Read* Ink

A Collection of Writings for Medical and Biological Engineers

* Meant as the past tense of "Read".

Arthur T. Johnson

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About the Author

Arthur T. Johnson attended Cornell University for his undergraduate and graduate degrees. His PhD was awarded in 1969, and he immediately began serving as an officer in the US Army, eventually serving in Viet Nam at the rank of captain. He was awarded the Army Commendation Medal and Bronze Star Medal. He joined the faculty of the University of Maryland in 1975, and was Professor from 1986 until 2009, when he became Professor Emeritus. He was cochairman of the committee to found the American Institute for Medical and Biological Engineering (AIMBE) from 1988 to 1992, and served as the Executive Director of AIMBE in 2004. He has been President of the Alliance for Engineering in Medicine and Biology (1984-1988), Institute for Biological Engineering (1998), and International Society for Respiratory Protection (2004-2006). He was the Secretary of the Biomedical Engineering Society from 2004 to 2009. He has been on the Board of Directors of the American Society for Agricultural and Biological Engineers (1995-1997). He is a Founding Fellow of the American Institute for Medical and Biological Engineering (1992), Life Fellow of the American Society for Engineering Education (1996), Life Fellow of the American Society for Agricultural and Biological Engineers (2002), Fellow of the American Industrial Hygiene Association (2005), Fellow of the Biomedical Engineering Society (2005), Fellow of the Institute for Biological Engineering (2009), and the Life Fellow of the Institute for Electrical and Electronics Engineers (2010). He is a member of the honor societies: Phi Kappa Phi, Sigma Xi, Tau Beta Pi, and Alpha Epsilon. He has written three books: *Biomechanics and Exercise Physiology: Quantitative Modeling*, *Biological Process Engineering, and Biology for Engineers*, and coauthored a fourth, *Design of Biomedical Devices and Systems,* with Paul King and Richard Fries. His research interests are human performance wearing respiratory protective masks, respiratory mechanics and measurement, and transport processes. He has taught many course topics, including electronic design, transport process design, and engineering in biology. He is currently working to continue development of the Airflow Perturbation Device as a noninvasive measurement of respiratory resistance. He is also operating a 49 acre farm producing organically-raised fruit for sale at the local farmers' market.

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Part 1

Medical and Biological Engineering

The Winning Team

Arthur T. Johnson

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Preparing to meet the challenges of globalization demands new approaches to bioengineering education. In a previous editorial (Johnson, 2008), I expressed the view that the fittest for survival were those who were generalistic, versatile, and creative. Of course, this may always have been true, but globalization is rapidly expanding the choices for bioengineering service needs. With about 400,000 engineers graduating per year in Asia, compared to 75,000 annually in the U.S., the number of qualified engineering practitioners in the world outside the U.S. will soon be overwhelming. Intense engineering tasks of a routine nature can be accomplished almost anywhere with global communications what they are. So, it doesn't seem productive to try to compete with skills possessed by huge numbers of other engineers.

Although it was previously asserted (Johnson, 2008) that medical and biological engineers, because of their relatively broad range of interests, are positioned to take advantage of modern technological trends, changes are still necessary to assure a future for our graduates. Goldberg (2008) has written that the engineering curriculum is broken, and it needs to be fixed by wholesale reformulation. The Cold War curriculum that emphasized math and science at the expense of creative thinking should be trashed. In its place should be the skills that future engineers will need to survive and thrive. He names analytical ability, creativity, and communication as three of these, which together he calls qualitative thinking. The global economy places a premium on creative engineering activities performed locally; routine engineering services can and will be supplied from elsewhere. We need to educate future engineers by preparing our students to conceptualize, create, and communicate.

Jerry Theodorou (2008) expressed it differently. He wrote that:

> "*. . . . I've found that the key to staying creative is inductive logic. If one reads widely with an uncritical eye, processes information from unlikely sources far afield from one's area of "expertise," and manages to maintain curiosity and awe of a child, one increases the chances of seeing patterns and identifying connections that would otherwise remain invisible*."

He goes on to say that:

> "*Deductive reasoning, in which truth and solutions flow only from the proven and tested, often serves as a drag on creativity*."

Engineering designs, those that are truly innovative need both induction and deduction. The induction comes at the very beginning, as a new idea takes shape and the concept of the product is just being born. This is the creative part of engineering, or the essential art of engineering practice.

Deduction is needed when an engineering concept is reduced to reality. Calculations are used with well-established knowledge to ensure that the design succeeds. No product should ever be attempted if the parameters are not all known. Deduction, or interpolation, of known information is necessary to avoid probable failure.

So, both being necessary for a successful engineering practice, are we doing right by our students? I am quite sure that engineering science and mathematics courses exercise and enhance left-brain skills. Routine problem solving becomes familiar, if not automatic in these courses. Engineering design courses, on the other hand (or is it the other half-brain?) emphasize and exercise creative right-brain skills. General education courses should be chosen to stretch thought processes and develop new neural connections. They lead to more than just new concepts—they can lead to new paradigms of thought. Imagine, for example, Bach's Toccata and Fugue in D Minor suggesting new ways to present information. Imagine, also, an engineer so assured of her communications skills that she can sell the idea to others. Voilá! a successful engineer of first magnitude.

But, in case we forget the competition, let's take note of the fact that in India, too, soft skill training has drawn attention and is beginning to be seen to be important. While many engineering graduates in India have state of the art technical skills, only one in four is considered to be employable by multinational firms because their interpersonal and communications skills are poor (Singh, 2008). They cannot fit into a cosmopolitan work environment.

Enter Dale Carnegie training, and everyone metamorphoses into hand-shaking, smiling, glad-talking bundles of self-confidence. Competition was always very important biologically, but competition in the global arena is becoming much more intense.

The Red Queen principle, "*It takes all the running you can just to stay in the same place*," (Carroll, 1865) applies to all bioengineers in the 21st century. Hard running requires the best well-rounded individual we can produce. Winning the race requires a fair advantage, and that advantage can take the form of location, imagination, communications skills, absorbing free-thinking attitudes from the local culture, or any combination of these. That advantage will not likely come in the form of technical skills better than others in your class.

I have seen this over and over in my own students. Some students know exactly how to solve a heat transfer problem or design a simple electronic circuit. For others, it's a struggle. But let those others give an oral presentation, and their true skills shine. Arlo Guthrie said that "*everyone is good for something*," and it's true. I fully expect the "C" students in my class to become the millionaires, or the politicians, or the movers and shakers of the world, while the "A" students become underpaid professors like myself with very limited influence. Who will be most successful? By many measures it could be the "C" students.

Who do you hire to be the baseball team's batting coach? Is it the natural hitter, the guy who could hit home runs with his eyes closed? Or is it the guy who always struggled with hitting, who had to analyze and re-analyze his batting stance and his swing? I would hire the struggler, because he is the one who could teach batting skills to others. The first guy would expect everyone to be able to bat successfully with their eyes closed.

So it is with our future bioengineers. We need creative engineers capable of original thinking and also capable of communicating their ideas to others. Hire the best coaches, and give them a simple job to do: make our guys and gals be the winning team.

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Biological Engineering: What It Means to Me

Arthur T. Johnson

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I have been involved with Biological Engineering for almost my entire professional life, and have been totally committed to its definition, promotion, and dissemination during that time. Here are some thoughts that come to mind when Biological Engineering (BE) is discussed. These are, of necessity, only very briefly presented.

1. History. Although the history of BE goes back farther than this (Johnson, 2006), Pat Hassler changed the name of the NC State program to Biological and Agricultural Agricultural Engineering in 1965. Bill Fox and Jim Anderson followed at Mississippi State in 1967, and, together with Rensselear Polytechnic Institute, were the first two accredited BE programs. There were many in ASABE who championed BE, among them Norm Scott, who, as IBE President in 2000 pushed for a common definition of BE, that, by consensus, became: "*BE 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*." My own BE efforts were more concentrated outside of ASABE, in The Alliance for Engineering in Medicine and Biology, The American Institute for Medical and Biological Engineering, and the American Society for Engineering Education.

2. Attributes of Biological Engineers.

- *They are generalists.* They have an appreciation for interrelationships and interconnections, approach BE problems from a systems perspective, and use analogical thinking.
- *They are enthusiastic.* They appreciate the wonders revealed about the ways of living things, see themselves as positive contributors to humankind and the state of the world, and are, consequently, highly motivated.
- *They are creative.* They work with biological tendencies rather than against them, do not need to subdue or dominate other living things, and use imagination to extend natural tendencies.
- *They are skilled.* Hands-on experiences enhance understanding and remembering. Personal involvement in making or doing begets inspiration and improvement for present or future BE solutions. They have confidence in their abilities. It is important for BE students to have meaningful laboratory experiences as part of their educations.
- *They are science-based.* This means that their interest and knowledge base encompasses all possible applications. Their interests are not tied to any particular industry, and advances in one specialty apply to all. This is one of the hardest attributes to embrace, and stands as an obstacle to full development of BE as a separate discipline. No matter what the foundational disciplines are for those moving in to BE, their concept of BE is colored by their former backgrounds.

- *They know biological principles.* These are important to know in order to be effective as a Biological Engineer. These include, but are not limited to (Johnson, 2010),
    - Competition for resources
    - Reproduction (amazing in itself; what other chemicals do you know that are compelled to reproduce at the expense of all other chemicals in the world?)
    - Selection of the most likely to reproduce
    - Information legacies
    - Influence of physical, chemical, and biological environments
    - Likelihood of unintended consequences
    - Redundancies
    - Exceptions to the rule is the rule

  They must be thoroughly familiar with the ways of biology. Web searching should be used to find details, not general information. Googling will not be effective if the Biological Engineer doesn't know where to start.
- *They are visionary.* They ask questions, such as:
    - What is possible?
    - How would this problem be solved biologically (bioinspiration)? Is there a biological solution to a similar problem (biomimetics)?
    - What are the limits?
    - How can I work with biological principles, not against them?
- *They have a common knowledge base.* Besides the principles outlined in Johnson (2010), they conform to the IBE definition of BE given earlier in the broadest possible sense.

3. Basic Textbooks. When inchoate Agricultural Engineering (AE) was just emerging as a discipline it was much more isolated than is BE at this stage. There was no explicit fundamental agreement about common educational objectives or foundational knowledge, but it did have the Ferguson series of textbooks that served the purpose of forming disciplinary cohesiveness. These became the basis for AE as a separate discipline. There is need in BE to do the same thing.

I have written three textbooks that could either serve a similar purpose or lead the way toward such an academic understructure. The last two are probably more relevant than the first:

- *Biomechanics and Exercise Physiology: Quantitative Modeling.* In this book are contained the means to predict physiological and ergonomic responses to work and exercise as would be needed in a BE design.
- *Biological Process Engineering: an Analogical Approach to Fluid Flow, Heat Transfer, and Mass Transfer Applied to Biological Systems.* This book uses analogs to demonstrate the concepts behind transport processes, and presents design equations and tabled values meant to assist with BE designs.
- *Biology for Engineers,* with significant Addenda at http://www.bioe.umd.edu/~artjohns/books/biology-for-engineers/1stEd-Addenda.pdf . This is the most fundamental of the three, but presents biology as engineers should know the science. It is broad and comprehensive, emphasizing how things work so that Biological Engineers know what to expect when working with living things.

4. The Future. BE can emerge as a separate and distinct discipline, but only if there is agreement about what it should contain and it is given time to develop (Johnson, 2002).

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Bioengineering in the U.S.: The Rush is On

Arthur T. Johnson

Published in the AIMBE News, pp. 9-11 (April *2002) and in the IBE Newsletter vol. 6.1, pp. 3-4 (2001).*

The plethora of new biology-based technologies has sparked a frantic rush to establish and enhance academic bioengineering programs in the U.S. The economic boom of the 1990's and the Whitaker Foundation, with its goals to contribute its entire sizeable endowment to bioengineering projects and programs by the year 2006, enabled bioengineering research and academic activity to reach an unparalleled frenzy in recent years. However much good these pressures have been for the field, they may also have kept bioengineering from emerging in an orderly and thoughtful way necessary for the establishment of a truly independent engineering discipline.

What characterizes a discipline? There are two generally-accepted characteristics: 1) a distinct body of knowledge, and 2) distinct methods. Of the two, the body of knowledge is generally easier to define; methods require that the discipline emerges from its nascent period. Without both of these, a new discipline is just an extension of prior disciplines, and the new discipline may never achieve recognition as being separate.

