Int. J. Engng Ed. Vol. 22, No. 1, pp. 3–8, 2006
Printed in Great Britain.

0949-149X/91 $3.00+0.00

The Making of a New Discipline*

ARTHUR T. JOHNSON
Biological Resources Engineering, University of Maryland, College Park, MD 20742, USA.
E-mail: ajohnso2@umd.edu

The transformation of agricultural engineering into biological engineering is a larger change than meets the eye. First of all, agricultural engineering is an applications discipline, and biological engineering is a science-based discipline. Thus, the emphasis of the education must change from its specific uses to a more general utilization of biological systems. Second, any discipline must have a core set of technical materials and methods. In agricultural engineering, these were largely supplied by the Ferguson Foundation series of textbooks that were used very widely. A new agreement must be reached about how to supply these for biological engineering. Third, biological engineering is not likely to evolve only from agricultural engineering. chemical engineering, and to some extent biomedical engineering, also has designs on the discipline. Fourth, although the goal of biological engineering has been fairly clear since the early 1970's, the steps to reach the goal are not obvious to those who are trying to form the new discipline. The prospects for the new discipline of biological engineering are great, but much work remains to be done.

Keywords: biological engineering; agricultural engineering; new discipline

INTRODUCTION

TRANSFORMING Agricultural Engineering (AgE) into Biological Engineering (BiolE) in the USA is a major undertaking of proportions not seen since the early twentieth century when Chemical Engineering (ChemE) was formed. Indeed, there are some parallels with the formation of that discipline, but there are also huge differences. Confusion and chaos were attributes of ChemE in its formation; the same is true today of BiolE. There is much more involved in the making of a new engineering discipline than just a decision on somebody's part to define what it is and what should be included. Consensus needs to be reached and approaches need to be modified. All this has to be done by visionaries who are not themselves trained in the new discipline and who have only imperfect ideas about where the discipline is headed.

SCIENCE-BASED AND INDUSTRY-BASED ENGINEERING

The earliest engineering disciplines were based on the science of physics, and had as their applications military and civilian structures. The advent of mechanical power then led to Mechanical Engineering (MechE) to include heat transfer and fluid flow, in addition to the strengths of mechanical members. Later, when the state of knowledge of electricity had reached the stage where a whole technology could be based upon the use of electricity, Electrical Engineering (ElecE) emerged. Still, these engineering disciplines were based on the science of physics.

Parallel to the development of these science-based disciplines, other engineering disciplines emerged for particular economic segments. Applications-based disciplines such as Mining Engineering, Power Engineering, and AgE were among them.

ChemE was the first science-based discipline that included a science other than physics. ChemE borrowed many technical approaches from MechE, and added a lot more mass transfer to its technical domain. Its unique methods included unit operations, a black-box approach to processing involving the transport of fluids, heat, and mass. Applications-based disciplines related to ChemE include Petroleum Engineering and Ceramic Engineering.

The science of biology is the last of the foundational sciences, and so it is expected that BiolE will be the last of the science-based engineering disciplines to be created. BiolE as a discipline, however, has not yet fully emerged. There is no vacuum in which the discipline is currently being formed. Rather, just as competition thrives among species occupying the same environment, BiolE is currently being formed from competing visions emerging from the professional experiences of the people who champion them. Thus, it is expected that BiolE will eventually amalgamate ideas and approaches largely from AgE, Biomedical Engineering (BME), and ChemE. Each of these seems to be moving toward establishing a strong biological component of its educational process.

AGRICULTURAL ENGINEERING ROOTS

BiolE had some early roots. There was an early segment of AgE that believed that the science of biology should be at its heart. These voices, speaking

* Accepted 21 August 2005.

from the early 1900s through the 1930s, were scattered across the USA and Canada, but were not very persuasive for the rest of the profession.

The Agricultural Engineering Department at North Carolina State University under the leadership of F. J. 'Pat' Hassler, was the first such department to change its name in 1965 to include BiolE [1, 2]. No specific curricular changes were made to support the name changes, however, until the early 1990s.

Driven by a low student enrollment in its AgE program, Mississippi State University initiated its BiolE curriculum in 1967 under the leadership of William Fox and James Anderson [3]. They based their new curriculum on properties of biological materials and the measurement of these properties, theory and design with biological materials, and biological applications of control systems [4]. This program was accredited by the Engineers Council for Professional Development (the forerunner to the Accreditation Board for Engineering and Technology) as one of the first two accredited BiolE programs; the other was at Rensslelaer Polytechnic Institute [3].

