Master's Degree Program in Engineering and Applied Physics of Biomedicine

Richard A. Farrell, Vincent L. Pisacane, Isaac N. Bankman, Artin A. Shoukas, and Murray B. Sachs

The Applied Physics Laboratory, along with the Biomedical Engineering Department and other faculty at the Hopkins Homewood campus, has organized a collaborative part-time master of science program in biomedicine. The research activities of the instructors are a major strength of the program. APL participates in this program as part of its educational mission and to contribute to the growing importance of biomedical technologies to the economy of the Washington–Baltimore area.

INTRODUCTION

The Engineering and Applied Physics of Biomedicine Part-Time Master's Degree Program in The Johns Hopkins University G. W. C. Whiting School of Engineering adds a new dimension to the productive Biomedical Engineering and Health Care Program at APL. The strengths of the program, which began in the mid-1960s, derive in large measure from collaborative efforts between medical experts at the Johns Hopkins Medical Institutions (JHMI) and engineers and physical scientists at the Laboratory. The medical school's Biomedical Engineering Department (BME) has the primary responsibility for the research program. Biomedical engineering was just emerging as a technical discipline at the inception of the collaboration, and the need to expose APL participants to the fundamentals of this discipline was obvious. Consequently, the BME faculty designed and taught a two-semester course at APL on the physiological foundations for biomedical engineering. The research efforts of many early APL participants in the collaborative program were influenced by the knowledge they obtained from that course.

These APL scientists and engineers apply their professional skills to understand the function and structure of the human body and to develop innovative biomedical tools. There are diverse engineering and physics challenges involved in the pursuit of biomedical research and development. Research challenges range from the micro level, where molecular structure dictates physiological function, to the systems level in problems such as the complex electromechanical activity of the heart. Development challenges include instrumentation for diagnostics and therapy as well as medical informatics and clinical systems. The techniques and approaches used in biomedical projects are also diverse and include biomaterials, signal processing, imaging, modeling, software engineering, electronics, and solid and fluid mechanics.

Biomedical engineering is inherently an interdisciplinary field based on synergism between scientists or engineers and health professionals. In some instances, the health care professional approaches the scientist or engineer with a diagnostic or therapeutic problem needing a technological solution. In other cases,

diagnostic or therapeutic tools used daily in clinics across the country are first conceived by scientists and engineers whose intuition compelled them to investigate the use of physical techniques for sensing physiological variables or anatomical structures in ways not imagined before. At APL, examples include the use of electromagnetic radiation to probe, alter, and excite structures within tissues; theoretical modeling to deduce structure–function relations and to interpret signals; and miniaturization technologies to change the ways in which medications are administered.

The magnetic resonance imaging (MRI) scanner is a classic illustration that was developed outside APL. Physicists and engineers realized that the nuclear magnetic resonance phenomenon applied to localized spectroscopy could also be the basis of a large-scale imaging approach that scans and records magnetic field strengths at different locations. This realization was followed by efforts to improve high-field magnets and to design a scanning mechanism that would provide better resolution. Outstanding technical achievements in the development of MRI were motivated by the ever-present need to map the interior of the human body in order to determine more promptly and accurately the cause of disease. Many other innovations in instrumentation or basic research were made possible by the dedicated contributions of physical scientists and engineers.

One difficulty faced by researchers in this arena is the need for communication among physical, biological, and medical scientists in order to overcome cultural barriers. Based on the outstanding success of the full-time biomedical engineering curriculum at JHMI, the part-time program in Engineering and Applied Physics of Biomedicine was instituted to help address these interactions.

PROGRAM HISTORY

In 1992, as part of the Laboratory's efforts to reinvigorate the Collaborative Biomedical Programs, a status report was presented at a meeting of the external advisory council of the BME Department. The report concentrated on joint research and engineering projects and on recent initiatives to strengthen APL's ties with the Department. One adviser asked about collaborative efforts in education. The above-mentioned physiological foundations course was discussed, as was the fact that it was no longer offered at APL. The first suggestion was to reintroduce that course at APL; however, further discussion soon made obvious the advantages of designing a complete Master's Degree curriculum within the Whiting School of Engineering part-time program at APL. Those advantages include increased mutual awareness of the research interests and capabilities through joint teaching by technological and health professionals; a clear message to Laboratory staff that biomedical activities are valued at APL; and an opportunity to help APL satisfy that part of its mission "to participate in the educational programs of the academic divisions of the University to which its staff can make an especially favorable contribution."