There are two basic categories of engineering discipline: 1) applications-based, and 2) science-based. The first category defines the discipline by those served. For example, mining engineering, agricultural engineering, and petroleum engineering are all applications disciplines. The second category defines the discipline by its scientific foundation. For example, mechanical engineering and chemical engineering are science based disciplines based upon mechanics (physics) and chemistry, respectively. Education in an applications discipline is usually more specific and applied than that for the fundamental science-based discipline.

It is not particularly clear whether bioengineering will become an applications discipline or a science–based discipline. Much of biomedical engineering, constituting the core of bioengineering, is applications-based. Biomedical engineering utilizes knowledge and techniques from electrical, mechanical, or chemical engineering, and applies them to the field of medicine.

Biological engineering, a term sometimes used synonymously with the term bioengineering, is science-based, and requires a strong background in biology as well as in engineering. It is recognized within biological engineering that unique solutions to technical problems may as well come from the biological side of the discipline as from the engineering side.

One big difference between these two is the loyalties, or identifications, of their practitioners. Those who practice an applications discipline are likely to have studied a more fundamental discipline and to retain their identification as part of the fundamental discipline. Thus, many biomedical engineers who work with signal processing identify themselves as electrical engineers. Many rehabilitation engineers still think of themselves as mechanical engineers. When these practitioners work with a particular application, they often do so with minimal knowledge of the system of application, and they use the methods they were taught in their fundamental discipline.

Biological engineers, on the other hand, have a thorough and intrinsic knowledge of biological systems. They are aware of nuances and expectations typical of biological systems, and identify with no other discipline.

The trouble is that the formation of biological engineering (or bioengineering) has not been completed. A body of knowledge has not been completely defined and unique methods have not been identified. There are few true science-based bioengineers because there is no pattern for automatically forming engineers with this type of education. The students of today are being taught by the students of yesteryear, and those students were taught in fields different from biology-based biological engineering. Thus, progress toward a truly separate discipline with distinct bodies of knowledge and methods can only be incremental.

There are many distractions hindering this process of development. To use a biologically-based analogy, a new species can only emerge from isolation. Continued interbreeding with established species only adds to the richness of the gene pool, but does not lead to a new species (one trait of which is the inability to breed with other species). Likewise, the establishment of a new discipline requires a certain isolation and reflection on the vision of that discipline. In these days of unparalleled opportunity and multidisciplinary research, that isolation is not occurring. Consequently, visions for the bioengineering discipline are numerous, and often reflect the habits derived from the many source disciplines that are now feeding into what we presently call bioengineering.

Thus, we see bioengineering described in terms of biomedical engineering, which is engineering applied to medicine and health care. The biology in this vision is at the organismal level, and specifically the human organism. We also see bioengineering described in terms of cellular and tissue engineering, which is engineering applied to living cells and tissues, including genetic engineering. This vision encompasses the biotechnological and nonmedical applications, and is science-based up to the level of tissues. We also see bioengineering described in terms of biological systems engineering, which features biology and engineering as coequal foundations. This vision includes all levels of biology, including the population interactions of ecology. Because the potential applications are so numerous, this is a science-based vision.

And then there are hybrids of these approaches that combine them in different ways. The U.S. National Institutes of Health promotes one of these: by its definition bioengineering is an integration of "physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behavior, or health. It advances fundamental concepts, creates knowledge from the molecular to the organ systems level, and develops innovative biologies, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health."

There are opposing research directions that also influence this field. Reductionism is the tendency to view a system on its smallest possible scale. In biology this means that to understand organisms or populations of organisms one needs to understand completely their functional genomics. Many of the present bioengineering opportunities owe their importance to the reductionist approach.

On the other hand, other researchers are struggling to understand relations among groups of organisms and to model ecological outcomes. This holistic systems view does not presently view the system from its genetic base.

How do these two approaches affect bioengineering? They tend to pull it in two different directions. There hasn't been time nor the isolated reflection necessary to show how these approaches fit together, and, as a consequence, bioengineering is still largely undefined. At best we can say that the field is still being formed, or in a transitional state.

The present distraction posed by cellular and tissue bioengineering is particularly strong. The opportunities are so vast that many educators have been lured into defining bioengineering in terms of their research interests. The curricula that have resulted often ignore the science of biology at levels higher than tissue. The term "bioengineering" is often applied to this portion only of the field, and this largely applications-based usage is often not distinguished from the more broadly-based scientific discipline usage of the same word that is promoted by others.

Given some thought, it could be realized that the big distinction in biology occurs at the cellular level. At or above that level, biological responses of cells or groups of cells of any complexity are fundamentally similar. Below the cellular level can be characterized as a chemical system. This discontinuity is closely analogous to that in physics above and below the atomic level. Therefore, any bioengineering that does not recognize the supercellular biological continuum is not the science-based discipline that is separate and distinct.

As far as distinctive methods are concerned, there are few candidates from which to choose. My own bias is to view the field of biology from a systems viewpoint. Whether at a subcellular, cellular, tissue, organ, organism, or population level, biology can be considered to be another system with input/output relationships that can be anticipated as following certain general principles with some important exceptions. Looked at this way, a biological system is a product both of its genetic basis and the environment in which it finds itself. Thus, both reductionism and ecological systems approaches have their contributions to make.

It is hard to say whether bioengineering will someday emerge as a separate and distinct discipline. There are many influences from many sources that are tending to keep the field from coalescing as a cohesive unit. Until that happens, there will not be general agreement about a specific knowledge core, courses to offer, or typical academic programs to design. And, without these, industrial or other employers will not be completely sure about the capabilities of graduates from the 90 or so bioengineering programs in the U.S.

Nonetheless, these are exciting times. The opportunities are great and the contributions that an individual can make are numerous. We have a frenetic pace in the field that is not waiting for a definition or a unique discipline to emerge. That will take some time and a lot of reflective thought.

Engineering Applied to Biology

Arthur T. Johnson

Published in the January/February 2009 issue of Resource

The central message given by Mark Riley in the October issue of Resource, that a systems approach is necessary in order to appreciate fully the outcomes of engineering applied to biology, is one that I agree with very much. As Mark has noted, the genome isn't the only determination of biological outcomes; each biological unit is a product of the interactions it has with its physical, chemical, and biological environments, something that has been taught in agricultural engineering since before I went to school. The problems are several:

1. environmental conditions are chaotic in the mathematical sense of the word.
2. individual genes in the genome may or may not be activated.
3. cultural practices passed from older to younger generations are a parallel legacy of information and behavioral outcomes.
4. biological units are adaptable and changeable.

That is why engineers need to learn about biology differently from the way biologists learn. Engineers need principles and basic concepts related to utilization, and they need the ability to avoid unintended consequences that are likely when dealing with living things.

As to the difference between civil engineering designs and biological engineering designs, one major difference is the time that civil engineers have had to develop empirical knowledge to help avoid disasters. Biological engineers have been in business a much shorter span of time, and the range of applications is so much greater than it is for civil engineering, that it will take a long time to catch up.

Lastly, I think the real biological revolution is exhausted. By that I mean that most, if not all, of the basics are now known. What is left is to fill in the details, and there are certainly many to fill in. There are application opportunities galore, and these will continue to expand as long as anyone can imagine. Products and processes hardly considered possible until recently will become reality within the foreseeable future. Distinctions between the physical world and the biological world will blur, and we will have empirical models assisting in the designs of nearly all aspects of life. It's almost scary.

Missionaries on a Quest

Arthur T. Johnson

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Movements don't go anywhere without zealots. While Biological Engineering is not what some would call a religion, it has many of the elements nonetheless: there is an underlying need, its principles are emerging, and those dedicated to its cause can exhibit a strong passion for its spread.

Passion and emotional involvement beget excitement, and excitement is what Biological Engineering is all about. You hear the excitement in the voices of those discussing the field, and you see it in their actions. It is the same excitement that comes from discovering a new connection in your research findings, or from experiencing a new piece of music for the first time, or from learning some new skill.

I have seen this same excitement in the field of biomedical engineering when it was first being formed. During those years, if you wanted to provoke raised voices and passionate debate, you just had to bring up the issue of what the field should be called or what specialties should be included. Many a late night was spent and many a malt was consumed debating the nuances of biomedical engineering.

Those days for biomedical engineering have passed. The field is mature now, and in gaining maturity, a lot of the passion of the new field attenuated.

There is no reason to expect any different from Biological Engineering. The time for passion is now. The time to debate its qualities and inclusions is the present. Soon enough, should we succeed, Biological Engineering will enter into its mature phase and people will think little of what it has become or how it got there. And few will appreciate the passion of its founders.

You will read elsewhere in this newsletter about the efforts by several passionate people to reach out to the rest of the engineering community to bring more people into the fold. This effort is to be applauded. If it succeeds then Biological Engineering can achieve permanence.

Our Fundamental Commonality

Arthur T. Johnson

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I last wrote about disunity for expectations of bio-based engineers, and decried the fact that many of us seem to assess expectations of these engineers based upon the application areas with which we are familiar. However, application areas can only define applications based engineering disciplines, not science-based engineering disciplines. If we are an engineering discipline based upon the science of biology, and I think most of us would prefer to think of ourselves that way, then we must stop thinking primarily of applications when we describe who we are.

That is not easy to do. Bio-based engineers work on problems confined to some small locus within the biological realm. They are thus experts in some particular applications areas. They think first and foremost about their areas of specialization and are not always comfortable thinking outside the confines of these little boxes. So, sticking with the familiar, they have little to say about what they may share in common with those inhabiting other little boxes.

Duane Bruley used to talk of the four basic pillars of bioengineering: physics, chemistry, mathematics, and biology. We can start there when listing those features that define bioengineering or biological engineering. Biomedical engineering tends to be focused primarily on applications in medicine and may or may not fit the construct we are about to offer.

Physics was the first pillar on the list, and we have all studied physics. Bioengineers need to know a lot about physics. They need to know about optics, mechanics, fluids, electricity, and thermodynamics. They need to know about the difference between potentials and things that flow in response to a potential. They need to know about forces, velocities, and accelerations. They need to know about mechanical strengths of different materials, stresses created in these materials, and deformations that result. They need to know about fluid pressures exerted equally in all directions, about vessel resistances, and about input/output relationships. They need to know about material diffusion, convection (advection), and osmosis. They need to know about interactions among like and unlike charges, ionic currents, and electrical hazards. They need to know about the equivalence between work and energy, the second law of thermodynamics, and energy conversions. They should know about the states of matter and how each serves a different purpose in living things. They should appreciate that the order inherent in living things requires energy to maintain that order. Further, bioengineers should know about the methods physicists used to arrive at scientific truths, their quantitative methods, and their ingenious experimentation.

Bioengineers need to know about chemistry, how chemical compounds are formed, and energy transfer among different chemicals. They should know something about chemical equilibrium and disequilibrium, and how chemicals can be used as energy-storage repositories. They should know about normal metabolic pathways and metabolic and chemical efficiencies. They should know about classes of biochemicals, general characteristics of each, and where they are normally found in living things. They should know about physical chemistry, the differences in physical attributes that accompany different chemical compositions. They should know about surface energies and bioactivity. They need to know about molecular shape effects, geometrical conformation, and the physical basis for enzyme reactions and complementary DNA formation. They should know about pH effects, and appreciate the uniqueness of carbon chemistry and water as a solvent. They should also appreciate the meaning of free energy and what it means for living things. In addition, some appreciation of the methods of chemical detection and quantification should be retained.

Bioengineers should know mathematical concepts. They should know about the basis for differential and integral calculus, and when to switch from continuum to discreteness. They should be familiar with first-and second-order responses. They should know about randomness, probability, and statistics. They should be familiar with the concept of chaos, and path-based outcomes. And, certainly, they should be aware of the differences between different modeling approaches, especially between theoretical and empirical models, and the limitations of each. Methods of mathematical manipulation should also be committed to memory.

Bioengineers should also draw knowledge from the engineering sciences. Many of these are based on physics, and won't be repeated. Others are more mathematical in nature. Information theory is one of those, and the equality between information and biological order should be appreciated. Control systems are extremely important for living things, and bioengineers should have a thorough understanding of the elements of a control system (including means of communication among elements). They should also know about redundancy, optimization, amplification techniques, sensory discrimination, and reliability. Pattern recognition is important, as is just noticeable difference.

From the science of biology, came important concepts for bioengineers to know. First and foremost is the first law of biology: survival and reproduction. What should bio-based engineers know about biology? They should certainly know that form and function are related. They should be familiar with genes as information storage units, but also aware of intergenerational information transfer by cultural means (learning). They need to know about competition and selection pressures, and about necessary conditions for evolution. They should appreciate the different contributions of information legacies and environmental effects on biological outcomes, including genetic expression. Lastly, biological engineers or bioengineers should be aware of the difficulty defining what life is or isn't

I know that this list is a long one. There are many facts and concepts that I have enumerated that many would consider unnecessary. Likewise, there are others that might be added to the list. In particular, I can imagine some readers who would add a number of physiological facts to this list. But, remember, I am writing here of foundational knowledge for a science-based discipline instead of information necessary for particular applications. There are additional facts and concepts necessary for specific sub-fields, and these must be learned later, in addition to foundational knowledge.

