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A Guest Editorial

Selected Perspectives on a Quarter Century of Rehabilitation Engineering

by Robert W. Mann, Sc.D.
Whitaker Professor of Biomedical Engineering, Massachusetts Institute of Technology

The past 25 years have brought widespread developments in rehabilitation engineering. A consideration of the history of selected cases provides useful insights on the dynamics of the cycle of technology transfer from ideation through commercial availability. My experience suggests that the following five factors have proven to be central to the technology transfer process:

1) Innovative concepts;
2) A context for engineering development and leadership;
3) Student participation in research and development;
4) Financial support for early high risk work;
5) Investigator motivation to carry ideas through research to application.

Two case studies illustrate the commonality of these factors, while differences in outcomes highlight the significance of each factor.

Case Study #1: Braille Translation Programs

The Fall 1985 edition of *Sensus—A Consumer's Guide to Technology for Blind and Partially Sighted People* devotes 25 of its 40 pages to describing commercially available paper braille-embossing hardware and braille translation software. Seventeen devices, ranging in price from just over $2,000 to over $60,000 and manufactured in the United States, Europe, and Japan are included. Virtually all of them are compatible with personal computers. Five versions of braille translation programs are described. They range in price from $95 to $500 and translate "English, Spanish, British (sic), Arabic, and several African languages" into "Grade I and II braille" (25).

Certainly the full cycle of technology transfer is realized when any braille reader with a personal computer can produce excellent contracted-braille translations and make embossed copies at home. Some historical reflection on how this came about forms the basis of this case study.

In 1959, John Kenneth Dupress was Director of Technological Research for the American Foundation for the Blind. Blinded and maimed as a prisoner of war during World War II, he was an extraordinary person with an unswerving commitment to apply science and technology to benefit blind persons. In an effort to recruit help, Dupress instigated a biweekly "brown bag" luncheon seminar at M.I.T. His knowledge of modest but world-wide efforts to relate science to blindness, his incisive appraisal of the needs of blinded persons, his catalogue of possible approaches, his conviction that progress was possible, his willingness to debate with technologists the appropriate courses of action, and the inspiration he himself provided in his adaptation to his own disability, spurred faculty and students in several M.I.T. departments to sensory aids research. I was one.

Braille seemed the logical place to start. Human translations and manual embossing severely limited and delayed the production of brailled materials. At M.I.T., Dupress organized a conference on automatic data processing of braille (24) which helped define a future modular processing system that would accept a wide range of inputs—from key punch and keyboard through optical character recognition and type-compositor's tapes. It provided for classes of braille translation with

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flexibility for update, and accommodated output modes from typewriter-sized paper embossers through metal plates for press braille and future portable braille display devices.

By 1962, at the *International Congress on Technology and Blindness,* we could report progress (15). The modular software program for braille translation and automatic management of input and output modes, subsequently called "DOTSYS," was underway, and two undergraduate theses and a master's thesis were advancing a typewriter-sized, 16-character-a-second embossing device which became known as the "M.I.T. Braillemboss." By the middle 1960s, the Braillemboss software/hardware was being evaluated as a telecommunications terminal in mathematics instruction at the Perkins School for the Blind, by a blind professional in the Boston area, and by several blind students at M.I.T. who routinely used the device for homework and during summer employment. We gained confidence in the performance of the system and made it available in Canada, England, and Israel. A Braillemboss system, installed at the Internal Revenue Service in Little Rock, Arkansas, provided braille versions of the tax code and other information needed by blind service representatives answering taxpayer inquiries. The first demonstration of remote, time-shared access to computer braille translation was at the National Braille Press in Boston, where "Jiffy Braille" was produced on an M.I.T. Braillemboss via a commercial time-shared computer in Waltham, Massachusetts (23).

The DOTSYS system's ability to process different input media was demonstrated in August 1966, when the teletypesetter tape used to publish regional editions of the *Wall Street Journal* produced a braille version. In November 1966, DOTSYS transformed part of a book from type compositor's tape to the code which controlled the embossing of braille press plates. Finally, in 1968, an entire new novel, the *East Indiaman,* was concurrently published in ink print and braille, using the same type compositor's tape as source (19).

The technology transfer of the DOTSYS software was straightforward. Reproduction simply involved copying the magnetic tapes which were the computer storage media in those days. A fortunate opportunity for a major upgrade in the DOTSYS code occurred due to the massive need for braille reproduction following the fire at the Regional Library of the National Library Service in Atlanta, Georgia (M.I.T. contracted that work to the Mitre Corporation), which in turn led to the founding of one of the companies currently producing and selling braille translation software.

Our demonstration of the effectiveness of on-site braille embossing via compact and convenient machines encouraged the manufacture and marketing of braille embossing devices from one company, initially, to the many manufacturers needed to meet current consumer demands.

What do we learn from this case study?