Among the first departments to begin a BiolE program was the Agricultural Engineering Department at the University of Guelph, in Ontario [5]. BiolE was established as a major area of specialization in 1969, and was 'to fill the need for a liberal engineering education to solve problems of the biological world, and its associated environment of soil, water and atmosphere' [6]. The BiolE major was elevated to the status of a program in 1970 in order to distinguish engineering at Guelph from four other engineering schools in Ontario, and a full BiolE curriculum was established. The program was accredited in 1973 by the Canadian Accreditation Board of the Canadian Council of Professional Engineers. Contrary to the trend in the USA, however, faculty and students in the 1990s began to show less interest in a general BiolE at Guelph compared to other programs.

Even with this leadership, BiolE did not emerge from its nascent period during this time. Carl Hall, President of the American Society of Agricultural Engineers (ASAE), and Department Head at Michigan State University, was an early proponent. It took the convergence of several events to bring agricultural engineers to consider moving generally to BiolE. The first of these was an explosion of knowledge about biology and its fundamental mechanisms, beginning slowly in the 1950s with the discovery of the DNA double helix by James Watson and Francis Crick. The second of these was a crisis of low enrollments in most AgE programs in the US, and to a certain extent, in Canada. While many academicians were wondering what to do about this problem, the Agricultural Engineering Division of the American Society for Engineering Education (ASEE), under the leadership of Denny Davis and Art Johnson, held a series of sessions advocating the replacement of AgE with BiolE. These sessions were videotaped, and the videotapes widely disseminated. Thus, a movement toward BiolE had begun. Further progress was made when a project was proposed by Art Johnson to have ASEE request funding from the National Science Foundation (NSF) to sponsor a series of workshops to bring together parties interested in discussing the needs of the new field. NSF rejected the proposal, but the project was eventually funded in 1990 by the US Department of Agriculture through the efforts of Roger Garrett at the University of California, Davis. A series of workshops was held and consensus formed on a model BiolE curriculum [7].

There were early attempts to mold AgE into a biological science-based engineering discipline [8–10], but none were successful until a drastic decline in undergraduate AgE enrollments occurred in the 1980s. Searching for solutions, administrative heads of AgE academic departments met in Columbus, Ohio in 1987, and again in 1990 to recommend that undergraduate programs in BiolE be offered and that a core curriculum be developed [11]. They concluded that the 'undergraduate engineering curriculum should be substantially based on the science of biology and should be focused on applications in biological systems.' This reference to biological systems recurs throughout the report. Emphasis areas associated with BiolE curricula were identified as Biotechnology Engineering (Biosystems Engineering), Bioenvironmental Controls, Machine Systems Engineering, Bioprocess Systems Engineering, Natural Resources Engineering, and Food Engineering. BME as an emphasis area was not included.

With the establishment in 1995 of the Institute of Biological Engineering (IBE) under the guidance of Brahm Verma, the discourse continued in an atmosphere divorced from specific biological applications. IBE was established with the objective 'to encourage inquiry, application, and interest in biological engineering in the broadest and most liberal manner . . . ', and it has made ardent attempts to live up to this objective. However, there is no obvious route to the goal of effectively defining BiolE with all its attributes, distinctiveness, and complexion, so IBE has recently attempted to encompass the entire field of BiolE by including most of the popular applications of BiolE within its meetings. This trend can possibly be interpreted as an abandonment of the goal of unification and coalescence of the field. If the field of biology and related engineering can truly be understood in terms of general principles applicable to all biological levels, then the discipline of BiolE will be defined by commonality among applications and not by dissecting BiolE into segments.

BIOMEDICAL ENGINEERING ROOTS

The influence of BME occurred in several steps. Electrical engineers were probably the first to see opportunities in medicine and biology. Soon after, biomechanics emerged from MechE. ChemE contributed mainly through artificial kidney blood dialysis. BME academic programs were established in the 1960s [12], but most had little or no course work in biology. Some, but not all, included physiology. There were early attempts to teach physiology from an engineering perspective [13], and many believed that the term 'biomedical engineering' included both biological and medical engineering [14], but the reality was that the focus was almost completely on medicine. Even the establishment of the Alliance for Engineering in Medicine and Biology (AEMB) in 1969 by Lester Goodman *et al.*, was not able to raise BiolE to the status of Medical Engineering.