Can the Chasms Be Bridged?

Arthur T. Johnson

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Earlier this summer the Biomedical Engineering Society (BMES--an AIMBE member) received a letter from the National Council of Examiners for Engineering and Surveying (NCEES) about interest in a meeting to discuss beginning a Professional Engineers examination common to all bio-based engineers. The American Society of Agricultural and Biological Engineers (ASABE--an AIMBE member) had initiated this inquiry. Also involved was the Society for Biological Engineering (AIChE-SBE--an AIMBE member). Invited to the meeting, in addition, were the American Society of Mechanical Engineers (ASME--an AIMBE member), the Engineering in Medicine and Biology Society (IEEE-EMBS--an AIMBE member), National Institute of Ceramic Engineers, and the American Academy of Environmental Engineers. Not invited was the Institute for Biological Engineers (IBE--an AIMBE member), and other AIMBE member societies that may or may not be interested in a licensure exam).

The responses to the invitation that I have heard go something like this: it is probably a good idea to have professional registration for biological and biomedical engineers whose work relates to public health and safety, but. . .

BUT, how can we expect biomedical engineers to know about ventilation requirements of stored fruits and vegetables, how to operate a compost pile, or how to optimize a bioreactor? How can we possibly expect biomedical engineers to know about environmental toxins, biochemical extractions and enzyme kinetics?

But, how can we expect biological engineers to know about medical practice? about imaging? about bioinformatics? How can we possibly expect biological engineers to know about Markov chains, surgical techniques, and automatic cardiac defibrillators?

Well, excuse me, but aren't these the wrong questions to ask? Isn't this like asking how mechanical engineers can know all about engine design, refrigeration, and electronic controls? Isn't it true that electrical engineers can deal with energy grids, electrical motors, nanofabrication of computer chips, and communications systems? Isn't there just one PE exam for all mechanical engineers and another for all electrical engineers? Why is there no one from each of these groups questioning how everyone from their respective field could possibly take the same PE exam?

The answer, of course, is that mechanical engineers, electrical engineers, and all of the others, focus on common knowledge: that which all members are expected to know. There may be some applications-specific questions that make their way on the PE exam, but the exam is structured in such a way that anyone in that field should be able to pass as long as they have had the expected common education.

One thing is clear from sessions at the American Society for Engineering Education, from Rob Linsenmaier's Delphi studies of required BME courses, from the Whitaker Foundation educational summits, and from intersociety discussions related to biological engineering and biomedical engineering. That is that there is no fundamental agreement about core knowledge for bio-based engineering fields. Each academic program approaches education of its students in a different way. Some, especially those located close to associated medical schools with teaching hospitals, mandate that their students should spend a lot of time learning medical technology. Others require several laboratories on bioreactors and bioseparations. It occurs to me that both of these are preparing their students for particular types of careers, and only for those careers.

Perhaps the problem is that faculty members who designed and administer these programs were themselves not educated as bio-based engineers. The great advances in biology over the last few decades came during a time when their formal educations had ended. They had only enough time to learn the one small portion of biology relevant to their research area, and that constituted their view of what a bio-based engineer should know. And, then again, perhaps the problem is this and a host of other factors.

I believe that any bio-based engineer who doesn't appreciate how any living being (or system) interacts with, reacts to, and is affected by its total chemical, physical, and biological environment is not well prepared. I believe that almost any engineer can work with living things, and, most likely, produce credible products and processes involving those living things. Perhaps right away, or perhaps eventually. That doesn't make that engineer a biomedical engineer or biological engineer, or whatever.

What distinguishes a true bio-based engineer from the others, I believe, is the essential study of biology forming an intrinsic part of the foundational knowledge base of that engineer. This bio-based engineer has a biological-science based understanding at least equal to the understanding of engineering sciences. This bio-based engineer is equipped to deal with the vagaries of living things. This bio-based engineer is versatile and valuable and able to look ahead to a long career filled with adjustments of technology and capability. But, maybe that's just my expectations.

Apparently, the people considering the common PE exam didn't see it that way. They were apparently looking at the application more importantly than the science. They saw the divisions, but didn't see the commonality.

As long as those perceptions pervade, there will be a divide that cannot be bridged. There will be at least one group on one side of the crevass and at least one group on the other. Each group will, in turn, believe it is superior, and that the other group has no validity. The chasm will prevent common communication, and misunderstanding will prevail. It will not be apparent to either group why they want exchange with the other.

That is, until we have a bridge. We need to build a bridge.

Gazing Into the Crystal Ball

Arthur T. Johnson

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The world around us is undergoing major change, and all of us are going to have to change with it. Hill (2007) posits that the U.S. has entered a post-scientific age, in which the basis for our continued economic and societal advancement will primarily come, not from technological advancement, but from new organizational structuring. There will still be need for engineering and scientific innovation, just as there is continuing need for some manufacturing, mining, and agricultural production, but there will be an increasing dependence on commercial and functional innovation, such as the new commercial and interpersonal paradigms offered by Ebay, Google, and YouTube. It will be the new means of presentation and organization that drive our future society forward.

With world-wide communication becoming so facile, the cost of new information falls to nearly nothing. The only ones who will pay substantially for the new information will be those who develop it, and, due to globalization, information development is becoming more and more diffuse. The U.S. used to have a huge technological lead over much of the rest of the world. Now, the lower costs of doing research in China and India are moving those countries closer to technological leadership.

Engineering education administrators have largely applauded the National Academies' report *Rising Above the Gathering Storm*, largely because they have seen the report as justification for new financial allocations. As an engineering educator myself, I took a look at recommendations in the report and said, "I'm already doing that." It's not that I wouldn't be happy to have more resources, but it just seemed as if actions taken in accordance with the report recommendations would just be bulking us up against inevitable change. What good would it do to train more engineers in science and math, if, when they were finished, there wouldn't be a place for them in the post-scientific society?

A few years ago, when I served briefly as Executive Director of AIMBE, I helped to organize a session at the Annual Event that had as its theme the effect of globalization on medical and biological engineering (MBE) in the U.S. We publicized the session to congressional offices and successfully had some congressional staff members in the audience when presentations were made.

What happened next had me shaking my head in dismay. Each of the speakers ended up by saying that globalization would have no untoward effect and that everything would be fine for MBE in the U.S. I still think that globalization is having and will have a profound effect on U.S. MBE. What an opportunity was missed when those staffers went back to their bosses, our representatives in Congress, and said that everything was fine and there was no reason to do anything about problems that didn't exist.

If you follow Hill's argument, we need creative skill more than math and science skills to meet the challenges of tomorrow. I am not saying that we don't need math and science at all--we do need them, but math and science are largely left-brain skills. We presently do well teaching those skills to our students. In order to meet the challenges of the future, we need to start exercising the right brain a lot more. We haven't always done such a good job at that.

When you look objectively at the effects of economic and, consequently, technical globalization, you see that a lot of the skilled engineering and science development jobs will migrate to the least expensive, yet reliable, source. If computer programming, engineering design, and applied research move offshore, innovation (the strength of U.S. technology) will move with them. It seems inevitable.

Those engineers who remain and who service in the new climate will have to be versatile, general, and local. They will have to be the ones who can manage projects detailed offshore, or they will have to be the ones who can apply global products to local customers, or they will have to be able to change focus of their careers maybe one or maybe many times.

MBE is in a particularly good position to meet the challenge. Although bio-based engineers may receive some specialized education, they are more likely to be generalists than some other engineers. The MBE field draws its strength from physics, math, chemistry, and biology, thus being inherently broader than electrical or mechanical engineering. There is, I suspect, a broader range of personality types (Myers-Briggs) in MBE than in most other engineering and scientific disciplines. This, it seems to me, augers well for the future of MBE. This is also one reason why we need to embrace the biological part of MBE as well as the medical part.

The post-scientific society will come, and we will be ready for it. We will, that is, if we emphasize generality, versatility, and creativity in our educational systems as well as in our professional activities. To paraphrase Walt Kelly, creator of Pogo, "We have met the future, and it is us."

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Are Biomedical Engineers Doing Their Jobs?

Arthur T. Johnson

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Medicine is a very complicated process that involves multiple diagnoses, courses of action, and more interactions than are commonly recognized. Indeed, when a patient complains to the physician about some conditions either real or imagined, the physician usually prescribes multiple tests to pinpoint the most likely medical scenario. In this intercourse, the physician can be hampered by the ability or inability of the patient to correctly describe the symptoms, his or her own experiences in dealing with similar circumstances, and time limits that preclude finding out all relevant patient histories. Indeed, each patient comes into this interchange as an individual, but leaves as part of a queue of patients with similar conditions.

Enter the biomedical engineer. Most biomedical engineers that I know, and virtually all who present at BMES meetings, have new instruments, materials, or diagnostic aids that they are developing. While each of these is a wonderful advancement of medical technologies, they can serve to compound the practices of medicine by offering more choices and more bits of information that must be carried in the physician's head. Whether they are more efficacious or not, whether they are more economical or not, whether they are more helpful or not, each of these new technologies is recognized as an improvement, if for no other reason than that it is new.

As our country debates national health care, there are heard many opinions about differing options, approaches, and methods. Clearly, we have a problem—no, many problems involving health care cost, the looming insolvency of Medicare, uninsured patients, and political philosophies. The debates will go on, and compromises will be made such that no one will be completely satisfied.

As engineers we should be searching for answers—we are supposed to be problem-solvers, no? Nowhere in this whole debate do I hear reasoned arguments dealing with an overall assessment of the health care system and the ways in which technology can be used to improve patient care <u>and</u> decrease costs. This is where I believe biomedical engineers have not functioned as they should be capable. As we have become invested in our own specialties, we have lost appreciation for the big picture.

Liebman (2005) has said:

"*As clinical investigators, we stand to reap significant benefits on behalf of society by expanding our focus and viewing translational medicine not through the eyes of a scientist, but as an engineer might. Why an engineer? Because an engineer uses the fruits of science to feed the appetite of technology. Unlike scientists, who tend to approach problems from a "bottom-up" perspective by collecting data and seeking patterns, engineers take a "top-down" approach, probing a specific system for clues, taking it apart and considering how each component can be handled in a tailored solution. An engineer is a problem solver rather than a hypothesis generator*."

Viewed from the outside looking in, this may be how the engineer is seen; looking from the inside, there is certainly a large question about how integrative biomedical engineers really are. A systems viewpoint often requires experiences, and so I would expect the best systems people to have worked in multiple scenarios and to be more mature.

We educators can help this process by being sure that our students are exposed to the widest possible range of knowledge, skills, and experiences that time and resources will permit. Instead of narrowing course choices to only those that directly reinforce technical competence, art, history, political science, and other liberal studies courses can be just as valuable. Real life includes hard science, soft science, and nonscience, so a global perspective requires all of the above.

The result of all this, that is needed right now, is some model or decision-making process that can assist the policy makers in choosing the best course of action. Or, if not that course, at least some indication of the costs, both monetary and nonmonetary, of choosing other options.

A truly global approach would certainly include medical health care options, but would also include other conditions not normally considered as part of health care—conditions such as environment, occupation, family, nutritional habits, exercise, and frame of mind. I came across some interesting facts when I was researching my book *Biology for Engineers*. Some examples of those are fever therapy (where fever can be induced to strengthen immune responses to disease), helminth therapy (where parasitic worms are given to calm overactive immune systems), and quorum sensing (where microbes communicate among themselves by chemical means). Some of these could be very effective in maintaining health or treating disease, but will never be advocated because they are not new technology nor will they pay profits to any groups. The most likely ways in which these types of medical approaches will become widely accepted as legitimate medical choices is if they can be shown to be effective in a holistic approach to medical care and health maintenance.

We really need engineers who can take the larger view and demonstrate the likely consequences of different courses of action. Their results could benefit the medical community, policy makers, and the general public. Where will these engineers come from? In a world that rewards specialization, we know that there are few opportunities for generalists. Exposure to information outside one's particular specialization is important, and BMES could contribute in ways to cross-specialty communication. To use an analogy, we need to plant some weed seeds among the vegetables of the garden of the mind.