Three critical elements were viewed as necessary for a successful endeavor: (1) it should be collaborative, e.g., the curriculum should be designed jointly by BME and APL, and most of the courses should be team taught by faculty from all three campuses who are active researchers; (2) most of the courses should be taught at APL in order to facilitate and encourage its staff to work in this area of growing importance to the Laboratory and to enhance the opportunity for other Maryland citizens to contribute to making the state one that advances excellence in biomedicine; and (3) quality should be paramount in selecting courses, faculty, and students.

The faculty in the full-time program are rightfully proud of being recognized as the #1-ranked biomedical engineering graduate program in the country. The part-time program complements the full-time master's degree program offered by BME. The requirements of the full-time program include a thesis, whereas the requirements of the part-time program can be satisfied by course work alone, with research projects being an available credit option.

To avoid potential confusion, the part-time program was titled Engineering and Applied Physics of Biomedicine (EAPB). Its goal is to educate and train practicing scientists and engineers to apply knowledge from engineering and physics to enhance the understanding of and provide solutions to problems in biology and medicine. The program is also intended to provide a sound foundation for further studies at the doctoral level. The part-time nature of the program makes this educational experience available to residents in the Washington–Baltimore area who cannot participate in the full-time program. Thus, the part-time program helps fulfill the public service mission of the University. Significantly, the courses offered in the Engineering and Applied Physics of Biomedicine Program also supplement those offered in the Master of Science in Biotechnology Program of the School of Arts and Sciences Part-Time Graduate Programs in the Montgomery County Center. These two programs are distinct enough that they complement one another effectively and offer students a wide range of options. Students can cross register with the concurrence of their advisers and instructors.

THE PROGRAM

The curriculum for the Master of Science degree in Engineering and Applied Physics of Biomedicine was developed by the program committee, which currently includes

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

Vincent L. Pisacane: Principal Professional Staff and Assistant Director for Research and Exploratory Development, JHU/APL; Associate Professor of Biomedical Engineering, JHU School of Medicine

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

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

Artin A. Shoukas: Professor of Biomedical Engineering, Professor of Physiology, and Director of the Undergraduate Biomedical Engineering Program, JHU School of Medicine

The course offerings listed in the boxed insert include those with a theoretical emphasis (e.g., Mathematical Methods for Physics and Engineering and Molecular Biology); those with a medical technology emphasis (e.g., Medical Imaging and Medical Sensors and Devices); and those with a laboratory experiment and model emphasis (e.g., Physiology for Engineering and Applied Physics of Biomedicine, Biological Fluid and Solid Mechanics, and the Special Project and Directed Studies offerings). All but two courses have been taught; Biochemical Sensors will be offered for the first time in the fall of 1995, and Medical Image Processing will be offered in the spring of 1996. With the exception of Molecular Biology and Cell Mechanics, the teams teaching these courses come from both APL and BME.

All candidates must meet the general requirements for admission to a part-time graduate program of the Whiting School of Engineering. In addition, applicants must have compiled an average of B (3.0 on a 4.0 scale) or above for all courses in mathematics, physics, engineering, and the other physical and biological sciences. Enrollment in the Engineering and Applied Physics of Biomedicine Program may be limited, especially during the early phases of its development. The applicant's preparation must include (1) mathematics, through vector analysis and ordinary differential equations; (2) physics, including mechanics, heat and energy, electricity and magnetism, and calculus-based college physics; and (3) both inorganic and organic chemistry. In special cases an applicant who does not meet the general requirements, but who may have sufficient competence in related areas, may be admitted as a special student to take courses without graduate credit.

