

BIOMEDICAL ENGINEERING AT NORTHWESTERN

1969-1999

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The seeds for biomedical engineering were planted in the 1950s by the pioneering efforts of Professor Richard Jones of the Electrical Engineering Department and Professors John Gray and Fred Grodins of the Physiology Department in the Medical School. Professor Jones had extensive experience in electro-mechanical control systems and Professor Grodins worked on understanding physiological control systems. The engineering school responded to these efforts by approving research space in the Electrical Engineering Department for a young Assistant Professor, Christina Enroth-Cugell, and by hiring John Jacobs and Franklin Offner into the Electrical Engineering Department in the late 1950's and early 1960's. Professor Enroth-Cugell, with traditional training in medicine and physiology, was given a faculty appointment in Electrical Engineering and Biological Sciences in 1972. Professors Jacobs and Offner were full professors, with extensive prior industrial experience. Professor Jacobs was trained as an electrical engineer and Professor Offner as a biophysicist. Professor Offner had previously founded a very successful company, Offner Electronics, which was known for innovating numerous medical devices.

In the beginning of the 1960's the University administration had supported biomedical engineering in the form of generous office and laboratory space, including space to house animals, in a new wing (now known as the E-wing) that was added to the northeast corner of the Technological Institute Building. Also, thanks to the leadership of Professor John Jacobs, two grants from the National Institutes of Health were awarded to Northwestern. One, a Center Grant, which later became a Program Project Grant, supported The Biomedical Engineering Center (established in 1960) and provided funding for biomedical engineering research until 1979. That grant, in its early years, also supported a mechanical and electronics shop in the Medical School. The second grant, a Training Grant, provided stipends for Biomedical Engineering Graduate Students. These were among the very first such grants awarded an Engineering School by the National Institutes of Health.

Administrative aspects of Biomedical Engineering before departmental status was achieved in 1985

The 1970's represented the third decade of biomedical engineering at Northwestern and it was clear that the biomedical engineering program was doing quite well in several respects. However, prior to 1976 the administration of Northwestern's Biomedical Engineering Program was not well structured. There was a Biomedical Engineering Center - a university wide Center - directed by a Biomedical Engineering Center Committee (Chairman Professor John Jacobs) - that reported to a University Vice President in Northwestern's Central Administration, not to the Tech Administration. Two faculty groups in the Engineering School were involved with the administration of the Graduate and the Undergraduate Degree Programs: an Interdisciplinary Biomedical Engineering Graduate Program Committee that reported to the Dean of the Graduate

School and a similar Undergraduate Program Committee, which reported to the Engineering School Administration. In February, 1976, Bruno Boley, the Dean of the Engineering School, created a Biomedical Engineering Council "in order to establish some structure to the administration of Biomedical Engineering in Tech." Prof. Lyle Mockros was named the Chairman of the Executive Committee of the Council. In 1981, Dean Boley established Biomedical Engineering as a Division of the Department of Engineering Sciences and Applied Mathematics. Prof. Mockros was named the division chairman and the Biomedical Engineering Council ceased to exist. The administrative functions of the Council were taken over by the Biomedical Engineering Division.

Biomedical Engineering Department 1985-1999

The Division in the Department of Engineering Sciences and Applied Mathematics was replaced in October 1985 by a full-fledged Biomedical Engineering (BME) Department, with Prof. Andrew Kertesz as Chairman. Prof. Robert Linsenmeier succeeded him as the second chair in 1997. Thus, the department had evolved in slow steps, from a loose-knit university-wide program. Although "new born" as a department, its members could look back with satisfaction at approximately thirty years of high quality interdisciplinary biomedical engineering research, which had been well funded from external sources. Moreover, by 1985 the biomedical engineering educational program was nationally and internationally respected. During the early 1980's both pre- and postdoctoral students from numerous foreign countries (Australia, The Netherlands, England, Scotland, and China) studied biomedical engineering at Northwestern.

The new department also faced, to no one's surprise, some problems. One was the cramped quarters. Despite the fact that some biomedical engineering faculty had their offices and research space in the Departments of Chemical Engineering, Civil Engineering, Materials Science and Engineering, and in the Medical and Dental Schools, the offices and the research laboratories in the E-wing, which constituted "generous new space" for Biomedical Engineering in 1964, had by 1985 become disturbingly crowded due to the rapid growth in the number of faculty members and the increase in the number of graduate and undergraduate students. Professor Kertesz argued persistently for more space, staff and budgetary resources for the new department.

