The Master's Degree Program in Applied Biomedical Engineering

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The Master's Degree Program in Applied Biomedical Engineering was established in 1993. This article describes its history, organization, curriculum, faculty, and students.

INTRODUCTION

Biomedical engineering emerged as a recognized discipline during the 20th century, and its growth accelerated rapidly during the last half of that century. The first formal academic programs were established at The Johns Hopkins University, the University of Pennsylvania, the University of Rochester, and Drexel University in the 1950s when they received training grants for biomedical engineering from the National Institutes of Health (NIH).[1] At Johns Hopkins this action ultimately led in 1970 to the establishment of the Biomedical Engineering (BME) Department in the School of Medicine.[2] In 1980, the undergraduate BME Program was established in the Whiting School of Engineering, thus drawing on the strengths of both schools. It is now the largest undergraduate program in the Whiting School. There are now more than 90 established biomedical engineering programs and departments in the United States.

In recognition of the importance of this growing field, NIH established the Bioengineering Consortium (BECON) in 1997. Its membership consists of senior-level representatives from all institutes, centers, and divisions of NIH plus representatives from other government agencies that are concerned with biomedical research and development. BECON continues to be the focus of biomedical engineering activities at NIH. The consortium developed an excellent definition of this discipline:

> Bioengineering integrates physical, chemical, mathematical, and computational sciences and engineering principles to study biology, medicine, behavior, and health. It advances fundamental concepts; creates knowledge from the molecular to the organ systems levels; and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health.[3]

Recognition of biomedical engineering as an established discipline culminated in 2000 with the formal establishment of the new Institute of Biomedical Imaging and Bioengineering at NIH.

Biomedical research and biomedical engineering at APL began in 1965 with the creation of the Collaborative Biomedical Program with the Johns Hopkins School of Medicine.[2] Five issues of the *Technical Digest* have been devoted to describing biomedical programs and projects,[4–8] and individual articles on biomedical topics have appeared in several other volumes of the *Digest*. The APL Science and Technology Council has

included Biomedical and Biochemical Technology as one of the categories in their taxonomy describing the current and anticipated climate for technology development at the Laboratory.[9]

PROGRAM HISTORY

As an initial offering, BME Department faculty designed and taught a two-semester course at APL on the physiological foundations of biomedical engineering. This excellent course was offered from 1970 to 1974 and was taken by many of the participants in the Collaborative Biomedical Program, including the author.

The need to design a complete master's degree curriculum to be offered in the Whiting School of Engineering's part-time program at APL became apparent during discussions following a presentation to the external advisory council of the BME Department in 1992.[10] Planning for the new program commenced shortly thereafter under the guidance of the original program committee, whose members were

Richard A. Farrell, Program Chair: Principal Professional Staff of APL; Associate Professor of Biomedical Engineering and Ophthalmology, JHU School of Medicine

Vincent L. Pisacane: Principal Professional Staff of APL

Murray B. Sachs: Principal Professional Staff of APL; Professor and Director of Biomedical Engineering, JHU School of Medicine

Artin A. Shoukas: Professor of Biomedical Engineering, JHU School of Medicine

The committee established the goal of the new program: to educate and train practicing scientists and engineers to be able to apply knowledge from engineering and physics to enhance the understanding of and to provide solutions to problems in biology and medicine. They designed the new part-time program to complement the full-time BME Program by making it available to residents in the Baltimore–Washington area who had conflicting demands on their time that made full-time study difficult. The committee also intended that the program provide a sound foundation for further studies at the doctoral level. The part-time program differs from the full-time program primarily in one respect: the graduation requirements of the former can be satisfied by course work alone (with research projects being optional), whereas the latter requires a thesis.

The program was initially titled Engineering and Applied Physics of Biomedicine to avoid potential confusion with the full-time BME Program. A proposal for the program was submitted to and approved by the Maryland Higher Education Commission in 1993. The first classes began in the fall of 1993, and the first student graduated in 1995. To date, 91 students have graduated from the program. Figure 1 shows enrollments from 1993 through the summer of 2005.