Philosophical Foundations of Biological Engineering

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Abstract
Biological engineers apply engineering methods to biological systems. There is a current interest in revising or establishing new biological engineering curriculums and courses. This paper gives a philosophy from which biological engineering curriculums can emerge. Biological engineering should have the conceptual framework of a broad fundamental, and integrative discipline. Biological engineers should be capable of synthesizing their creations from many disparate sources and of communicating with practitioners from many distinct disciplines. Hierarchical competencies are given to distinguish all college graduates, all engineering graduates, and all biological engineering graduates. Basic engineering concepts and basic biology concepts are sometimes conflicting, but must nevertheless be incorporated in undergraduate courses. Specific required courses will vary from university to university, but all biological engineering curriculums must include courses on engineering topics, life sciences topics, and courses that integrate the two. Issues of interfaces between biological engineers and biologists, and with potential employers are also considered. This paper was intended to guide the establishment of new or revised biological engineering programs.

I. Introduction

Significant changes in biology have occurred in the last forty years. Not only has there been the usual accumulation of scientific facts, but new fundamental knowledge has advanced biology toward a more quantitative discipline. The trend is clear: new means to quantitatively predict biological processes lead to new means to control them. Design of new biologically-based products and processes soon follows. Thus the field of biology has entered the domain of the engineer.

Biology is so broad that the revolution bringing engineering and biological practitioners together has been more like a guerilla war than a coup d'état. There was early linkage between medicine and electrical engineers to produce more effective diagnostic or remedial equipment; that linkage continues. Medicine next obtained assistance from chemical engineers for the design of dialysis machines. Mechanical engineers assisted with orthopedic, prosthetic, and cardiovascular assist devices.

Another branch of biology also began to require engineering skills; the environmental sciences begot environmental engineers, and sanitation, public health, water quality, waste treatment, and bioremediation began to use engineering design and control skills to harness biological mechanisms.

Agricultural engineers have always dealt with elements of biology in their practices [1]. Production of food and fiber requires knowledge of environmental cause/effect relationships, physical properties of biological materials, and human/machine interfacing.

Most recently, genetic manipulation, cellular processes, molecular biology, and tissue culturing have spawned interest by biochemical or bioprocess engineers. Numerous applications in medicine, agriculture, and industry await the development of these kinds of processes and products.

Indeed, the importance of biologically-based processes and products has become so great that convincing arguments have been made that the three basic sciences traditionally studied by engineering students: physics, chemistry, and mathematics, should be augmented with a fourth: biology [2]. All engineers, no matter what their ultimate career objectives, should be exposed in their undergraduate years to the biological sciences. In fact, this is beginning to happen at institutions such as the Massachusetts Institute of Technology.

Beyond the assertion of universal biological sciences exposure, however, each of the engineering applications disciplines of agricultural, biochemical, biomedical, environmental, and others, have struggled with fundamental questions concerning the core of each of their identities. Some of these fields have realized that completion of undergraduate education is not sufficient to produce graduates of great value to employers. Other fields are coming to this realization, and there is a continuing call for the first professional engineer's degree to be at the master's level [3].

With a recent surge of interest by students and faculties in establishment of curricula that combine engineering with biological sciences, there is a need for definition of undergraduate programs that prepare students for more specific applications training at an advanced level. What should be the educational goals, means to achieve these goals, and relationships to others who share similar goals? The objective of this paper is to present a philosophy for such curricula. Ideas in this paper have been developed from numerous conversations, man published papers, and several workshops devoted to biological engineering educational topics. The philosophies presented in this paper are currently forming the basis for new educational programs in biological engineering.

We present the broadest issues first, starting with the conceptual framework, then moving to a list of competencies expected of all graduates. This leads to essential engineering and biological principles to be included somewhere in the curriculum. Some specific courses to be included are discussed. Finally, two interfacial issues are also discussed: the interface with biologists and the interface with potential employers.

II. Conceptual Framework for the Curriculum

While attempting to define the foundations of biological engineering, some statements must be made concerning all of engineering. The biological engineering curriculum should include progressive visions for the entire engineering profession, and this is where we start.

Engineers of the future must become true synthesizers instead of just designers. Computer systems, becoming ever more powerful, will allow repetitive design functions and support to be performed by engineering technologists. As computer systems and software evolve, more and more design problems will become included in the repetitive category.

The functions of engineers will thus change: they will need to know how to incorporate legal, ethical, aesthetic, sociological, environmental, economic, and safety aspects into products and processes [4]. They will be required to assume responsibility for the designs produced by others. Because of these changes, engineers of the future must become more creative, broadly-interested, and basically trained than their predecessors. They will require the ability to think analogically and comprehensively (analogic thinking is the ability to transfer knowledge from a system that is familiar to a system that is unfamiliar). The ideal engineer should be able to organize and conceptualize, while incorporating additional liberal arts ideas in the creative thinking process.

Obviously, this concept of an engineer contradicts some long held engineering education principles. There always has been a tension between the hands-on, design-oriented, mechanism-focused approach to engineering education and those who advocate a liberal, philosophical, and creative approach. The present ABET accreditation requirements represent a compromise between these two extremes, but the incorporation of the humanities is sometimes considered to be an imposition on an otherwise pure engineering curriculum. Although engineering students are educated to think both in a methodical engineering way and also in a more freely artistic way, they are not often given practice to integrate the two. The end product of undergraduate engineering education should be graduates who not only know what the design process is about, but who can also add perspective, judgment, creation, and a sense of the broader needs of society [5].

This view of engineering underlies the vision for biological engineering that we propose. The biological engineer should be one who can incorporate ideas and concepts from many disparate disciplines into an overall engineering creation. This means that biological engineering should tend strongly toward inclusion rather than exclusion, and that the biological engineer be considered a specialist in technical diversity.

We propose a new undergraduate curriculum intended to produce engineers able to solve problems that bridge between biology and engineering. Graduates must be able to communicate well with both biologists and engineers. To do so, they must be well versed in both the meanings of engineering terms and the specialized language of the biologist. Just as important, these engineers should be familiar with problem-solving approaches used by both groups. Whereas engineers tend to use physico-mathematical approaches to solve problems, this straightforward technique does not always apply to biological systems. Modern biologists have developed some sophisticated techniques of their own style to deal with the sometimes mandatory indirectness required to solve biological problems. Therefore, biological engineering students should be exposed to biological science courses taught by biologists instead of engineers.

The envisioned undergraduate curriculum is a general curriculum that offers basic instruction in physics, mathematics, chemistry, biology, and engineering. Students should be able to view the full horizon of potential biological applications, from sub-cellular to ecological levels. They need not learn all the details of every application level, but they should not be forced, in the undergraduate years, to choose their eventual specialty. Such a curriculum requires that students be taught commonalities between seemingly disparate biological systems; students should be taught analogic thinking and be given practice in transferring knowledge from one context to another.

Clear definitions sometimes require a statement of what is not included as well as what is included. As envisioned, biological engineering is the discipline of engineering based on the science of biology. “Biological engineers should be to the science of biology what chemical engineers are to chemistry, electrical engineers are to electricity, and mechanical engineers are to mechanics”[1,2]. Biological engineering does not imply a particular application or industry. In this way it differs from biomedical engineering, environmental engineering, or agricultural engineering, each of which applies knowledge about biology to particular application areas. Indeed, there is even a continuum of engineering involvement with biology, from (for example) the electrical engineer who might work in a hospital environment, to the biomedical engineer who must be able to effectively interact with medical personnel, to the biological engineer whose work requires a substantial and intrinsic knowledge base in the biological sciences. Only the engineer who has a substantial knowledge of, and continuing interest in, the field of biology, should be called a biological engineer.

This proposed undergraduate curriculum is similar in many respects to the general engineering science curricula found at some colleges and universities. It stresses fundamental education at the expense of applications and specialized knowledge. It leads to an “unfinished” engineer in the traditional sense of engineering education [6,7]. Thus, graduates from this program will require further education before becoming practicing engineers, either by graduate studies or by employer orientation. This is not a novel requirement, nor should it be considered a weakness: engineering science majors have for years made some of the best graduate students, and the generally educated agricultural engineers have been appreciated by industry for years. Moreover, general education of biological engineers can be excellent background for more specialized graduate study in biomedical engineering, bioprocess engineering (or biochemical engineering, or biotechnology), environmental engineering, agricultural engineering, and other applications of engineering to or with biological systems [8,9].

As with any hybrid, it is sometimes difficult to define completely the relationship between the offspring and its parents. Some engineers would say that biological engineers must be engineers first with the biology added later [10]. Others would want equal weighting given to the biological and engineering sciences. While modern biology is too sophisticated to be relegated to the background, engineering can still dominate, as it does in chemical engineering. With such a strong emphasis on biological sciences, the biological engineer may need to learn to turn to other engineers for specialized engineering expertise just as she/he must turn to biologists for specialized biological expertise.

There is a great deal of emphasis these days on teamwork [11], and engineers are required to learn to operate in teams. Industry prefers the type of engineer who can work alongside others with different skills, knowledge bases, and approaches. Working in such teams requires interpersonal and communications skills that engineering must emphasize more than in the past. Inherent in the conceptual basis for biological engineering is the assumption that biological engineers will be working as team members both with biologists and with other engineers [12].

III. Competencies

A separate and distinct discipline requires a specialized field of knowledge. Biological engineering can be defined by the expectations required of graduates of its programs. Thus a hierarchical set of competencies has been developed [13] for biological engineering.

The late philosopher, Sidney Hook [14], has given a suggested list of expectations of all college graduates. Restated, these are:

- Clear and effective communication.
- At least some rudimentary knowledge about the world around and humankind's place in it.
- Some grasp of the principles that explain observations, including a concept of the scientific method.
- An intellectual awareness of the function of society, including historical, economic, and social forces shaping its future.
- An informed awareness of the conflict of values and alternative paths to future solutions.
- Some methodological sophistication that sharpens judgment of evidence, relevance, and validity.
- Induction into the cultural legacies of civilization.

Certainly, there should be a commonality between engineering graduates and other college graduates on these expectations, and the ABET humanities requirements help to ensure that they are fulfilled.

To distinguish engineering graduates from all others, the following set of competencies were proposed [13]:

- A well developed ability to conceptualize and fit physical phenomena into a conceptual framework.
- A solid fundamental knowledge of the engineering sciences.
- Reasonable familiarity with computers, computational techniques, and computational aids.
- The ability to carry the design process from problem definition to solution, including the ability to gather pertinent information and deal with incomplete problem definition and aesthetic, reliability, economic, political, ecological, legal, sociological, and general safety constraints.
- The ability to reduce data, concepts, and designs to clear pictorial form.
- The ability to make reasonable engineering assumptions when required, approximate solutions, and produce specific recommendations from indeterminate data.
- A developing sense of engineering ethics and principles by which moral choices may be made within a professional context.

In addition, biological engineering students should also possess:

- A familiarity with at least one specialized biological vocabulary and have the ability to use this vocabulary in effective technical communication with biological, physiological, medical, biochemical, ecological, or applied biological scientists.
- A specialized knowledge of segments of the biological realm, especially problem-solving techniques, related to the biological area of work.
- The ability to deal effectively with uncertainties of biological behavior and properties.

• A generalized knowledge of application of engineering techniques to a broad range of biological subjects, and to be able to develop new applications through analogic conceptualization.

These last four competencies should identify biological engineers from among the remainder of college and engineering graduates. Viewed in this manner, biological engineering education becomes a product of an evolutionary process with many commonalities and some differences from other educational relatives.

IV. Basic Engineering and Biological Concepts

Given these competencies expected of every biological engineering graduate, and before required curriculums are defined in terms of new and existing courses, a set of basic engineering and biological concepts can be listed with the expectation that graduates would be familiar with all of them. Such a list can be used to check whether the biological engineering curriculum at any given institution conforms to the expectations of a broad, but fundamental, education.

There are some commonalities and some divergences between traditional engineering science and biological science concepts. Engineering education is largely aimed toward developing the abilities of conceptualization and calculation, whereas biology education develops descriptive and connective abilities. Each of these is important for biological engineers to understand and appreciate.

Engineering concepts that should be included within one course or another are:

• effort and flow variables
• balances
• analogy, equivalence and conversion
• simplicity, parsimony, and incrementality (start simple and add complexity)
• approximation
• calculation
• positive entropy (tending toward disorder)
• reversible and irreversible processes

Fundamental biological concepts are:

• order and negative entropy
• variability
• gradual adaptability
• communication, including patterning
• complex interconnections, simple building blocks
• exquisite control, optimization, and catastrophic failure
• redundancies
• nonlinearity.

There are some concepts that biological engineers must see from both sides. For instance, the physical world tends to disorder, but the biological realm tends to be ordered. Also, engineering solutions tend to use simple connections (such as the development of simple equations or connections to an integrated circuit chip) whereas biological systems usually use complex connections (such as the use of simple sugars, fatty acids, and proteins connected together in a complex way to produce functional biomaterials). Traditional engineering approaches each possible problem from a linear standpoint; biological systems are usually highly nonlinear. There are many other examples that can be given.