The "newborn" BME department also faced various administrative difficulties. A tight departmental budget was accentuated because the training grant had expired. During the first "departmental year", 1985-1986, the severe budget problems were partially relieved by a slight increase in the University's budget allocation and the assignment of first year graduate student Murphy Fellowships to the Department.

Most areas in the Tech Building were renovated extensively in the 1990's at a total cost of more than \$120 Million. In the fall of 1991 the Biomedical Engineering Department moved to temporary quarters in the Tech building and returned to its renovated E-wing quarters more than a year later. The total space for laboratories, faculty offices, both pre- and postdoctoral students, and for departmental staff increased by about 5000 square feet, but the reconstruction had a greater impact by consolidating biomedical engineering spaces that were spread through many

departments around the engineering school. The departmental Parson's Teaching Laboratory was also improved and expanded.

The renovation, however, was not without negative consequences. Considering the very substantial time and energy that individual faculty members and their students invested in dismantling elaborate experimental setups and getting them functional again, it was disappointing to return to the renovated quarters to find some infrastructure systems, such as the hot water supply, not functioning as well as the old system, a significant problem that was slowly resolved.

Faculty

Most of the faculty involved in biomedical engineering prior to the late 1960's had been trained in traditional fields, had simply developed an interest in the new field, and then redirected their careers. The one exception was Professor Peter Dallos, who had trained with Professor Jones and had been appointed to the faculty in the Department of Communicative Sciences and Disorders of the Speech School in 1962 and to the Electrical Engineering Department in 1966. Starting in 1966, several individuals whose PhD research was in biomedical engineering were added to the faculty in various departments. Dudley Childress (who also trained with Professor Jones) was appointed in the Departments of Orthopedic Surgery and Electrical Engineering in 1966, Thomas Goldstick was appointed in Chemical Engineering and Biological Sciences in 1967, Steve Carr was appointed in Materials Science and Engineering and Chemical Engineering in 1970, Andrew Kertesz (who also trained with Professor Jones) was appointed in the Electrical Engineering Department in 1972, and Jack L. Lewis was appointed in Civil Engineering and Orthopedic Surgery in 1972.

These appointments, recommended by biomedical engineering faculty, had to be approved by traditional departments. Some faculty in these departments were not sympathetic to the needs of a program outside their department's mainstream. This was a particular problem when the biomedical faculty saw an urgent need to hire faculty to teach a quantitative physiology course series. This series, which included neurophysiology taught by Professor Enroth-Cugell and the rest of human physiology taught by Professors Gray and Grodins was initiated in 1958, but disintegrated somewhat, for various reasons, in the late 1960's. Professor Enroth-Cugell continued to teach her course, but Professors Gray and Grodins, who had been teaching on a voluntary basis, no longer wished to participate. Later Professor Gray retired and Professor Grodins moved to the University of Southern California to become chairman of their biomedical engineering program.

The majority of the biomedical engineering faculty from various departments in Tech believed that if the program at Northwestern was to maintain the worldwide reputation for excellence it had achieved and make further progress during the ensuing years, then the curriculum had to continue to include quantitative biology courses on the Evanston Campus. One compelling reason for advocating the reintroduction of such biology courses on the Evanston campus was that by the early 1970's approximately 40% of first year undergraduates in the engineering school were enrolling in the Interdisciplinary Biomedical Engineering Program. In order to re-

establish a quantitative biology curriculum on the Evanston campus, the biomedical engineering faculty urged that a biologist with a strong quantitative background be appointed to the Engineering School as soon as a suitable candidate could be identified. The primary requirement was that he/she be a good biologist with a quantitative approach, capable of talking to engineering students in engineering language, and able to develop and teach a portion of a biology curriculum designed for engineering students.

In spite of these specific recommendations neither of the two goals -- the course sequence, and the appointment of a biologist to the Tech faculty -- was to be achieved very soon. Objections were raised to establishing quantitative biology courses (including human physiology) on the Evanston Campus, on the basis that such courses would constitute a duplication of the Chicago Campus curriculum and might be seen as competition between the two campuses. A few life science courses suitable for engineering students were available on the Chicago campus, but the considerable distance between the campuses, the lack of any intercampus shuttle, and the non-quantitative approach in the Medical School discouraged biomedical engineering students from taking advantage of these courses.