ABET accreditation of undergraduate BME programs reached a plateau of 18–22 schools in the 1980s–1990s [12], and the number has only recently increased to 24 programs [15]. The core curriculum for BME has been a topic of conversation for years, without complete agreement or essential courses for all BME programs [16].

There developed a strong rivalry between the Biomedical Engineering Society (BMES) and the Institute for Electrical and Electronics Engineering—Engineering in Medicine and Biology Society (IEEE–EMBS) that reached fever proportions when BMES attempted to wrest control of the accreditation of BME academic programs from IEEE–EMBS. The attempt was beaten back in the late 1970s.

Since those days, IEEE–EMBS has allowed BMES to become the lead society for BME accreditation, and most BME programs have been including more and more biology and physiology. With the strong emphasis today on cellular and subcellular biological mechanisms in medical diagnosis and treatment, BME academic programs are beginning to look very similar to BiolE programs.

At the same time, many BiolE programs now embrace BME as a specialty area. A large number of formerly AgE programs have recruited BME faculty to teach their BiolE undergraduate courses. The popularity of BME has increased BiolE student enrollment manyfold. As an example, interest in BME among BiolE undergraduate students at the University of Maryland has increased from 40% in 1994 to 90% of students at present.

CHEMICAL ENGINEERING SOURCES

The same reductionist trend toward biochemical mechanisms important in biotechnology, and especially medical biotechnology, has seen the rise of research interest by chemical engineers. For many years, chemical engineers with interest in biology were interested mainly in bioreactor processes and extraction of valuable biochemicals. Although the number of biochemical engineers or bioprocessing engineers was relatively small within ChemE, they formed a ready pool of potential faculty members when AgE departments underwent the transition toward BiolE. Indeed, many of the first new faculty hires for BiolE programs came from ChemE backgrounds.

The undergraduate enrollment in ChemE has been declining steadily over the recent past [17, 18], and this has motivated a new look at BiolE, although with a decidedly ChemE flavor. Academic programs in ChemE have been rapidly changing their names to add some variant of BiolE. As yet, very few of these programs have added substantial education in biology to their curricula. Just as is now happening with AgE, it took a crisis of membership and finances in their professional organization, the American Institute for Chemical Engineering (AIChE), to focus on BiolE, as the solution for many of these problems.

SYNTHESIS

The BiolE that eventually emerges from these three sources will likely include a broad systems approach (from AgE), a strong medical modelling component (from BME), and substantial bioprocessing (from ChemE). It is imperative, however, that the resulting discipline treats all possible applications equally without undue specialization at the undergraduate level. AgE and BME could then emerge as specialty applications at the upper undergraduate level or at the graduate level. ChemE that does not involve biology will eventually return to its pre-BiolE form.

CURRENT TRENDS

So, where is BiolE today? Much has been written about BiolE. Two foundational documents have been published in the engineering education literature defining and laying a blueprint for further development at the undergraduate [19] and graduate levels [20]. These papers appeared very early in the development of BiolE compared with development of other disciplines. Both of these papers draw the distinction between science-based engineering disciplines and applications-based (some say sector-based) disciplines, a distinction that was not so well defined before BiolE was conceived. Other articles and papers in the ASAE, IBE, and ASEE literature helped to convey the vision of BiolE as broad and fundamental, but based on the science of biology.

The persisting perception of BiolE emanating from AgE roots is that of an engineering still largely related to agriculture. Indeed, that perception has been reinforced by:

- academic programs that changed their names from AgE to BiolE but were slow to change their courses and curricula;

- departmental research projects still largely agriculturally-inspired;
- continuing administration of BiolE departments within colleges of agriculture rather than in colleges of engineering;
- minimal activity and exposure of BiolE faculty on a professional level with other faculty with interests in biology and medicine in professional societies other than ASAE.

Some of these have been slowly changing. When more faculty with ChemE ties were added to BiolE programs, they maintained membership in professional societies such as AIChE. The perception of BiolE departments from AgE roots is probably more favorable among Chemical Engineers than among other engineering disciplines as a result. As BME faculty are added to BiolE departments, it is expected that the strengths of BiolE will be more fully appreciated among that group. However, the continuing administration of BiolE departments within colleges of agriculture has become an obstacle to adding BME faculty to BiolE departments.