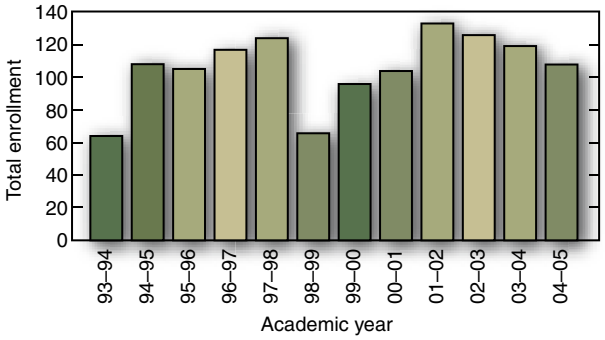

Figure 1. Enrollment history in the Applied Biomedical Engineering Program.

In 1999, after consultation with Dr. Murray Sachs and the full-time BME faculty, the program was renamed. The new name, Applied Biomedical Engineering (ABE), was deemed to be less awkward and more descriptive of the program's goals. Also in 1999, Dr. Richard Farrell stepped down as Program Chair and the author assumed that role.

PROGRAM DESCRIPTION

Faculty

The quality of the ABE faculty is a major strength of the program. The faculty includes members of the Principal Professional or Senior Staff of APL; faculty members of the full-time BME Program at Johns Hopkins, the Johns Hopkins Medical School, and the University of Maryland Medical School; and NIH and Food and Drug Administration (FDA) staff members. Most faculty members have a Ph.D. or M.D. degree (some have both), and three from APL have joint appointments at the School of Medicine. All faculty members are actively involved in research and development related to the subjects they teach.

Program Committee

The program committee's primary functions are to discuss ways of ensuring and maintaining academic quality, to review the progress and status of the program, to discuss possible new initiatives for increasing enrollment, and to evaluate possible new courses or areas of concentration. The committee normally meets yearly during the fall semester. In addition, the Chair has informal conversations with individual committee members as needs arise. The membership of the current committee is

Russell L. McCally, Program Chair: Principal Professional Staff of APL; Associate Professor of Ophthalmology, JHU School of Medicine

Isaac N. Bankman, Principal Professional Staff of APL; Assistant Professor of Biomedical Engineering, JHU School of Medicine

Vincent L. Pisacane: Robert A. Heinlein Professor of Aerospace Engineering, U.S. Naval Academy

Murray B. Sachs: Principal Professional Staff of APL; Massey Professor and Director of Biomedical Engineering, JHU School of Medicine

Admission Requirements

In addition to meeting the general Engineering Programs for Professionals admission requirements, applicants to the ABE Program must have compiled at least a "B" (3.0 on a 4.0 scale) average for their undergraduate courses in mathematics, physics, engineering, and other physical and biological sciences. The applicants' preparation must have included mathematics through ordinary differential equations and vector analysis; calculus-based physics, including mechanics, heat and energy, electricity and magnetism, and elementary quantum concepts; and inorganic and organic chemistry. Because many engineers may not have had the opportunity to take a course in organic chemistry, the program offers a noncredit course to satisfy that entrance requirement. Similarly, because many applicants have backgrounds in either the biological sciences or chemistry, and therefore may lack all of the required mathematics courses, the Applied and Computational Mathematics Program offers a noncredit course to enable them to meet the mathematics entrance requirements. Potential students also can use this course to refresh their mathematics knowledge.

Curriculum

A total of 10 one-semester courses must be completed within 5 years. The curriculum (see the boxed insert) consists of five required courses, three or four electives from the ABE curriculum, and one or two courses elected from other offerings of JHU. At least four of the elective courses must be taken for advanced graduate credit, i.e., at the 600, 700, or 800 level. An elective course may be substituted for a required course if the student has previously completed an equivalent graduate-level course or can demonstrate competency. Students may also select electives from the graduate courses in the BME Department. These courses are offered either at the Medical School or Homewood campus at their regularly scheduled hours during the day. In addition,