As a partial solution, Professor Goldstick was given a two-year leave in 1971 to study physiology and medicine at the Medical School of the University of California, San Diego. Upon returning he started teaching some of the physiology series. This left the crucial series of courses in a precarious position, however. It was too dependent on two faculty members, Professors Enroth-Cugell and Goldstick, and it gave the program no backup in case they were unable to teach the courses for one reason or another. A major breakthrough occurred when Dean Boley approved the courtesy appointments of many of the existing biomedical engineering faculty to the Department of Engineering Sciences in the early 1970's. Upon the recommendation of this biomedical engineering faculty, Dean Boley approved, in 1976, the hiring of Professor Richard Bergman, a physiologist who had an engineering degree, to the Department of Engineering Sciences. This was the first time the program had acquired a faculty colleague without having to have the blessing of a traditional department. He was a full-time faculty member in the engineering school and added significantly to our ability to offer a somewhat complete physiology course sequence. Unfortunately he left in 1980 for a position in the Physiology Department of the University of Southern California. A second breakthrough occurred when Dean Boley created the Division of Biomedical Engineering in 1981, and converted several salary lines so that they would be filled by existing biomedical engineering faculty members. This permitted the faculty to have more cohesion and independence in making recommendations for future hires. Three new hires followed shortly thereafter: Professor Arthur Campfield, a physiologist with undergraduate and masters degrees in engineering and somewhat of a replacement for Professor Bergman in 1981; Professor James Grotberg, an MD with a PhD in Engineering in 1981; and Professor Robert Linsenmeier, a PhD in Biomedical Engineering with post doctoral training in physiology in 1983. All had half-time appointments in the new Biomedical Engineering Division of the Department of Engineering Sciences and Applied Mathematics. Professor Campfield was hired with a joint appointment in the Physiology Department of the Medical School; Professor Grotberg was hired with a joint appointment in the Anesthesia Department of the Medical School; and Professor Linsenmeier was hired with a joint appointment in the Neurobiology and Physiology Department of the College of Arts and Sciences.

The Division represented great progress in faculty appointments, but in the fall of 1985 not a single member of the BME Department held a 100% paid appointment in BME. Every department member also had a fractional paid appointment in some other department. Some of the department faculty had only a courtesy (unpaid) appointment in BME. At the onset of the 1985-86 academic year, 24 individuals were listed as members of the BME Department, but together these 24 individuals contributed only 5.55 Full Time Equivalents (FTEs). Such a small number of full time faculty equivalents, "patched together" from many part time departmental appointees, had many drawbacks. With that kind of departmental structure and considerable physical separation between the offices and laboratories of faculty members with common interests and goals, there was minimal likelihood of "bumping into each other in the hallway," the informal encounters that are so important for generating interactions between the members of a department and their students.

The creation of the department made it possible for the first time to appoint a faculty member fully in BME. One key goal for the new department was to hire new faculty members with appointments that increased the ratio of FTEs to the total number of departmental members. Over the years the situation has improved substantially, albeit slowly. Between 1987 and 1997 five new faculty members joined the BME department, all full time. The first of these were Professors Matthew Glucksberg, Joseph (Jay) Walsh, and John Troy. In addition, some BME faculty members changed their departmental affiliations in favor of BME. Although the number of FTEs was still rather small during the 1998-1999 academic year (34 faculty members and only 10.10 FTE's) an important and encouraging change in the composition of the department had occurred. At the start of the 1998-1999 academic year seven members of the BME department had 100% paid appointments whereas twelve years earlier there was no departmental member with a 100% paid appointment.

The ability to appoint faculty fully in the department also allowed the department to set its own research directions. During the 90's the focus has been to solidify areas that had been strong prior to the creation of the department, including fluid biomechanics and mass transport, rehabilitation engineering, and quantitative neuroscience, and to build two new areas: one in and one in medical imaging, and one in biotechnology, biomaterials and tissue engineering, which had roots in the biomaterials effort at the medical school and in the presence of a faculty member who must surely have been one of the first molecular biologists in a BME department, Prof. Tai Te Wu.