First, a spur to innovation is essential. John Kenneth Dupress was central to the initiation of the project and he remained a dedicated and vital contributor. By 1964, M.I.T. had established a Center for Sensory Aids Evaluation and Development with support from the then Vocational Rehabilitation Administration, with Dupress as the inaugural director (16).

Second, even inspired individuals need a context in which to carry out their ambitions; in this case M.I.T. provided that context. I had been looking for challenging projects in which to involve my engineering design students and was delighted with the opportunity to beat my (missile) swords into (rehabilitation) plowshares. Through the missile R&D, we had demonstrated the practicability of involving students in challenging tasks—the hardware they produced met, or exceeded, the goals desired by sponsors who funded the work. And, at M.I.T., we had access not only to the new digital computer but also to the intellectual resources needed to program it to achieve the translation task we undertook.

Third, an ingredient essential to the inauguration and implementation of the research was satisfied when the Office of Vocational Rehabilitation of the DHEW provided initial support in January, 1961. Later, as the Vocational Rehabilitation Administration, it continued support of our Mechanical Engineering Department-based project and added the support of the new Center for Sensory Aids Evaluation and Development. In fact, since the beginning, our efforts at M.I.T. have been continuously supported by the same group—in OVR and VRA, then the Social and Rehabilitation Services (all of DHEW), and now constituted as the National Institute of Handicapped Research of the Department of Education. Along the way, that core support has been supplemented in important ways by other agencies—National Science Foundation, National Institutes of Health, by significant foundation grants, and by private benefactors. But, the persevering core support has been essential.

Fourth, it is crucial that both investigators and supporters be willing to carry ideas past research and the demonstration prototype into application, for it is there that both limitations and improvements on the system are discerned by actual users and a market is created by demonstrating practical utility in the real world. The proliferation of manufacturers of braille embossing devices and of braille software translators would not have occurred if commercial marketers had not realized a return on investment.

Case Study #2: Cybernetic Artificial Limbs

Norbert Wiener, the coiner of "cybernetics," and faculty member at M.I.T., speculated in the forties and fifties on the feasibility of employing computers and the then-also-new servomechanisms to couple the brain to an artificial limb and thereby provide the limb amputee with an improved prosthesis (6). In 1962, Professor Wiener suffered a broken hip, which precipitated discussion among his physicians and faculty colleagues that it was time to test this hypothesis.

Out of those intersections grew the project that became known as the "Boston Arm." I was recruited into it because I was a designer and an expert on how to store and supply energy in small, lightweight packages—a clear requirement for any future wearable cybernetic amputation prosthesis. Prior to Professor Wiener's accident, we had prepared a paper applying missile power system design principles we had learned to externally-powered upper extremity prostheses (18). By 1966, again with student participation, we were able to describe an electromyographically controlled elbow (14) and demonstrated in 1968 a wearable limb in Boston, London, and Soviet Armenia (11,12).

Thus, the confluence of components from a missile project, a cybernetical concept linking humans and machines, and an accident created a new technology for handicapped persons. The "Boston Arm," available through the Liberty Mutual Insurance Company, has been moderately successful and about 100 are now in use. The "Utah Arm," conceived by one of our students and developed in a 1972 doctoral thesis at M.I.T., was later implemented in Salt Lake City. The "Utah Arm" is now commercially available with 250 fittings in use (10).

Discussion

The lessons implicit in the limb prosthesis case study and in the braille exposition are in some ways very similar. The initiating person, now Norbert Wiener, was the innovator. A receptive environment was essential and, again, our M.I.T. group provided it. There was financial support, part from the Social and Rehabilitation Services and part from Liberty Mutual. Again, investigative student theses helped carry the project's development into prototypes, into wearable hardware, into evaluation, into multiple production and fitting. The "Boston Arm" was marketed through support from Liberty Mutual and the "Utah Arm" through collaboration between the University of Utah and the manufacturer, Motion Control, Inc.

The number of handicapped persons that the developed devices reached in the two cases is, however, quite different. As the citation from *Sensus* indicates, the braille applications are broad and diverse. The limb prosthesis application is still small compared to the number of potential benefactors.

How can the difference in the number of users of these devices be explained? In my view, it is partly due to the separation of the blind and severely visually impaired population from the medical care system. The braille system is not an intimate part or extension of the human body. Technological aids, certainly in braille communication, are not professionally prescribed. They are available on the commercial market, and individual consumers make decisions on what is best for their needs. Furthermore, the braille system has benefitted from and capitalized on the cost reductions and enormous expansion of computer availability—both hardware and software. Handicapped people are most readily and economically served when devices for their benefit are but modest adaptations of commercially produced, aggressively marketed products purchased by a significant segment of the public.