Some of the most successful engineering solutions have come from studying existing biological solutions to similar problems. The fields of bionics, biomimetics, and biological cybernetics have contributed in this way. Neural networks illustrate the biological principles of adaptability and redundancy; Velcro connectors illustrate the biological principle of complex interconnections using simple building blocks; modern communications and control are becoming more and more like those of biological systems. Biological systems are such good models for the solutions to many complex problems that the case can be made, if for no other reason, that all engineering students should take at least an introductory course in biology.

V. Common Courses

Engineering science courses add much more detail to the engineering concepts listed in the previous section. Biological science courses do the same for biology. There have been many attempts to define the absolutely essential courses for biological engineering undergraduate curricula [10, 15-18], and many details appearing in these previous reports will not be repeated here because there can be many valid approaches to provide broad, fundamental, and inclusive undergraduate biological engineering curriculums. Most of these reports affirm the usual engineering core courses: physics (especially macroscopic scale), chemistry (inorganic, organic, and biochemistry), calculus (through differential equations), statics, dynamics (some question that this course is required), thermodynamics, strength of materials, materials science (many would opt for more biomaterials and less standard materials), and computer science.

How much biology should be required? Some have said that just one course may be adequate [19]. However, to be an effective biological engineering curriculum, one biology course is not sufficient. Some biological engineering curricula (including the University of Maryland) include up to seven biological science courses, enabling students to take complete biological science course sequences. As many as possible of these biological science courses should be taught by biologists.

At the upper level, engineering courses have been suggested in fluid mechanics, transport processes, biochemical kinetics, instrumentation, control systems, optimization, systems analysis, physiological modeling, material properties, electronics, and communication theory. The ability to deal with biological uncertainty requires some probability and statistics. Upper level courses that integrate engineering and biological systems are essential, and each of these courses should integrate the engineering subject matters with examples drawn from a wide range of biological applications. That is, attempts should be made to expose the students to medical, environmental, horticultural, biochemical, and other possible applications.

Of course, there must be strong components of design and communication in the curriculum. If possible, these skills should be integral to engineering courses.

Humanities courses are essential and must remain part of the curriculum. If possible, material from humanities courses should be integrated into upper-level biological engineering courses. In particular, sensitivity to ethical issues related to living organisms should be developed in upper level biological engineering courses including design.

The philosophy given in this paper envisions biological engineering as broad, fundamental, integrative, and unspecialized. In general, we do not see this approach applying to the graduate level where specialization occurs. Thus, no graduate level courses are suggested.

In a final report of a project sponsored by the United States Department of Agriculture to study curriculum requirements for biological engineers [19], five core courses were identified for the curriculum. These were: 1) Biology for Engineers, 2) Biological Responses to Environmental Stimuli, 3) Transport Processes, 4) Engineering Properties of Biological Materials, and 5) Biological Systems Control. Content descriptions were developed for each of these courses that reflect the philosophy of broad (yet somewhat shallow) treatment of included subject matter. Further USDA funding allowed development of several of these courses, and they are being shared among interested institutions [20-22]. It is intended that all of these courses will be developed eventually if interested and competent developers can be identified.

Young [23] conducted a survey of biological engineering courses at land-grant universities traditionally offering agricultural engineering curricula and their derivative biological engineering curricula. Most courses included in these curricula were upper-level undergraduate courses that included a significant portion of biologically-related material. Course subjects ranged from general to very specific. Many were clearly related to agriculture or food processing, but some were oriented toward biophysics, medicine, or bioprocessing/biotechnology. The range of courses offered can only increase, but some cohesion is expected to result from the report by Garrett et al.[19].

A similar project sponsored by the National Science Foundation was used to survey undergraduate courses and curricula in biomedical engineering [24]. Courses, as expected, tended to be medically-oriented and less general than biological engineering courses surveyed by Young [23].

VI. Interfacing Between Engineers and Biologists

Forging the new discipline of biological engineering often requires satisfying the concerns of other interested groups. On any given campus, the groups most interested have ranged from other engineering disciplines to segments of the biological science community. Satisfying these groups requires that biological engineers are thoroughly familiar with the position their new discipline is to play in the world of science and technology.

As links between the fields of engineering and biology, biological engineers must appreciate the identities and personalities of both groups. Johnson [25] has identified differences between science and engineering that should be appreciated by both sides. There are three different perspectives to consider: 1) phylogeny, 2) motivation, 3) methods.

A. Phylogeny

The evolution of technology usually occurs with at least four distinct phases: 1) A random phase where events occur by chance and observation occurs haphazardly. The major outcome of this phase is to make the observers aware of the phenomenon being observed. 2) A descriptive phase where cause and effect relationships are established.

The result of this phase is that the observed phenomenon no longer remains random, but can be expected whenever a series of foretold events happens. The phenomenon is still not able to be brought about at will, but its appearance is at least expected. 3) A quantitative phase wherein measurements are refined and dependencies are given numerical values. These values may be deterministic or probabilistic, but during this phase there is a growing knowledge about the intensity of the phenomenon as related to the strength of the precursor variables. 4) A control phase where modeling and predictive equations lead to knowledge of useful substance amounts, design of systems, and applications to achieve desired ends. The result of this stage are products and processes using the phenomenon. Examples are given in Table 1.

For some sciences, the early phases began long ago. The science of mechanics, for example, entered its descriptive phase before the time of Aristotle, but the science of electricity was still partially random in the time of Ben Franklin and the science of genetics entered a long descriptive phase in the time of Gregor Mendel. The first two of these four phases clearly belong to the field of science. Engineering contributes primarily in the control phase by using quantitative information to design useful products. The overlap between science and engineering generally occurs during the quantitative phase. Early attempts at quantification are largely made by scientists, but engineering researchers, usually motivated by the need for design information, can accelerate the quantitative process. Engineering is involved more with the latter stages of technology than with the earlier stages where science dominates.

Table 1. The Four Phases of Technology

Phase	Description	Physical Example	Biological Example
Random	Phenomena are encountered haphazardly	Heavenly bodies are observed to move	Differences and similarities are noted in animals and plants
Descriptive	Cause-and-effect relationships are est	Apparent heavenly movement appears to be related to seasonal changes	Genetic material is discovered and transgenic organisms are developed
Quantitative	Measurements are refined and dependencies are given numerical values	Kepler's laws describe planetary motion	Optimal microbial growth environments are determined
Control	Modeling and predictive equations lead to knowledge of useful substance amounts, design of systems, and applications to achieve desired ends	Satellites are orbited around the Earth, moon, and other planets	Transgenic microbial production of biochemicals becomes reality

B. Motivation

Scientists and engineers can both be highly motivated, but the sources of work-related interests are often different for each group. Neglecting the recent trend toward entrepreneurship in both groups, the major source of motivation and satisfaction for engineers comes in the final products or processes as a result of their efforts. Engineering is largely creative, forming things that never were, and engineers, like artistic painters, become highly motivated by the tangible realization of their ideas and concepts. If, in addition, there are visible groups that can be helped by these realizations, a strong drive and sense of urgency can develop within the engineer.

Biologists, generally more removed from the ultimate applications of their work than are engineers, are often motivated by the subjects of their study. They feel empathy toward these subjects, and study them because they are interested. This study, of course, leads to more interest, and a strong bond can develop between the observer and the observed. Biologists are thus motivated more by their involvement with their subjects, and engineers by their involvement with the things they produce.

C. Methods

There is a fundamental difference in methods used by scientists and by engineers. Biological scientists often perform experiments to ascertain new facts. Since many of their observations are related to phenomenon description, the pattern of scientific experimental episodes may be determined more by the observed phenomenon than by any regular scientific plan. Such is often the case while observing various life-forms in their natural habitat: observations about eating only occur when the object of the attention decides to eat. Any attempt to tamper with the behavior of the being would result in criticisms of methods and observations, rendering them practically invalid.

Engineers rarely, if ever, become involved with their experimental objects at the descriptive phase, and hence are often remote from these types of experiments. The impatience of most engineers would not allow them to observe phenomena without trying to tinker with the experiment to see what happens. Engineers are not educated to be distanced, impartial observers; they are educated to become involved, to attempt to predict or control an outcome, and to synthesize fragments that may not naturally fit together.

There is a difference between typical scientific literature and typical engineering literature. Scientific experiments beyond the completely descriptive phase are conducted for specific sets of conditions, with as many variables controlled as possible. To cover an entire scientific field with scientific observations requires a very large number of specific experiments, wherein control over the multitude of variables may be either tightened or relaxed, but many, if not most, combinations of imposed conditions must be tested before a phenomenon is considered to be well-understood.

There are very few, if any, surprises appearing in scientific papers of this sort, and these papers have scientific value by extending the realm of the known by additional increments. The differences between scientific papers, cited and uncited, related to a particular field are often few, and they all form a congealing mass that establishes scientific truth by the weight of consistency of experimental results [26].

Science, therefore, is inductive. Scientific facts accumulate until an overall unifying concept emerges as irrefutable. The conceptual framework is induced, in science, from the many facts that precede it.

The engineering approach is different. Engineers generally try to conceptualize first and fit facts within this established framework. Engineering is thus deductive. This method suits engineers well, because it tends to reduce all knowledge to a small set of fundamental principles: the conservation of matter and energy, Newton's laws of motion, the laws of thermodynamics, and Maxwell's equations are among these. Engineering designs are thus based upon a rather limited set of simple principles, or concepts. Given the choice between one of these fundamental principles and a conflicting fact, the principle is nearly always chosen by engineers.

Such a fundamental methodological difference between scientists and engineers inevitably leads to conflicts. Scientists are often bothered by the engineer's tendency to simplify, while engineers wonder why scientists can't see readily-apparent connections. Starfield et al. [27] state that mathematical models are like caricatures: they overly emphasize some aspects at the expense of others to make conspicuous those results due to the emphasized aspects. Thus, models are not always general descriptions of a phenomenon. Indeed, a thorough mathematical description of some scientific phenomenon would be as complicated as the original phenomenon itself, and serve very little purpose. It is often difficult for a scientist to truly believe what value is contained in a model that does not predict all scientific observations related to a particular phenomenon.

D. Synthesis

Although science and engineering are separated by dominant domain, methodology, and approach, engineering is complementary to science and science is supplementary to engineering (Table 2). Engineering represents the ultimate application of the facts generated by science. And, engineering approaches are having their effects on scientific methods. Science, on the other hand, not only discovers the basic phenomena that are the subjects of later engineering models, but science also discovers pertinent variables for inclusion in those models.

Relative merits of experimental and conceptual (or model) approaches to a scientific phenomenon are well known. Each approach is so compelling that the ideal means to study the phenomenon is to incorporate both approaches. It is the willingness of scientists over the last 30-40 years to include modeling and conceptualization in their work that has enabled the rapid application of scientific knowledge by (usually) engineers.

Although biological scientists are often capable of generating the information necessary for the design of a new product or process involving a biological system, they don't often deliver the information in a form suitable to make design trade-off decisions. Biological engineers are in positions to function as key participants in the synthesis of biological science and engineering to produce results useful to humankind.

Table 2. Summary of Contrasts between Science and Engineering

	Science	**Engineering**
Phylogeny	Random phase through quantitative phase	Quantitative phase and control phase
Motivation	Objects of study	Objects of creativity
Methods	Inductive: large numbers of facts	Deductive: a small set of basic principles

	suggest a unifying concept	leads to specifics
Literature	Incremental	Conceptual
Synthesis	Scientists need engineers to show eventual applications	Engineers need scientists to identify basic facts

VII. Employment

As general engineers who often require further training in specific applications, biological engineers may not be completely prepared to step into positions that require immediate engineering output. Nonetheless, employers who realize the strengths possessed by biological engineering graduates (notably their abilities to work with biological scientists and to work in team situations), often become enthusiastic about hiring them.

Not all biological engineers will pursue graduate schooling. It is still too early to tell exactly how much employment potential exists for biological engineers terminating their schooling at the bachelor's level. Nonetheless, there are several courses of action that can be taken to boost employment demand at the B.S. level. The first is to avoid a curriculum that is too specialized. B.S. biomedical engineers have often been seen as too specialized in medicine and not enough in engineering skills to be readily employable. The biological engineers we envision, while probably comparable to biomedical engineers in engineering skills, should be more readily employable because of their familiarity with a broad range of biological applications. These engineers should be valuable to industry because of their flexibility and general knowledge.