Faculty have distinguished themselves in too many ways to recount here. It is significant that Professor John Jacobs was a Founding Member and Professors Dudley Childress, Fred Grodins, F. John Lewis, Lyle Mockros, Milton Paul, and Hans Wessels were Charter Members of the Biomedical Engineering Society, founded in 1968. Professors Dudley Childress, Jack Lewis, Lyle Mockros, and Franklin Offner were Founding Fellows of the American Institute of Medical and Biological Engineering, founded in 1992. (Three graduates in biomedical engineering from Northwestern, H.K. Chang, Wilson C. Hayes, and Anthony Sances were also Founding Fellows of the Institute.) Several faculty members have been inducted into national academies, Professors Jacobs and Offner into the National Academy of Engineering (1969 and 1990 respectively),

Professor Childress into the Institute of Medicine (1995), and Professors Enroth-Cugell, Dallos, and Stupp into the American Academy of Arts and Sciences (1983, 1997 and 1998 respectively).

Curriculum

Prior to Fall of 1969, graduate students wishing to study biomedical engineering pursued graduate degrees in traditional engineering and life science departments. An interdepartmental graduate degree program was established in the Graduate School in 1969. As noted above, it was administered by a specially appointed Biomedical Engineering Administrative Committee, which reported directly to the Dean of the Graduate School. Students wishing to pursue graduate study in biomedical engineering could choose (1) a program in various departments in the College of Arts and Sciences, in the Medical School, or in the Technological Institute, or (2) the program administered by the Biomedical Engineering Committee. Those wishing general competence in a traditional discipline with a sub-specialty in biomedical engineering were encouraged to pursue the former program. Such students were subject to the requirements of their respective department, with degrees awarded by that department. Those students wishing more specific competence in biomedical engineering were encouraged to pursue MS and PhD degrees in the interdepartmental program, with degrees specifically indicating 'the field of Biomedical Engineering.' These were the first such degrees awarded by Northwestern. Several traditional engineering departments, starting in the early 1960's, formally offered a biomedical sub-specialty within their undergraduate degree programs. These included Electrical Engineering starting in 1962, Engineering Sciences starting in 1969, Mechanical Engineering starting in 1970, Chemical Engineering starting in 1968, and Materials Science and Engineering also starting in 1973. Chemical Engineering, Electrical Engineering, Materials Science and Engineering, and Mechanical Engineering continue to offer such biomedical sub-specialties to this day. At the request of the then dean Walter Owen, a formal specific "interdisciplinary undergraduate program" in biomedical engineering was established in 1971 by Professors Elliott Bayly and Thomas Goldstick, with Professor Bayly serving as the first Program Chairman. When he left NU in 1973, Professor Steven Carr replaced him as Program Chair. This program continued until it was replaced by the Biomedical Engineering Division program in 1981.

Courses specific to biomedical engineering, other than the basic physiology series, were offered starting in the early 1960's. These were Introduction to Biomedical Engineering and Biological Control Systems offered by Professor Jones in the Electrical Engineering Department. Several additional courses were offered by many engineering departments in the 1970's. These included: Transport Phenomena in Living Systems and Cardiovascular Transport Processes in Chemical Engineering; Cardiovascular Mechanics, Pulmonary Mechanics, and Biosolid Mechanics in Civil Engineering; Feedback in Biological Systems, Communication in the Nervous System, and Biophysics of Excitable Membranes in Electrical Engineering; and Introduction to Biomaterials in Materials Science and Engineering.

Both the graduate and undergraduate degree programs became programs of the Biomedical Engineering Division when it was established in 1981 and departmental programs when the Biomedical Engineering Department was established in 1985. The undergraduate program since its inception in 1971 has been based on the philosophy that students should have depth in one of

the traditional branches of engineering as well as in biomedical engineering. To achieve this it has had "areas of specialization" whose names and course composition have changed, but which have had the consistent goal of providing depth in some area of BME, mapped roughly onto the various branches of engineering. It thus covers many branches of biomedical engineering. At the graduate level there has been little evolution of the basic pattern requiring coursework consisting of one third math, one third engineering and one third biology. This recognizes the diverse backgrounds of the incoming graduate students and the need to provide programs tailored to individual research careers.

A positive curricular development during the 1998-99 academic year was that Northwestern's Biomedical Engineering Department became part of the Vanderbilt-Northwestern-Texas-Harvard/MIT (VaNTH) Engineering Research Center in Bioengineering Educational Technologies funded by NSF. Apart from the additional funds the grant provides, this award will improve the national visibility of Northwestern's educational programs in biomedical engineering. Another positive development during the '90s was the increased opportunities for biomedical engineering students to obtain industrial experience, fostered in part by the receipt of a Whitaker Foundation Industrial Internship Award. This reflected the growing demand for undergraduates in industry, and a change from the beginning of the program, when more than half of the students went to medical school after graduation. In 1998 the number of undergraduates going to careers in industry exceeded the number going to medical school for the first time. (The percentage going on to graduate degree programs has been stable at about 15% of the total during the 90's.)