There are a number of descriptions of BiolE and variants currently in use. N. R. Scott, when President of IBE, expended a large amount of effort to achieve a consensus definition of BiolE:

> Biological Engineering is the biology-based engineering discipline that integrates life sciences with engineering in the advancement and application of fundamental concepts of biological systems from molecular to ecosystem levels.

The US National Institutes for Health has a definition of Bioengineering influenced greatly by Doug Lauffenberger from a ChemE background:

> 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.

The US National Science Foundation program in Biochemical Engineering and Biotechnology (BEB) describes its program in this way:

> Advances the knowledge base of basic engineering and scientific principles of bioprocessing at both the molecular level (biomolecular engineering) and the manufacturing scale (bioprocess engineering). Many proposals supported by BEB programs are involved with the development of enabling technologies for production of a wide range of biotechnology products and services by making use of enzymes, mammalian, microbial, plant, and/or insect cells to produce useful biochemicals, pharmaceuticals, cells, cellular components, or cell composites (tissues).

And the Whitaker Foundation definition of BME is:

> Biomedical engineering is a discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. It includes: 1) the acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences, and 2) the development of new devices, algorithms, processes and systems that advances biology and medicine and improves medical practice and health care delivery.

As used by the foundation, the term 'biomedical engineering research' is thus defined in a broad sense: it includes not only the relevant application of engineering to medicine but also to the basic life sciences.

The climate for an immediate emergence of a BiolE recognized by all interested groups is not the best [21]. The opportunities for research funding of engineering related to biology and medicine are so great that large numbers of engineers from other disciplines are being attracted. Many of these either have their own ideas about what BiolE should be or think that there is no need for a separate BiolE discipline. New disciplines, like new species, require a degree of isolation and calm to emerge. Engineering related to biology cannot be characterized by either of these descriptions. Thus, until a general concept of BiolE can be widely supported, and energy directed toward establishment of a common undergraduate curriculum, it is unlikely that BiolE will become the discipline that has been defined thus far.

TEXTBOOK NEEDS

Engineering is a profession: it is an occupation that involves liberal education and mental rather than manual labor. BiolE is expected to be a discipline within the engineering profession. A discipline is characterized by a distinct body of knowledge and methods. The body of knowledge for BiolE is fairly easy to discern: it involves engineering related to and using living things. The distinct methods have not been agreed upon.

An engineering discipline requires a core curriculum consisting of courses similar across academic institutions. This is certainly facilitated by a set of textbooks commonly used in many locations. AgE education was defined by the Ferguson Foundation series of textbooks below:

- *Electricity In Agricultural Engineering* by Truman E. Hienton, Dennis E. Wiant, and Oral A. Brown
- *Principles Of Farm Machinery,* by Roy Bainer, E. L. Barger, and R. A. Kepner
- *Soil And Water Conservation Engineering,* by G. O. Schwab, R. K. Frevert, T. W. Edminster, and K. K. Barnes
- *Agricultural Process Engineering*, by S. M. Henderson and R. L. Perry
- *Tractors And Their Power Units,* by E. L. Barger, J. B. Liljedahl, W. M. Carleton

- Farm Structures, by H. J. Barre and L. L. Sammet.

BME has generally had a wealth of textbooks in core areas such as physiology, biomedical instrumentation, and imaging [12]. ChemE had transport processes and unit operations books [22, 23] to unify their educational experiences. Y. C. Fung's biomechanics texts helped to establish commonality in that field [24–26]. As yet there is no such set of commonly-accepted texts for BiolE.

The report by Garrett *et al.*, [7] essentially laid out a blueprint for undergraduate core courses in BiolE. These were further detailed in the papers by Johnson and Phillips [19] and Johnson and Schreuders [20]. However, these specifications have not been generally accepted thus far. One reason for this is that the AgE literature is largely unfamiliar to others outside of AgE. Another reason is that those developing course materials have few models from which to draw. Most recently published materials [27–30] have taken more or less traditional engineering approaches and added biological examples. The transport processes book by Truskey *et al.*, [31] is a major improvement in amalgamating biology with engineering, but it is not strictly a BiolE textbook. From the biology side, even the book entitled *New Biology for Engineers* [32] contains traditional biology, but with a little less detail and limited mostly to the cellular level. These materials may be adequate at present, but they do not do much to define a new science-based discipline.