COURSES FOR THE MASTER'S DEGREE PROGRAM IN APPLIED BIOMEDICAL ENGINEERING

Required courses	
585.405	Physiology for Applied Biomedical Engineering 1
585.406	Physiology for Applied Biomedical Engineering 2
585.407	Molecular Biology
585.408	Medical Sensors and Devices
585.409	Mathematical Methods for Applied Biomedical Engineering (The two-semester Mathematical Methods course from the Applied Physics Program may be substituted for this course with advisor approval.)
Elective courses offered at APL or the Dorsey Center	
585.605	Medical Imaging
585.606	Medical Image Processing
585.607	Medical Image Processing II—MRI
585.608	Biomaterials
585.609	Cell Mechanics
585.610	Biochemical Sensors
585.611	Practices of Biomedical Engineering
585.614	Applications of Physics and Technology to Biomedicine
585.618	Biological Fluid and Solid Mechanics
585.620	Orthopaedic Biomechanics
585.800	Special Project in Applied Biomedical Engineering
585.801	Directed Studies in Applied Biomedical Engineering
Elective courses offered at Homewood and the Medical School	
580.625–626	Structure and Function of the Auditory and Vestibular Systems
580.628	Modeling the Auditory System
580.630	Theoretical Neuroscience
580.632	Ionic Channels in Excitable Membranes
580.634	Molecular and Cellular Systems Physiology Laboratory
580.637	Cellular and Tissue Engineering
580.638	Cell Mechanics and Motility
580.644	Neuronal Control of Movement and Vocalization
580.651	Introduction to Non-linear Dynamics in Physiology
580.673	Advanced Seminar in Magnetic Resonance Imaging
580.683	High Performance Computing in Biology
580.684	Experimental Foundations for Neural Models
580.702	Neuroengineering

students may also partially fulfill the elective requirement with related courses offered through the Zanvyl Krieger School of Arts and Sciences Advanced Academic Programs. Students are required to file a program plan listing the courses they intend to take. All electives and program plans require the approval of the students' advisors.

Students

Students in the program come from a variety of educational backgrounds. Although the majority have a grounding in engineering, many have backgrounds in biology or other areas such as physics or chemistry. Several students have had other engineering master's degrees and have enrolled in the program seeking to broaden their experience with a second degree or professional certificate. A few have had Ph.D. or M.D. degrees and were taking one or more courses to gain additional expertise in a particular area such as image processing. Several graduates have used the program as a basis for further post-graduate education, including Ph.D. programs, medical school, dental school, and law school. However, most students use the program to advance in their existing professional careers.

Although some students in the program work at APL, most are employed elsewhere in the Baltimore–Washington metropolitan area, e.g., the Johns Hopkins School of Medicine, NIH, the FDA, the U.S. Patent and Trademark Office, the National Institute of Standards and Technology, Northrop Grumman, and a variety of small biotech firms.

The 20-20 Program

At the suggestion of Dr. Vincent Pisacane in 1999, we began to formulate a program that would enable selected students to obtain their degree in 20 months while working 20 hours per week on a biomedical project at APL. The initial goals of this new program were to

- Increase the number of students in the ABE Program
- Increase APL's collaboration with the Whiting School of Engineering and the BME Department of the Medical School
- Provide on-the-job experience for students
- Provide a means for APL to evaluate potential employees to participate in its biomedically related work

Students selected for the program would become employees of the Whiting School and would receive a stipend equivalent to that received by master's degree candidates in the full-time BME Program in addition to their tuition.

The 20-20 Program was proposed to Dean Ilene Bush-Vishniac in December 1999 and approved by her in June 2000. Dr. Richard Roca, Director of APL, subsequently endorsed it. The first two students began their studies in the fall 2001 semester and graduated in May 2003. Although these students were very successful academically and in their work at APL, both chose to pursue their careers elsewhere. The third student in the program is expected to graduate in May 2006 and will attend medical school.

Applicants continue to express considerable interest in the 20-20 Program, but obtaining the necessary funds from directly supported APL programs has been a continuing difficulty.

CONCLUSION

The ABE Program has highly qualified faculty members who are actively engaged in research and development activities related to the subjects they teach. The program serves students with a wide range of backgrounds, including engineering, the physical sciences, and the biological sciences. Several graduates have gone on to further post-graduate education, but most use the program to advance in their existing professional careers throughout the Baltimore–Washington area.

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