Interactions between Biomedical Engineering at Tech and the Medical and Dental Schools

It is difficult to define biomedical engineering in both succinct and complete terms, but one important aspect is the application of engineering sciences to the fields of medical and life sciences. Hence, interaction between faculty and students of the Engineering School with their counterparts in the Medical and Dental Schools was from the onset, and continues to be, an essential aspect of biomedical engineering at Northwestern. Less physical separation between the Evanston and Chicago campuses and the introduction of an intercampus shuttle (which did not exist until September 1, 1999) might have created even more interaction. As indicated above, however, the beginning of Biomedical Engineering at Northwestern involved the close collaboration between faculty of the Electrical Engineering Department in Evanston and faculty of the Physiology Department in Chicago. The first biomedical engineer appointed to a faculty position in the Medical School was Professor Dudley Childress, given a joint appointee in the Departments of Orthopedic Surgery and Electrical Engineering in 1966. Professor Jack Lewis was given a joint faculty appointment in the Departments of Orthopedic Surgery and Civil Engineering in 1972. Two distinguished senior faculty members from the clinical departments of our medical school were very active with the research aspects of the Biomedical Engineering Center, starting in the late 1960's and continuing for many years: Professor F. John Lewis, a pioneering heart surgeon, and Professor Milton H. Paul, Chair of the Cardiology Department at Children's Memorial Hospital.

Unfortunately, the Northwestern Department of Orthopedic Surgery lost interest in research in the 1980's, at a time when most distinguished Departments of Orthopedic Surgery around the country were aggressively hiring biomedical engineers. Professor Lewis left for a chaired position in the Department of Orthopedic Surgery at the University of Minnesota. Professor Childress later switched his Medical School faculty appointment from the Department of Orthopedic Surgery to the Department of Physical Medicine and Rehabilitation. In recent years several members of the Medical School's Departments of Physiology, Anaesthesiology, Medicine, Radiology, and Physical Medicine and Rehabilitation have collaborated with colleagues in biomedical engineering on the Evanston campus and have served as co- advisors for many doctoral candidates. In addition, there have been many interactions with Evanston Hospital (now Evanston Northwestern Healthcare), one the most productive being between Professor Sahakian of BME and Electrical and Computer Engineering and Dr. Swiryn in the area of cardiac arrhythmias.

Another important collaboration has been between the faculty of the Department of Biological Materials in the Dental School (a pioneering and distinguished department) and students of biomedical engineering programs. Those faculty members have directed the research of many graduate students as well as taught, on a voluntary basis, courses on the Evanston campus for the biomedical engineering students. Unfortunately, with the announced closing of the Northwestern University Dental School in 1997, most of those faculty members accepted positions at other institutions. One member of that Department, however, Professor Phillip Messersmith, accepted a full time appointment in the Department of Biomedical Engineering and moved his laboratories to Evanston. Also, the newly formed Institute for Bioengineering and Nanoscience in Advanced Medicine in the Medical School is expected to have a strong emphasis on biological materials. At the end of the 1998-99 academic year, the last year included in this somewhat random sample of recollections, the Biomedical Engineering Department could note several important positive developments which took place during the preceding ten years, developments which constitute good reasons for satisfaction. For example, during the 1990-1999 decade, Northwestern's Medical School expanded its activities in medical imaging and a number of medical school faculty members in medical imaging were given courtesy appointments in the Biomedical Engineering Department and taught courses on the Evanston Campus. This interaction with the Medical School also opened opportunities for biomedical engineering students to participate in medical imaging research at the Medical School. In 1999 the Biomedical Engineering Department was awarded a Whitaker Special Opportunity Award for "Development of Graduate and Undergraduate Programs in Medical Imaging."

In summary, the road from the 1954 "Physiological Control Systems Laboratory" (which consisted of two 2'x3' tables on wheels, filled with equipment for physiological experiments), to the 1999 Department of Biomedical Engineering in the E-wing, has been long, bumpy and always interesting.