There is a need for textbooks in all envisioned core courses. Among these are transport phenomena, instrumentation, physical and biological properties of materials, control systems, and biology. Each of these should at least take a broad view of all segments of the field of biology and show where engineering can be used to analyze or synthesize with living things.

If the common methods defining the undergraduate BiolE curriculum includes a systems approach emphasizing a broad, fundamental and principle-based approach to the study and utilization of biology, then the academic programs based upon these methods should have texts incorporating them. Recognition of this concept is evidenced by the number of programs with Biological Systems or Biosystems in their names.

Biological Process Engineering [33] is a text written with an analogical systems approach to the transport processes of heat transfer, fluid flow, and mass transfer applied to living things of all kinds. The advantages of this approach is that it is conceptual rather than mathematical, and it reduces all transport processes and all biological systems to a set of clearly-defined elements. Familiarity with these elements enables an engineering application involving biological systems to be outlined rather quickly and in a logically clear manner. This text is suitable for the first exposure of BiolE students to transport processes. More involved mathematical modeling of transport processes requires additional courses and texts.

A second text is *Biology for Engineers* currently under development but available on the Web [34]. The approach used here is to look at biology from a utilization viewpoint. There have been past attempts at reducing biology to a series of simple principles. None of these has been very successful. This text attempts to explain biological principles, but also attempts to present enough information in a form that will enable a BiolE graduate to predict the behavior of a biological system, no matter what hierarchal level is being scrutinized. As stated in this text, the objectives of this work are to:

1. enable the biological engineer to use biology to produce useful products and processes;
2. allow the biological engineer to transfer information from a familiar biological system to one that is new or unknown;
3. help the biological engineer to avoid the unintended consequences of dealing with any biological system.

Whether these two texts serve as models for future texts or are merely steps in the transition toward the final form of BiolE remain to be seen.

In any case, to develop into a clearly definable separate discipline, BiolE must have its own texts that are commonly accepted and that serve this discipline better than other disciplines. The technical area represented and the methods used in BiolE must be different enough that they define an independent field.

CONCLUSIONS

BiolE is presently unformed, although moving towards formation. Opportunities in the area abound, and interest has been piqued. From its three roots, a common BiolE synthesis is possible, but is still not a foregone conclusion. The discipline will be formed when agreement can be reached about the field of knowledge, methods, and a suitable set of textbooks supporting a core academic curriculum.

REFERENCES

1. R. D. Rohrbach, Biological Engineering at NC State University, Professor, North Carolina State University, Biological and Agricultural Engineering Dept., private communication (2004).
2. NC State University, A Brief History of Biological and Agricultural Engineering at North Carolina State University. www.bae.ncsu.edu/mission_history (accessed 22 Jan. 2004).

