provide students with advanced training in cellular and molecular biology relevant to tissue engineering and behavior of materials used in biomedical applications.

Bioinformatics
This specialization emphasized a systems engineering approach to provide a foundation in systems biology and pathology informatics. Students are provided students with hands-on experience in the application of genomic, proteomic, and other large-scale information to biomedical engineering as well as experience in advanced computational methods used in systems biology: pathway and circuitry, feedback and control, cellular automata, sets of partial differential equations, stochastic analysis, and biostatistics.

Doctoral Program in Biomedical Science

Superior students with training in engineering, natural science, or physical science as well as individuals with academic or professional degrees in the medical science disciplines will be considered for admission to the doctoral program.

To be awarded the PhD, students must complete 90 credits (credits earned toward a master's degree may apply toward the 90), fulfill a one-year residency requirement, and successfully pass the qualifying examination, the candidacy examination, and a PhD dissertation and oral defense. Prospective PhD students are welcome to contact the school to discuss their research interests
For more information, visit the School’s web site and click on Graduate Programs.

Articulation with Interdepartmental Medical Science Program at the Drexel College of Medicine

The School of Biomedical Engineering, Science and Health Systems collaborates with the Drexel College of Medicine, specifically with the Interdepartmental Medical Science Program (IMSP), to offer a unique pathway to a Masters in Biomedical Science. Students complete 1 year in the IMS program (described below) and then complete their second year at the School. This involves completing the core sequence and a thesis or taking a non-thesis option with additional coursework. Student may elect to pursue **Certificates of Advanced Study** in either **Biomaterials and Tissue Engineering** or **Bioinformatics**.

IMSP Curriculum
The IMS curriculum involves a full-time commitment to rigorous coursework with strong academic requirements. Six major medical school courses are taken simultaneously with the College of Medicine first-year class. These include Medical Biochemistry, Cell Biology & Microanatomy, Medical Physiology, Medical Nutrition, Medical Immunology, and Medical Neuroscience.

The medical school lectures are simulcast to the Health Sciences Campus (located in Center City, Philadelphia) from the Drexel University College of Medicine campus (located in East Falls, Philadelphia). The lectures are also videotaped and available in the Health Sciences library as well as being accessible via streaming video on the web. The students take the exact same courses and exams as the medical students and are evaluated based on their performance in comparison to our medical school students. Performance on tests, quizzes, and assignments equal to the mean grade of the medical school class signifies a letter grade of “B” for the IMS students. Thus, IMS students receiving A's and B's are performing at the top 50% of the medical school class and can then present themselves with strong academic credentials before the admissions committee. This permits medical school admissions committees to directly evaluate the student's competence compared with their own first year medical school class. This allows students an opportunity to test their preparation, motivation, and commitment to medicine.

In addition to the medical school courses, students take a medical ethics course each semester. The campuses are approximately five miles apart and a University shuttle provides free transportation between the two.

Additionally, course conferences and laboratory components for IMS students are conducted at the Health Sciences Campus where the program is based. The IMS curriculum allows exposure to both medical school lectures and individual attention from medical school professors in small group conferences.

For more information, visit Drexel's College of Medicine Interdepartmental Medical Science Program web page.

Advanced Certificate in Bioinformatics

24.0 credits

The Advanced Certificate in Bioinformatics emphasizes a systems engineering approach to provide a foundation in systems biology and pathology informatics. Students are provided with hands-on experience in the application of genomic, proteomic, and other large-scale information to biomedical engineering as well as experience in advanced computational methods used in systems biology: pathway and circuitry, feedback and control, cellular automata, sets of partial differential equations, stochastic analysis, and biostatistics.

Required Courses		**24.0 Credits**
BMES 543	**Quantitative Systems Biology**	4.5
BMES 544	**Genome Information Engineering**	4.5
BMES 545	**Biosystems Modeling**	4.5
BMES 546	**Biocomputational Languages**	4.5
BMES 551	**Biomedical Signal Processing**	3.0
BMES 604	**Pharmacogenomics**	3.0

Advanced Certificate in Biomedical Technology Development

24.0 credits

This certificate program is designed for working engineers interested in medical devices and technology. Students enrolled in this program will develop an understanding of the critical regulatory, economic, and legal issues in addition to the project management skills that facilitate the development of new medical devices.

Required Courses

BMES 501	**Medical Sciences I: Cellular and Tissue Biology**	3.0
BMES 502	**Medical Sciences II: Organ-Level Physiology**	3.0
BMES 503	**Medical Sciences III: Neural and Endocrine Control Systems**	3.0
BMES 509	**Entrepreneurship for Biomedical Engineering**	3.0
BMES 534	**Design Thinking for BMEs**	3.0
BMES 538	**Biomedical Ethics and Law**	3.0
BMES 588	**Medical Device Development**	3.0
BMES 590	**Clinical Rotation**	3.0

Advanced Certificate in Tissue Engineering

20.0 credits

The Advanced Certificate in Tissue Engineering is designed to provide advanced training in cellular and molecular biology relevant to tissue engineering and behavior of materials used in biomedical applications.

Required Courses		20.0 Credits
BMES 631	**Tissue Engineering I**	4.0
BMES 632	**Tissue Engineering II**	4.0
BMES 660	**Biomaterials I**	4.0
BMES 661	**Biomaterials II**	4.0
BMES 675	**Biomaterials and Tissue Engineering III**	4.0