The Master of Science degree in Engineering and Applied Physics of Biomedicine requires that 10 one-semester courses be completed within 5 years. The program can be completed in five semesters by taking two courses per semester, but more typically it will take 3 to 4 years to complete. (Summer offerings are available on a limited basis.) Students develop their own program plans, which must be approved by their advisers.

The curriculum consists of five required courses, plus three or four courses elected from the Engineering and Applied Physics of Biomedicine curriculum, and one or two courses elected from other offerings in the part-time program of the School of Engineering with the approval of the student's adviser. In addition, the student may elect graduate courses in BME to fulfill the electives with the approval of the adviser and instructor. Students may also select related courses offered through the part-time programs of the School of Arts and Sciences, again with adviser approval. At least four courses must be taken for advanced graduate credit (i.e., at the 600- to 800-level). With the approval of the adviser, an elective course may be substituted for a required course if the student has previously completed an equivalent graduate-level course and can demonstrate competency.

The curriculum can accommodate four major areas of emphasis: Medical Imaging, Biomaterials, Medical Instrumentation and Devices, and Theoretical Modeling. Another area of emphasis under discussion is Clinical Engineering, which includes health care and medical informatics. At present, this area can be accommodated through the Directed Studies and Special Projects courses.

The program, which began in the fall of 1993, graduated its first student in the spring of 1995. Enrollment figures attest to the success of the Master's Degree Program in Engineering and Applied Physics of Biomedicine; 45 people registered for courses during each semester of the 1994–1995 academic year, and about 10% were Laboratory staff, a percentage similar to enrollment in the other part-time master's degree programs at APL.

COURSES OFFERED IN THE MASTER'S DEGREE PROGRAM IN ENGINEERING AND APPLIED PHYSICS OF BIOMEDICINE (AS OF 1995–1996)

I.	Noncredit course	
	585.209	Organic Chemistry: **R. Potember**
II.	Required courses (5 one-semester courses)	
	585.405/.406	Physiology for Engineering and Applied Physics of Biomedicine: **E. Haase, J. Potts, P. Cutchis,** lecturers from BME senior faculty
	585.407	Molecular Biology: **T. Kistenmacher, R. Potember**
	585.408	Medical Sensors and Devices: **N. Thakor, W. Bryden**
	615.441	Mathematical Methods for Physics and Engineering: **P. Adelman** (625.701/.702, Mathematical Methods, may be substituted for this course and one elective with permission of the adviser.)
III.	Elective courses offered at APL	
	585.605	Medical Imaging: **I. Bankman, E. McVeigh, J. Prince**
	585.609	Cell Mechanics: **A. Popel, A. Spector, S. Kuo**
	585.608	Biomaterials: **R. Potember**
	585.610	Biochemical Sensors: **W. Bryden, N. Sheppard** (fall 1995)
	585.618	Biological Fluid and Solid Mechanics: **A. Popel, N. Rothman, S. Jones**
	585.6xx	Medical Image Processing: **I. Bankman,** other staff (spring 1996)
	585.800	Special Project in Engineering and Applied Physics of Biomedicine: **I. Bankman, W. Christens-Barry, R. Potember**
	585.801	Directed Studies in Engineering and Applied Physics of Biomedicine: staff
IV.	Elective courses offered at Baltimore area campuses (These may be taken for credit if the prerequisites can be satisfied and with the approval of the instructor.)	
	580.621/.622	Neural and Neuroendocrine Regulation of the Cardiovascular System
	580.625	Structure and Function of the Auditory System
	580.628	Neural Models in Auditory Theory
	580.631	Second Messenger Control Systems
	580.632	Ionic Channels in Excitable Membranes
	580.633	Mathematical Models of Molecular Motors and Cytomechanics
	580.640	Pharmacoengineering
	580.672	Advances in Biomedical Instrumentation
	580.675	Advanced Biomedical Sensors I
	580.676	Advanced Biomedical Sensors II
	580.681/.682	Theoretical Foundations for Neural Models
	580.684	Experimental Foundations for Neural Models
	580.724	Human and Machine Speech Processing