The second course of action is to depend heavily on experiential learning in the undergraduate years. Internships and cooperative education are very important to successful employment of B.S. biological engineers. Employer relationships developed in the process of establishing internships or cooperative employment will lead to greater interest by employers in both the curriculum and its product.

A study by Johnson and Rehkugler [8] projected that there will be an annual total of about 2000-3000 biological engineering employment opportunities in various specialty areas by the year 2000. These specialty areas include agriculture, animal systems, aquaculture, bioprocessing, biotechnological systems, ecology, environment, food, horticulture, human interfacing, medicine, microbial systems, and rehabilitation engineering. Some of these specialty areas require additional formal education to gain admittance, while others do not.

A survey of potential employers of biological engineers was conducted by Hoffman[28]. The list includes 288 entries, and many employers were eager to hire biological engineers from particular programs. This would indicate that the biological engineering programs are producing the types of graduates needed by employers, and gives confidence to faculties that their efforts are related to the reality of the workplace.

VII. Conclusions

Biological engineering curricula are presently being revised or established on many campuses in the U.S. and Canada. In this paper we have attempted to define important parameters for these curricula. It is usually much easier to establish a new structure if the plans have been drawn beforehand. The function of this paper was to supply the blueprint. Students trained along the lines given herein will have the ability to satisfy present employer needs as well as to meet challenges of the future.

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The Making of a New Discipline

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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 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 Rensselaer 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. Emphasisareas 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.

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Essential Concepts for Biological Engineers

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Abstract
Biological engineering courses and curricula can result in graduates who vary greatly in their abilities to deal with biological systems. Whereas there has been general agreement about a better understanding of biology and biological applications for all biological engineers, specific recommendations of competencies have not heretofore been formulated. A minimal list of principles and basic concepts expected of all biological engineering graduates would standardize commonalities no matter what educational institution attended. This paper supplies a list of 25 of these.

I. Introduction

Biological engineering is the science-based engineering discipline that commingles engineering with biology. It has been defined in general terms, without specific applications (Garrett et al, 1992; Johnson and Phillips, 1995; Johnson and Schreuders, 2003). It has had several disciplinary roots, including evolution from agricultural engineering and chemical engineering, both of which claim possession of true biological engineering approaches (Johnson, 2006). Sister engineering disciplines relating engineering to some aspect of biology or medicine suffer from the same historical lack of identity as does biological engineering. Exacerbating this problem for those of us attempting more general acceptance of biological engineering and related engineering fields is the fact that there is lack of uniformity within the educational curricula of most of these (Linsenmeier, 2003).

Before there can be any confidence in the uniformity of biological engineering education, there must be understanding of the necessary knowledge to be possessed by all biological engineers. Of course, uniformity will only come when there is consensus about the essentials that must be known to be successful biological engineers. At this point in its development, the field is too new as a separate discipline to have reached the consensus stage (Johnson et al, 2006).

Previous papers have dwelt on generalities related to biological engineering education. For instance, Costello and Carrier (2006) wrote about increasing the amount of biology and incorporating biological applications within the biological engineering curriculum. Scott (2006) presented a list of courses that he suggested should be taken by biological engineering undergraduate students. In both of these papers, as well as many others, there is no specific prescription for principles and concepts that should be known by all biological engineers as they graduate from colleges or universities. It is one thing to require biology to be taken. It is another to specify exactly what needs to be known about biology. Engineers who are expected to be problem solvers must know biology differently from biologists who are not.

Due to the present overwhelming popularity and importance of cellular and biomolecular biology, the field of biological engineering is being pulled in that reductionist direction. The result of this is that biological engineers are becoming more and more like applied scientists rather than engineers comfortable with biological applications at all levels. The philosophical foundations of biological engineering, however, describe biological engineers as "specialists in technical diversity", rather than specialists in applied cellular science.

The list of principles and concepts that follow are based on a vision that biological engineers, from whatever educational background they have, must be flexible in their abilities, versatile in their approaches, and capable of dealing competently with all levels of the biological realm. They are based on the three expectations for all biological engineers (Johnson, 2010) to possess the:

1. knowledge of biological principles and generalizations in order to design products and products involving living things.
2. ability to transfer knowledge from a known biological system to a different, unfamiliar biological system.
3. ability to avoid the unintended consequences involved when dealing with any biological component.

Thus, the set of concepts and principles set forth in this paper is intended as the minimum amount of knowledge that all biological engineers should possess to represent the field adequately. Basic science, engineering, mathematical, and liberal arts competencies have been assumed in addition to this list.

II. Basic Concepts and Principles

The following is one attempt to define the core knowledge that should be possessed by all practitioners of biological engineering. Each of these is listed, in no particular order except for the first, and some explanation is given for each. Explanations, however, are not meant to be exhaustive or complete, but rather as a short justification of the importance of that particular item to the listing.

1. Survival and Reproduction of the Genes. This is the first principle of biology, and the dominating theme of all biological actions. Living things will compete, control, modify, adjust, kill, sneak, cover up, and scrap in order to survive and reproduce. Death is so catastrophic to any living thing that no measure is spared in order to live. Survival and reproduction is important at many hierarchical levels. The obvious level for which survival and reproduction are important is at the organism level, but it is the genes that are driven to survive and reproduce. They do this in cooperation with other genes by surrounding themselves with survival mechanisms built into cells, tissues, organs, and organisms. There is competition among genes causing some genes to take advantage of others. So-called cheating genes duplicate themselves at the expense of other genes. *Transposons* are genes that move from one genetic location to another in order to duplicate themselves within the genome. Killer genes cause toxins to be produced that eliminate competitive genes. The ultimate competition in biology is among the genes. Survival and reproduction extends to groups of individuals as much as to individuals themselves. Forming herds, schools, or human families gives mutual cooperative support in survival mechanisms. Members of these groups assist each other to fend off threats posed by predators and to locate sufficient food and other resources to meet the group demands. If the survival advantage of group membership is great enough, then there may be a large sacrifice in order to belong to the group. Examples of this are ceding of breeding rights to dominant males in a herd or physical mutilation for some human groups. Even among plants, there are group survival mechanisms in play. *Masting* in oak trees occurs when all oaks in an area form copious quantities of acorns in certain years and not others. This increases the probability that some acorns will survive consumption by hungry animals. Seventeen year locusts synchronize emergence for the same reasons. Plants also communicate attacks by insect pests through airborne chemicals that induce other plants to buttress defenses.

2. Form is Related to Function. Related to modularity is the realization that form and function are closely aligned. More acute hearing requires larger ears. Night vision requires pupils that allow more light to be captured. Heat maintenance requires heavy insulation. Efficient mass transfer requires a large surface area. Each of these can be predicted from the laws of physics or chemistry. From form, one can infer function; from function, one can predict form. Realizing that organisms have been perfected over many generations to deal with environmental stresses is the key to using biological solutions to solve engineering problems of a similar nature. Copying biological solutions is called *biomimetics*, and this is one of the easiest and surest ways to formulate a problem solution.

3. Modularity and Incremental Change. Biology and technology operate similarly. Each begins with a new prototype and proceeds from there toward improvements by making incremental changes. Successful parts are maintained; others are improved. This similarity between biological evolution and technological evolution is the paradigm for all of technological progress. It is useful for biological engineers to be familiar with this concept. Not only does it supply context for engineering efforts, but it also can be a vehicle for greater understanding of biological organisms and why they appear as they do.

4. Environment Influences Outcomes. Actions and structures of living beings are strongly dependent on physical, chemical, and biological environmental factors. Biological actions and responses are not made without accounting for environmental factors. These actions can take the form of organismal cooperation or competition (biological environment), initiating heat loss mechanisms (physical environment), or detoxification of cyanide (chemical environment). But environment has more profound effects at the genetic level. Environmental factors can determine expression of certain genes. The ultimate manifestation of this is the formation of *epigenetic markers* that determine genetic expression for generations at a time. Biological engineers must be aware constantly of the role that environment plays in biological responses. Environment can determine not only the degree of action, but also whether it occurs at all.

5. Physical Limits Cannot Be Exceeded. Living things do not abrogate the laws of physics; they reaffirm them. Mechanical strengths of materials do not change because they are included into living creatures. Exceed these limits, and they break. Likewise, diffusion limits do not change because materials move inside living cells. The maximum distance that oxygen can diffuse passively at a rate sufficient to sustain life is equal to the thickness of two cells. Any farther than this, and other mechanisms (such as circulation) must be used to deliver oxygen. To accommodate physical limitations, biological things can manipulate shapes, sizes, and compositions of materials. The means that biology has developed to circumvent physical limitations are often good models for engineering designs, but, in the final analysis, physical limitations must be recognized.

6. Relationships Among Energy, Order, Entropy, and Information. Passing information from one biological unit to another requires communications channels. These channels may involve chemical, visual, auditory, touch, taste, magnetic, electrical, or neural mechanisms. Many communications in nature are chemical. Bacteria communicate their presences to others within a biofilm with chemicals called *autoinducers*. Insects indicate the presence of mating adults by airborne chemicals called *pheromones*. Many mammals mark their territories with chemicals sprayed on prominent physical features. Communications are important for organisms not only to know the presence of others, but to anticipate the intentions of others. Thus, signals of aggression, acceptance, threats, or love elicit emotional responses that are meant to enhance survival. Communications result in information that leads to order. This, in turn, reduces entropy, at least locally. In order to maintain order, a constant supply of energy is necessary. Stop the flow of energy, and death ensues, the organism decays, and entropy again increases. Shannon's relationship between information and the probability of the occurrence of an event, where information content is higher for rarer events, can also be used to determine the entropy of the order maintained by an abundant supply of energy (Shannon and Weaver, 1949).

7. Reversible Chemical Reactions. Chemical reactions that are extremely vigorous, generate too many products, or have extreme behavior in one way or another are not usually useful biologically. Life requires agility, both physically and chemically. Chemical reactions that can easily be reversed are the useful kind. For instance, adenosine triphosphate (ATP) is a very useful compound for storing and releasing chemical energy. ATP is converted into adenosine diphosphate (ADP) through hydrolysis, with the liberation of energy to drive other chemical reactions. ATP is used almost universally in living things as an energy storage chemical. ATP is neither a very energetic compound nor a very unenergetic compound; it is intermediate in energy. That way, it can store and release energy when needed. Maintaining human blood alkalinity level at about pH of 7.4 is necessary for maintenance of internal equilibrium. A bicarbonate buffering system is used to convert circulating carbon dioxide into carbonic acid or bicarbonate ion. These processes either soak up or release hydrogen ions. Thus, human blood pH can be maintained constant even during severe exercise when metabolic acids are released into the blood. Proteins are used that have different forms and purposes with little change in energy levels. Thus, very little energy is needed to control protein configurations and functions. Not all of these reactions are strictly reversible chemically, but they do represent reactions that move easily between reactants and products, so the energy differences between chemicals on both sides of the equation are small.

8. Molecular Shapes and Chemical Mass Action. Much of the chemical action attributed to enzymes and proteins is the result of molecular shape. The complex folding of proteins from simple strings of amino acids into molecules resembling knotted ropes results in parts of the molecule that fit well with other molecules. When two or more such molecules physically locate next to each other they are usually close enough to react readily. The chemical law of mass action states that chemical reactions are much more likely to progress when concentrations are high. Enzymes, by bringing reactants close together, increase the local concentrations many-fold. As an added benefit, because enzymatic action is based on physical shape, the enzyme does not take part directly in the chemical reaction and is not consumed. Chemistry inside a cell depends very strongly on physical shapes of molecules. In addition to the enzymes described above, genetic duplication depends upon the complementary shapes of the *pyrimidines* cytosine and thymine fitting physically with the *purines* adenine and guanine. Also, the physical integrity of the cell structure depends on the physical gel resulting from the way that polar water molecules line up with one another.

9. Osmosis. Osmotic pressure is a powerful motivator. For instance, tall trees do not have any physical means to pull water from the ground to the very top of the tree if the tree is taller than the height of water that can be supported by atmospheric pressure. This height is about 30m. However, water that evaporates from leaves at the tree top reduces the concentration of water, so this diffusion gradient pulls water as far up as it needs to go.