3. W. R. Fox, Biological Engineering at Mississippi State University, former Head, Agricultural and Biological Engineering Dept., Mississippi State University, private communication (2004).
4. H. C. Simrall, W. R. Fox and J. H. Anderson, To meet the demands of today's human environment, Agr. Engr. **49**(10) pp. 584–585 (1968).
5. J. Ogilvie, History of Engineering at Guelph, former Director, School of Engineering, University of Guelph, private communication (11 July 2001).
6. R. W. Irwin, *Engineering at Guelph: A History, 1874-1987,* Technical Report 126-81, School of Engineering, Ontario Agricultural College, University of Guelph, Guelph, ON (1988).
7. R. E. Garrett, D. C. Davis, D. M. Edwards, A. T. Johnson and G. E. Rehkugler, *Improvement of Competencies of Agricultural and Related Biological Engineers,* Report of CSRS USDA Agreement No. 90—38411-5734, University of California, Davis, CA 95616-5294 (1992).
8. R. M. Arthur, What is biological engineering? *Agr. Engr.,* 1970, pp. 151–691.
9. B. P. Verma, Biological engineering evolution, in *Encyclopedia of Agricultural, Food, and Biological Engineering*, Marcel Dekker, New York (2003).
10. O. J. Loewer, Biological engineering history, in *Encyclopedia of Agricultural, Food, and Biological Engineering*, Marcel Dekker, New York (2003).
11. ASAE, *Undergraduate Biological Engineering Curriculum: Vision for the Future,* Academic Program Administrators Committee, American Society of Agricultural Engineers, St. Joseph, MI (1990).
12. T. C. Pilkington, F. M. Long, R. Plonsey, J. G. Webster and W. Welkowitz, Status and trends in biomedical engineering education, *IEEE Engr. Med. Biol. Mag.,* **8**(3) Sept. 1989, pp. 9–17.
13. J. Kline, *Biological Foundations of Biomedical Engineering,* Little, Brown, and Co., Boston (1976).
14. J. D. Bronzino, Biomedical engineering: a definition, in *The Biomedical Engineering Handbook*, J. D. Bronzino, ed., CRC Press, Boca Raton, FL (1995) pp. v–vi.
15. R. A. Linsenmeier, What makes a biomedical engineer? *IEEE Engr. Med. Biol. Mag.* **22**(4) July/Aug, 2003, pp. 32–38.
16. Whitaker Foundation, *Educational Goals for Biomedical Engineering Curricula,* Whitaker Foundation, Arlington, VA (1998).
17. ASEE, Databytes: Ups & downs, *ASEE Prism,* **13**(5), Jan 2004, p. 20.
18. B. Halford, Pursuing new paths, *ASEE Prism*, **13**(3), Nov 2003, pp. 34–37.
19. A. T. Johnson and W. M. Phillips, Philosophical foundations of biological engineering, *J. Engr. Educ.,* **84**, 1995, pp. 311–320.
20. A. T. Johnson and P. D. Schreuders, Bringing life to engineering: biological engineering at the graduate level, *Eur. J. Engr. Educ.,* **28**, 2003, pp. 37–46.
21. A. T. Johnson, Bioengineering in the U.S.: The Rush is On, *AIMBE Newsletter*, April 2002, pp. 9–11.
22. R. B. Bird, W. E. Stewart, E. N. Lightfoot, *Transport Phenomena,* Wiley, New York (1960).
23. C. J. Geankoplis, *Transport Processes and Unit Operations,* Prentice-Hall, Englewood Cliffs, NJ (1993).
24. Y. C. Fung, *Biodynamics: Circulation,* Springer-Verlag, Berlin (1984).
25. Y. C. Fung, *Biomechanics: Mechanical Properties of Living Tissue,* Springer-Verlag: Berlin (1981).
26. Y. C. Fung, *Biomechanics: Motion, Flow, Stress, and Growth,* Springer-Verlag: Berlin (1990).
27. E. C. Alocilja, *Principles of Biosystems Engineering*, Erudition Books: North Chemsford, MA (2002).
28. J. S. Cundiff and K. R. Mankin, *Dynamics of Biological Systems,* ASAE, St. Joseph, MI (2003).
29. A. K. Datta, *Biological and Bioenvironmental Heat and Mass Transfer,* Marcel Dekker, New York (2002).
30. D. T. Haynie, *Biological Thermodynamics,* Cambridge University Press: Cambridge, UK (2001).
31. G. A. Trusky, F. Yuan, and D. F. Katz, 2004, *Transport Phenomena in Biological Systems,* Pearson–Prentice-Hall, Upper Saddle River, N.J. (2004).
32. A. Tözeren and S. W. Byers, *New Biology for Engineers and Computer Scientists,* Prentice Hall: Upper Saddle River, NJ (2004).
33. A. T. Johnson, *Biological Process Engineering,* John Wiley and Sons, New York (1999).
34. A. T. Johnson, *Biology for Engineers,* available on ww.bre.umd.edu/johnson.htm (2004).

Art Johnson, is Professor, Biological Resources Engineering, Bioengineering, and Kinesiology (Affiliate) at the University of Maryland, College Park, MD. He has been a member of the University's faculty since 1975. An alumnus of Cornell University, Dr. Johnson has his BAE in Agricultural Engineering (1964), and a MS (1967) and Ph.D. (1969) in Agricultural Engineering with a minor in Electrical Engineering. His interests include physiological effects of respirator wear, exercise physiology, bioengineering, respiratory mechanics and biomechanics. Doctor Johnson is a Fellow of the American Society for Engineering Education, The American Institute for Medical and Biological Engineering, the American Society of Agricultural and Biological Engineers, the Biomedical Engineering Society, and the American Industrial Hygiene Association. He has authored over 100 peer-reviewed publications, three books and 26 book chapters. He holds three patents. He teaches courses in biology for engineers, transport processes, biomechanics, instrumentation, electronic design and engineering design.