THE AUTHORS

RICHARD A. FARRELL is a Principal Staff Physicist and Group Supervisor at APL. He holds joint appointments as a part-time Associate Professor in the Departments of Biomedical Engineering and Ophthalmology at the Johns Hopkins Medical School and is Chairman of the Engineering and Applied Physics of Biomedicine Part-Time Master's Degree Program at the Johns Hopkins G. W. C. Whiting School of Engineering. He obtained a B.S. degree from Providence College in 1960, an M.S. from the University of Massachusetts in 1962, and a Ph.D. from The Catholic University of America in 1965. Dr. Farrell's research interests include relating the cornea's structure to its function, especially relative to its light-scattering properties, and developing theoretical methods for calculating wave scattering in random media. He received a 1990 Alcon Research Institute Award for outstanding research in vision and ophthalmology. His e-mail address is Richard.Farrell@jhuapl.edu.

VINCENT L. PISACANE is a member of APL's Principal Professional Staff and has been the Assistant Director for Research and Exploratory Development since 1991. He also holds a part-time joint appointment with The Johns Hopkins University School of Medicine as an Associate Professor of Biomedical Engineering. He is a fellow of the American Institute of Aeronautics and Astronautics, from which he received the Information Systems Award in 1991. He received a B.S. degree in mechanical engineering from Drexel University in 1955, and M.S. and Ph.D. degrees in applied mechanics from Michigan State University in 1957 and 1962, respectively. Dr. Pisacane joined APL's Space Department in 1962 and was Department Head from 1985 to 1991. He also teachers several courses in applied physics at The Johns Hopkins University G. W. C. Whiting School of Engineering. He has published over 50 articles and reports and was recently a co-editor of a book entitled *Fundamentals of Space Systems*, in which he was also the author of several chapters. His e-mail address is vlp@aplcomm.jhuapl.edu.

ISAAC N. BANKMAN holds a B.Sc. in electrical engineering from Bosphorus University, Turkey, an M.Sc. in electronics from the University of Wales, Britain, and a Ph.D. in biomedical signal processing from the Technion University, Israel. He joined the Biomedical Engineering Department of JHU as a postdoctoral fellow in 1985 and was a research associate between 1987 and 1990. In June 1990, he joined APL's Milton S. Eisenhower Research Center as a Senior Staff member. His field of interest is signal and image processing, including optimal signal detection and classification, image pattern recognition, neural network applications, modeling of neural systems, and algorithms for the analysis of biological signals. His e-mail address is Isaac.Bankman@jhuapl.edu.

ARTIN A. SHOUKAS is a full-time faculty member at The Johns Hopkins University School of Medicine, where he is Professor of Biomedical Engineering as well as Physiology. He is the Director of the Undergraduate Program in Biomedical Engineering in the JHU School of Engineering and a member of the advisory committee of the Part-Time Master's Degree Program in Engineering and Applied Physics of Biomedicine. He obtained a B.S. degree in aerospace engineering in 1968 from the Polytechnic Institute of Brooklyn and a Ph.D. degree in biomedical engineering/systems physiology in 1972 from Case Western Reserve University. Dr. Shoukas's research interests are in the systems analysis of overall circulatory regulation and homeostasis; multiple reflex control of the systemic and pulmonary vascular system; cardiac performance under reflex control; and modeling of physiologic systems, reflex interactions, and cardiovascular mechanics. He is the recipient of multiple teaching and advising awards as well as a 10-year NIH Merit Award. His e-mail address is ashoukas@bme.jhu.edu.

MURRAY B. SACHS is Massey Professor and Director of the Department of Biomedical Engineering and Professor of Neuroscience and Otolaryngology/Head and Neck Surgery at The Johns Hopkins University. He is also a member of the Principal Professional Staff of APL. He obtained a B.S. in 1962, an M.S. in 1964, and a Ph.D. in 1966 in electrical engineering at MIT. Dr. Sachs's primary research interest is the neural processing of speech. His work has included neurophysiological and modeling studies of neural encoding in the inner ear and processing of the neural code by populations of neurons in the central nervous system. He received a Jacob Javitz Neuroscience Investigator Award and is a member of the Institute of Medicine of the National Academy of Sciences. His e-mail address is msachs@bme.jhu.edu.