By contrast, the artificial limb is part of a system which involves surgery, rehabilitation, prosthetic fitting, physical therapy, etc. It is a much more complex system than that which applies to braille. The concordance of many professional decision makers is necessary for an amputee to acquire and become an accomplished user of a sophisticated prosthesis. The milieu in which the amputee finds him or herself is more complex than even the health care system. This was illuminated in a political science doctoral thesis at M.I.T., which was subsequently published as a case study by the Office of Technology Assessment of the Congress (27,28). The constraints on the application of this sort of rehabilitation technology go quite beyond issues of medical prescription, practical effectiveness, and customer acceptance. Public policy issues dominate. The amputee-veteran, the amputee-worker, and the amputee-citizen face different criteria in consideration for prescription, training, and financial reimbursement. Outcomes are dependent on specific federal, state, insurance company, etc., policies and the effectiveness with which they are implemented.

The benefits of the two case studies are not limited to the devices which ameliorate handicapping conditions. Projects like these, conducted in a university setting, sensitize the students who work on them and many other members of the academic community to the needs of persons with disabilities, and to the promise that science and technology offer for that amelioration.

Basic research also provides important rehabilitation information. For example, pressure readings from an instrumented femoral head replacement prosthesis (4) give quantitative data on the effects at the hip of different patient-management procedures and rehabilitation protocols (5).

This editorial is based in part on my keynote address to the National Rehabilitation Steering Committee in Washington on September 12, 1985, where the concept of the "SMART HOUSE" (2) was presented by the National Association of Home Builders Research Foundation. In this exciting effort are important aspects of the lessons I have learned over the past quarter century of work in rehabilitation engineering. A computer-integrated power/communication/control/entertainment/security/etc., electrical system for the American home will be of interest to the public in general. It also has the potential for facilitating the tasks of daily living of handicapped persons, since it will be designed for mass production. The cooperation between the Veterans Administration and the private sector in developing the specifications for this system insures the concept will develop as a benefit for disabled veterans and other handicapped persons.

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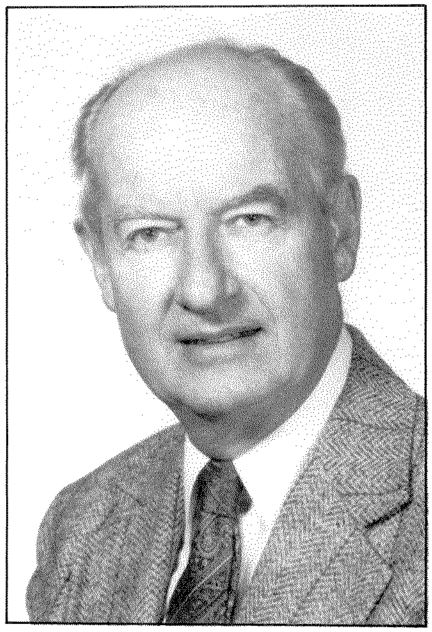
Notes on Author



Robert W. Mann, Sc.D.

Few rehabilitation professionals can offer as qualified a perspective on the development of rehabilitative engineering as Bob Mann. He has not only made major contributions to the state of the art, but also has played a leadership role in the establishment of national and international research agendas. His role in rehabilitation education programs and dynamic influence on students and other rehabilitation professionals has been outstanding. He also has been active in rehabilitation service organizations over many years.

Mann's professional contributions include braille translation, production, distribution, and use (3,7, 15,19,23), human interactive computer-based simulation environments for the study of the mobility problems of blind travelers (17,26), and cybernetic artificial limbs (10,11,12,14,18). Mann traces the history of his contributions in these areas to people and events at M.I.T. where he started as a student, joined the faculty, and has remained throughout his career.

At M.I.T., many experiences shaped Mann's development in rehabilitation engineering. During the late '40s and the '50s he was involved in work on power and control of air-to-air missiles (13,20) and the initial application of digital computers to engineering design (8). In 1964, he helped create and then chaired the Subcommittee on Sensory Aids of the Committee on Prosthetics Research and Development for the National Research Council (21). That subcommittee defined a blueprint for future research efforts in sensory aids (22). Mann subsequently organized and led the sensory aids activities of the Committee on the Interface Between Engineering in Biology and Medicine in the National Academy of Engineering.

Mann's contribution to rehabilitation education is a very special one. The statistics of the Newman Laboratory for Biomechanics and Human Rehabilitation are impressive: from 1959 through 1984, Mann and his group supervised 97 bachelor's, 84 master's, and 26 Ph.D. theses; instructed hundreds of students in elective subjects and seminars; and assembled a laboratory bibliography of 636 entries (1).

The depth of Mann's commitment to individuals with handicapping conditions is further reflected in his long record of leadership in service organizations: President of the Catholic Guild for All the Blind (now the Carroll Center for the Blind), corporation member of the Perkins School for the Blind, trustee and member of the Executive Committee of the National Braille Press.

Bob Mann's personal involvement in work on behalf of communication for the visually impaired and on artificial limbs is now past. His current foci are on quantitative functional assessment and remediation of musculoskeletal defects through the development of computer-aided surgical simulation systems (9)—a new look at another of his earlier research interests, computer-aided design (8)—and fundamental studies on the role of synovial joint mechanics in the etiology of osteoarthritis (4,5).

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