10. Benefits of Redundancy and Alternative Pathways. The success of biological entities is largely a result of dependency on redundancy and alternative pathways. This gives organisms the ability to adjust to new environments and new challenges. Redundancy is at the heart of the immune system. There are many ways to deal with foreign invaders, and, if one or several of these is overwhelmed, there are other lines of defense to be overcome. The organism is thus usually successful at maintaining self-integrity. There are alternate metabolic pathways that allow the organism to substitute one type of metabolism for another. Thus, the muscles normally act with aerobic metabolism, but are capable of anaerobic metabolism when oxygen is in short supply. Microbes in a bioreactor can be induced to produce certain biochemical products when given reactants different from those that are most efficiently used or preferred. In this way, alternative pathways can be exploited for economic benefit. One place where redundancy has not usually been consciously recognized is in the information legacy to pass information from one generation to the next. This function has usually been recognized as belonging to the genome. It is the genes, after all, that are uniquely posed to supply the basic information source for the chemical mechanisms of the cell. Nevertheless, there are at least three other transgenerational information sources that have not been as widely recognized. The first of these is *memes*, or cultural information taught by certain individuals to others. Through this cultural information, survival is enhanced among animals, such as meerkats that teach their young how to catch and eat dangerous prey, or sheep and goats that teach their young about the differences between poisonous and nonpoisonous plants, or humans who school their young for an extended childhood. The second additional information legacy is the microbes passed from one individual to another. These microbes have a profound effect on health and well-being. Probiotic microbes are passed from mothers to their young to help them digest food, calibrate their immune systems, and prevent dangerous diseases. The third, and perhaps not the last, information legacy is in the form of misfolded proteins, called *prions*, that have been found to be able to be passed from one generation to another, and have also been found to be able to replicate without a genetic DNA or RNA model. Many prions are associated with dangerous diseases, such as *transmissible spongiform encephalopathy*, or *Alzheimer's disease*. Other prions, however, help yeast cells cope with radically different environments, or assist in animal memory retention by altering frequently-used neural synapses (Saltus, 2010). The principle of redundancy has been taken very seriously when failures cannot be tolerated. NASA depends upon redundant components for its space ventures, for instance. Automobile safety systems are also highly redundant. The biological engineer attempting to control a dangerous microbe, as an example, should incorporate redundant controls to assure that the objectives of the process are met.

11. Adaptation Requires Energy and Resources. Life has developed as a means to survive and reproduce, with the emphasis on reproduction. Energy and resources are required to form new offspring, and energy and resources needed to adapt to environmental demands uses energy and resources otherwise able to be used to reproduce. Thus, environments that demand adaptation in order to survive reduce the ability to reproduce. If maximum reproduction is desired, then optimum environments need to be supplied to the organism. Such would be the case for breeding animals or producing a field of grain. If reproduction is not the goal, but something else is desired, then reproduction will suffer. Such is the case in a bioreactor to produce an economically-important chemical from genetically-modified organisms. Modification of the genome to improve the yield of a desired metabolite reduces the ability of the organism to reproduce. Thus, there may be more of the desired product, but it may take longer for the population to reach the critical level.

12. There is Competition for Limited Resources. It can be assumed that every niche that can support life, however limited, will contain living things to the maximum extent possible. This makes all biological systems limited by resource availability. Competition among species and among individuals of the same species keeps them from unchecked growth. *Staphylococcus aureus,* a dangerous microbe, is present on the skin of nearly all humans, yet normally causes little or no trouble because other microbes compete successfully with *Staph* and limit its influence. Human beings, as a matter of fact, contain about 1014 cells, only about 10% of them of human origin. The remainder are bacteria, small mites, and other microbes that compete for space and resources on the skin or in the digestive system. It would be wrong to ignore competition among microbes. *Competitive inhibition* keeps most microbes in check and does not allow them to become a threat to the host. Trying to disinfect all microbes, therefore, removes many benign competitors of the more dangerous types. The result can be worse than if no disinfection was attempted. Competitive inhibition can be used to control diseases of plants as well as of humans. A biological problem can often be solved in a biological way. To control one organism, it is often best to look for a natural enemy.

13. Antagonistic Mechanisms Give Precise Control. When it is necessary to control a process to a very close tolerance, antagonistic mechanisms are used. The idea is to attempt to control in two directions simultaneously. Then the resulting movement is the difference between the two efforts. Fine movements of the fingers are achieved with antagonistic muscle control. Exquisite control of glucose level in the blood is achieved by means of two hormones, insulin and glucagon, that have opposite effects. An alternative to antagonistic control is to use active control in one direction and use stored energy to restore the system to its resting position. Such is the case with human respiration at rest. Inhalation is active, and passive exhalation is achieved when stored gas in the lungs is released into the atmosphere. The restoring force is produced by gas compression and elastic stretching of the tissues. Active exhalation is initiated during exercise, when it becomes important to remove gases quickly from the lungs. Biological systems, even up to the ecological level, use a lot of antagonistic control, sacrificing energy efficiency for rapidity and precision.

14. Optimization Saves an Incremental Amount of Energy. Life is energy intensive. Thus, it may not appear to make much sense to save additional energy through optimization. Nevertheless, the biological environment is competitive, so, in a place where all the competition uses as much energy as is available, a small difference in energy requirements may have a large reproductive effect. Especially subject to optimization are overhead processes, such as blood circulation, and digestion, or survival processes, such as locomotion. It appears that heart pumping and respiration, especially during heavy exercise, are optimized to reduce the rate of energy consumption. So is the energy use of walking and running. There are probably optimized biochemical processes, and nutrient recovery and utilization in whole ecosystems appear to be optimized. Optima may either be narrow and highly precise, or broad with little penalty for deviation from the optimum value. Biological optima usually conform to the latter. Thus, we find that the rates of respiration around the optimum value to minimize energy expenditure during exercise vary both above and below the best rate, but center on the optimum. The same can be seen to be true both for heart rates and walking speeds. One intriguing question remaining in biology is why there are so many genetic variants still present in the genomes of different organisms. Selective survival should have extirpated the less favorable genes many generations ago. Looking at the genome as an optimal solution, however, infers that there will remain genetic variability in a manner similar to other biological optima. A slightly smaller energy demand in an organism could pay off in a huge difference in reproductive potential.

15. Directed Evolution. Relatively recently, it has been realized that evolutionary principles can be used as an engineering design tool. These principles are simple: set a series of design goals, start the design process with a prototype, make some change by some process that may include randomness, test the resulting new prototype against the design goals. If the new prototype is better than the old, even incrementally, keep it and make another change. Test again and change again. Continue to cycle until the design goals are met or until no further improvement can be made. Directed evolution has been used to design improved microwave antennas, buildings, and new enzymes that do not exist in nature.

16. Analogical Thinking. The ability to see connections among different physical and biological systems can be valuable for the biological engineer. If, for instance, all biological units, whether they are at the cellular, tissue, organ, organism, group, population, or ecosystems levels have certain traits in common. Some of these have been described above. If these commonalities can be understood as concepts, then they can be useful in forecasting expected biological behaviors at all levels, and help to achieve the three biological engineering goals given in the introduction section. Analogical thinking begins with characterizing physical laws obeyed by biological entities. Classifying all variables into either effort or flow, and understanding the relationships between these two can be a start (Johnson, 1999; Schreuders and Johnson, 1999). Analogical concepts in chemistry and the engineering sciences follow. When these are all brought together, biology is no longer a science consisting of a long list of facts, but is, instead, a coherent set of concepts and fundamentals that can be of value in formulating designs for new and improved products and processes.

17. Looping and Successive Approximation. Although it may appear as if there are elegant control algorithms embedded in the central nervous systems of animals, the real control mechanisms more likely involve trial-and-error procedures. Sensors feeding information directly to the brain can invoke motor responses that result in changes of sensor outputs. These, in turn, would invoke other changes. If these other changes bring the control system closer to the set point, then further changes in the same direction are attempted. This continues until the set point is passed, and then the invoked change is in the opposite direction. This successive approximation procedure results in hunting around the desired set point. The exact set point is not always met, but deviations are usually small.

18. Reliability Curves. These are so universal in shape that they apply to automobiles, computers, and tools, as well as to human beings. A product just off the assembly line has a relatively high probability of failure. This is a result of faulty components or improper assembly. After this initial high rate of failure, called the *burn-in* period, comes a relatively long period of satisfactory performance with low rate of failure. This is the normal working period. When aging begins, the rate of failure again increases and continues to climb. For very, very old products, the failure rate seems to level off at a high rate. This progression of failures, high when new, decreasing to a low value for most of its working life, and then increasing again with age has been attributed to redundant faulty components. Failure of one or two components can be tolerated as long as other parts can assume the functions of those that no longer function. When the last part fails, the whole product fails. Humans and other organisms are assembled from redundant, imperfect components. They follow the classical reliability curve just as human-made products do (Gavrilov and Gavrilova, 2004). All engineers should be aware of the product reliability cycle and plan accordingly.

19. Immediate Availability with Circulatory System. Instant hot water in your hotel room? With a hot water circulation system, hot water is transported in a cycle from source to far end and back again. Tapping into this circulation avoids the wait while pipes are purged of noncirculating cold water. Circulatory systems in higher level animals have common design characteristics that engineers are well to be aware of. First, to deliver oxygen to the tissues, the smallest vessels must be in intimate contact with the tissues. Small vessels have large resistances that dissipate large amounts of power. To overcome this, flow rates in these small vessels must be kept low, so there must be a large number of them in parallel. Also to minimize energy requirements, there must be a small number of very large vessels to feed the smaller ones and collect from the smaller vessels. Thus, there must be a branching pattern from large to small and from small to large vessels. Living things use circulatory systems to deliver oxygen, glucose, and hormones to various locations in the body whenever and wherever they are needed, without the delay that would be present without a circulatory system. This mechanism works so well that it can be used for applications other than in living beings.

20. Proportional Plus Derivative Sensors. It is common that biological receptors produce outputs (usually neural in animals) that are related not only to the level of the stimulus but also to the rate of change of the stimulus. This incorporates a derivative element in the downstream control. Derivatives anticipate future stimulus positions, so improve stability of the control system. For stimuli that are chronically present, the control system that includes sensors and controller often adapts to the continuous presence of the stimulus. This has the effect of saving attention for those elements of the environment that have meaning.

21. Weber-Fetchner Law. Biological sensing is inherently nonlinear, giving rise to the Weber-Fetchner Law, and its variants, Weber's Law and Stevens's Power Law. Each of these is somewhat different quantitatively, but expresses the fact that the just noticeable difference in a stimulus depends on the level of that stimulus already present. Thus, the ability to see a light depends on the background light level; the ability to hear an additional sound depends on the background sound level, and so on. The effective additional level of a stimulus appears to be so universal in biology that the same principle should be expected for enzymes, neural activity, and running speed, to name a few. To expect the ability to recognize an additional component to be influenced by the amount already there can influence biological engineering designs of all kinds. Perhaps the most important part of understanding the concept behind the Weber-Fetchner relationship is that it clearly identifies limits to discernment sensitivity.

22. Young's Principle. Very selective, narrowband sensors require a lot of energy to operate. In addition, there are only a few instances in biology where such selectivity is warranted. One of these is the detection of pheromones to indicate reproductive opportunities. Biological sensors are nearly all broadband, with responses that spread over a wide range of input qualities. Signals from these sensors are not very informative, because they could represent a wide range of possible stimuli. Yet, organisms are very much aware of their specific surroundings. How is this possible? The answer is a number of broadband sensors with center stimuli that differ from each other by finite amounts. Their outputs overlap. When contributions from each of these sensors are compared, the contribution of each sensor, when added to the others, can determine exactly what type of stimulus has been received. Examples in biology abound. One of the best examples is the color sensors in the retina of the eye. There are three types of receptors, each sensitive to a different range of light frequencies. They are broadband, and their outputs overlap. A specific color is determined by the relative contributions of each of these receptors. Thus, perception of a myriad of colors is possible from the outputs of only three types of receptors. A similar mechanism allows determination of the physical position of touching without having to have touch sensors at eachlocation on the skin.

23. Hägen-Poiseuille Formula. This formula relates vessel resistance to fluid viscosity, vessel length, and vessel diameter. What it tells us is that resistance is extremely sensitive to diameter, being inversely proportional to diameter to the fourth power. A small difference in diameter can have a large effect on resistance. This equation was developed for laminar flow in a uniform, straight conduit. These conditions rarely apply in biology. Nevertheless, the Hägen-Poiseuille formula is a simple, quantitative explanation of the effects of changing vessel size, and, as such, is a valuable rough guide even when flow is turbulent and the vessel is not straight or uniform. In the bodies of animals, there are many sphincter muscles that encircle fluid flow passageways. The Hägen-Poiseuille formula tells us that it is not necessary for the sphincter muscles to completely close these passageways in order to control fluid flowing in them. A small contraction has a large effect. When exposed to nitric oxide, arteriolar sphincter muscles relax and blood rushes in. It doesn't take much.

24. The Law of Laplace. The Law of Laplace (Johnson, 1999) results from a force balance on the shell of a sphere or cylinder and relates pressure inside the object to tensile stress in the wall, wall thickness, and radius of the object. It gives a clear reason why bacteria are rounded, flimsy capillaries can contain blood at high pressure, and why lung surfactant is necessary to keep respiratory alveoli from collapsing into one huge sac with surface area too small to sustain life. The implications of the Law of Laplace are counterintuitive, because it states that smaller vessels can contain higher internal pressures without bursting. Architects have used the Law of Laplace as the basis of building shell designs that withstand high loads without heavy thick roofs and walls. Biological engineers should understand this principle in order to avoid intuitive errors in judgment.

25. Class 3 Levers. Class 1 levers come to mind whenever a mechanical advantage is sought. Class 1 levers place the fulcrum between the applied force and the load such that a smaller force can be applied to lift a heavier load by lengthening the moment arm. However, the arms and legs don't work that way. Muscles produce high forces, but cannot produce them very quickly or with large displacements. Thus, they are matched well with class 3 levers where the force is applied between the load and the fulcrum. There is a mechanical disadvantage of a class 3 lever; the applied force must be higher than the load force. However, the class 3 lever multiplies both the speed and the amplitude of the force displacement, so it allows more rapid motion and larger excursions than muscles are capable of generating by themselves.

III. Additional Concepts

Other concepts taught to engineering students are, of course, also important for competent biological engineers to know. These include force, mass, and energy balances, Bernoulli's equation, Fick's equation, Ohm's Law, thermodynamic laws, Newton's Laws, and others. Maxwell's equations, Kirchhoff's Laws, and the Navier-Stokes equations are just as important for specialists within biological engineering. These have not been included in the above list because they are not as unique to biological engineering as are many of the above. Understanding them does not necessarily assist in understanding biological nature. The same is true for concepts related to mathematical modeling, chemical equilibrium, pharmacokinetics, chemical kinetics, and a whole host of other information important for some biological engineers. What were listed, however, are concepts and principles suggested to be expected of all biological engineers, as the core of what distinguishes biological engineering from other disciplines.

IV. Discussion

Many of these concepts are not presently taught in many Biological Engineering curricula. Nor are they taught to Biomedical Engineering, Biomechanical Engineering, Chemical and Biomolecular Engineering, Bioengineering, Biosystems Engineering, or Civil and Environmental Engineering students. Nevertheless, each of these bio-based engineering curricula would benefit from the ability to appreciate a basic understanding of biology, similarly to the ability to understand physics, chemistry, and engineering sciences and the means to utilize these in engineering designs. Instead of attempting to incorporate each of these, and others, in various engineering courses already full to overflowing with material that must be taught, these concepts could be most appropriately taught in a course on Biology for Engineers (Johnson, 2010). This course, with a focus on the ways in which living things work and how they can be utilized by engineers, could be taught as an engineering science course centered on the realm of biological applications. Such a course has been taught at the University of Maryland both at the freshman level and senior level. For incoming freshmen, the course has provided a prospective context in which further education can be understood to be needed; for seniors, the course gave a retrospective view of information that students may or may not have been exposed to, but puts this information in a biological context. Both of these have been experienced, but the upper class course has probably been somewhat better at Maryland because of prerequisite requirements for later sophomore courses. Seniors are less likely to be flummoxed by the range of ideas in such a course. The preceding 25 concepts were suggested as a means to an end. They were not necessarily intended to be exhaustive nor were they meant to be arbitrarily dictated dogma. They are, however, given as a starting point for further discussions regarding specific information items to be expected of all competent biological engineers (in the broadest sense) by someone who has explored biology from an engineering prospective, continues to be fascinated by advances in biological knowledge, and has had extensive experience teaching biology to undergraduate biological engineering students. If these concepts are to be incorporated into all biological engineering curricula, then some uniformity of expectations of graduates would follow. This would be good for the graduates, for the profession, and for the quality of eventual biological engineering applications. The local means to incorporate these concepts, as with so many other requirements, depends largely on individual faculties and the ways they can best serve their students.

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Should Bioengineering Graduates Seek Employment in the Defense Industry?

Arthur T. Johnson

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They say that the difference between a mechanical engineer and a civil engineer is that the mechanical engineer develops weapons whereas a civil engineer designs targets. The implication is that some engineers are involved with building peaceful infrastructure whereas others contribute to destruction. This brings to mind the question: what is the proper role for engineers in the creation of weapons and defenses against them? In particular, should engineers specializing in biology or medicine be involved in the defense industry? After all, bioengineers are supposed to be builders or healers rather than warriors or destroyers.

I was reminded of this question after reading the article entitled "Universal Conscription as Technology Policy" by Brad Allenby and Mark Hagerott in the Winter 2014 issue of the National Academy of Sciences *Issues in Science and Technology* (vol. 30(2): pp 41-46). The thrust of their article was to argue for the reinstatement of universal mandatory conscription (the draft) among the U.S. young men and women. Some of their main points were that weapons of war have lately become very highly technological, and we need an influx of savvy young people to run them, that the all-volunteer military is becoming increasingly isolated from civilian life, and that the drastic nature of war cannot be appreciated as well without a more widespread populace experiencing it. Whereas I agree with all of these points, and have long thought that universal service to the country would have the beneficial effects of adding discipline to young lives, improving appreciation for military service, infusing the military with new ideas and attitudes, providing useful occupational training for some in need of practical education, and would dampen civilian support for adventuresome military interventions, I don' t believe that universal military service can find enough political support to be enacted any time in the foreseeable future.

As a veteran of the Vietnam war, I was originally a reluctant supporter of the war, but developed a decidedly anti-war outlook after I witnessed what war really means to those who participated and those who, through no fault of their own except that they happened to live there, were caught up in its repercussions. War, I am sure, may be justified only in extreme circumstances, and maybe even not then. So, it is, then, that I had taken a negative stance against recommending to my students that they find employment with the many defense-related agencies located in my home state of Maryland.

We have in Maryland and nearby states numerous military facilities with research and development activities, the headquarters of the National Security Agency, and other Department of Defense governmental offices. All have engineering openings with comfortable salaries and locations close to many of the families of our students. So, the attraction of these employment opportunities is not inconsequential.

Nevertheless, many of our students are what one would call idealistic and interested in improving lives. They do not talk about destruction and hegemony. Examples and projects included in our classes reinforce this idealism directed toward using their engineering skills for beneficial improvements rather than toward the opposite. They learn about ethics and ethical considerations as guides to make decisions that are both moral and supportive of the common good.

It is for this reason that I have changed my mind on this issue. I have decided that it would be good if more conscientious engineering graduates find employment in the defense industry. If we can't have civilians spending a few short years of their lives in the military, as would be the case with universal conscription, then we can at least bring ethical and constructive attitudes to the tools of war. We need engineers with deep ethical beliefs to question whether it is good and right for an operator sitting comfortably behind a console in an environmentally-controlled location to control a drone intended to kill people thousands of miles away. We need engineers to realize the broader implications of the weapons they help to design in order to place limits on their use, if need be. We need people of conscience to be aware of the possible terrible repercussions of military actions, and to be able to give the military the tools they need to perform humanitarian activities. We need knowledgeable engineers to temper radical tendencies that could be developed by an isolated military.

Engineers specializing in biology and medicine are particularly needed because the rapid advances of knowledge in these fields are opening up new opportunities both for good and bad applications. Engineers are needed who can develop new weapons and countermeasures within an ethical context, and resist pressures to use their knowledge base to develop unethical or illegal bioengineering systems. Biological or psychological warfare can have far-reaching consequences. Our engineers should be involved in their development.

In October 1994, the famous astronomer Carl Sagan addressed an audience at Cornell University. Behind him on a giant screen was projected a small point of light that he identified as a photograph of our planet Earth taken from the spacecraft Voyager looking back as it was leaving our solar system. Sagan directed the audience to concentrate on that small, lonely dot in the midst of a vast darkness, and spoke:

"Look again at that dot …On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives …

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner; how frequent their misunderstandings, how eager they are to kill one another; how fervent their hatreds.

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the universe, are challenged by this point of pale light. Our planet is a lonely speck in vastness, there is no hint that help will come from elsewhere to save us from ourselves …

There is perhaps no better demonstration of the folly of human conceits than this distant image of our world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known."

This is the message of peace that I would hope that my graduates could bring to the military and to society in general: that we must be strong in defense but peaceful in intention, that as bioengineers we must act ethically and in harmony with each other and with the most beautiful world that we call home.

Part 2

Engineering in General

The Trouble with STEM

Arthur T. Johnson

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It has become popular to combine Science, Technology, Engineering, and Mathematics into the acronym STEM when discussing education. But, as an engineer, I have some difficulty with STEM. Science requires curiosity for new knowledge, technology requires skill, mathematics requires logic, but engineering requires creativity and judgment. Engineering, to be sure, requires science, technology, and mathematics (STM) as tools to assure that a design will be successful, but the first step in the design process is invention – the critical beginning of a new idea. In this respect, engineering is different from STM.

As a child, I had many interests, and dreamed that someday I would become either a scientist or an artist. That dream persisted until high school, when I learned about engineering. The path that I chose combined both of my passions into one profession.

The humanitarian and artistic side of engineering is often downplayed, if not ignored, in engineering education. Engineering science courses, essentially applied physics, use mathematical tools almost exclusively to solve problems. These engineering science courses give nascent engineers the technological skills to analyze a trial design to assess likelihood of success. But the design process involves synthesis as well as analysis, and the synthesis part of this process is not given the same attention as the analysis part. We engineering educators depend very much on the native creativity of our students to be able to synthesize.

Along with synthesis, engineers must learn judgment: how to go about the process of determining whether or not a new concept will work, often before the mathematical analysis stage. Judgment requires experience, and experience usually involves failure on somebody's part. If that failure does not happen in school, where its consequences are limited, then that failure, and its accompanying experience and growth of engineering judgment has to be developed in the workplace. That is why employers of just-graduated engineers often give their new employees mentored dummy projects to work on during the first six months of their tenure. An engineer who has not developed engineering judgment by that time is either not retained or faces potentially more catastrophic failure later in her/his career.

The Accreditation Board for Engineering and Technology (ABET) requires the inclusion of humanities courses in engineering curricula. The reason is clear: engineers often need to include non-scientific, non-mathematical, even non-technological features in their designs. There are artistic, historical, political, psychological, financial, spatial, and other elements that must be considered for a prototype engineering design to be successful. There have been many examples of new products that have failed because they didn't look right, were named wrong, didn't feel right, or were too complicated. All of these fit into the category of engineering judgment.

The reason that the "E" in STEM should be distinguished from the STM part is that engineering can appeal to those who are not so good at STM, but who have superior skills or interest in the softer side of engineering. They can become great patent lawyers, engineering managers, recruiters, teachers, insurance adjusters, human factors engineers, or sales/applications engineers. Some engineering disciplines are more people-oriented than others. I have had "C" students in my Transport Processes and Electronic Design classes who could talk a lawyer into the ground. With the technical backgrounds that they had barely mastered, they used the softer skills in which they excelled to find successful careers on the fringes of engineering. We need these kinds of people, too.

The American Association of University Women has a 2010 report entitled *Why so Few? Women in Science, Technology, Engineering, and Mathematics*, in which they deplore the fact that it is difficult to attract young women into STEM fields. One reason they give for this is the stronger interest young women have in people and interpersonal relationships that are not usually associated with STEM fields. But, if it were better known that engineers do not have to be nerds and recluses, that as engineers they could have a rich involvement with other people, then the "E" part of STEM might attract more women and men to the profession. This is the problem with the acronym STEM; it does not do justice to the full range of opportunities available in engineering.

Pride in Our Profession

Arthur T. Johnson

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"*You can be a physician and save people one at a time, or be a biomedical engineer and save them a thousand at a time*." That's what I have been telling my undergraduate students for years now. It has not been my intention to disparage those who want to enter the medical profession and care for those in need, but rather to ennoble the field of biomedical engineering and to express my pride in the much under-appreciated activities of professionals who have now made possible miraculous diagnostics, treatments, and cures.

Herbert Hoover expressed it very nicely by saying:

It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege.

The great liability of the engineer compared to men of other professions is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope the people will forget. The engineer simply cannot deny he did it. If his works do not work, he is damned.

On the other hand, unlike the doctor, his is not a life among the weak. Unlike the soldier, destruction is not his purpose. Unlike the lawyer, quarrels are not his daily bread. To the engineer falls the job of clothing the bare bones of science with life, comfort, and hope. No doubt as the years go by people forget what engineer did it, even if they ever knew. Or some politician puts his name on it. Or they credit it to some promoter who used other people's money. But the engineer himself looks back at the unending stream of goodness which flows from his successes with satisfaction that few professions may know. And the verdict of his fellow professional is all the accolade he wants

And, although Hoover was a civil engineer talking mostly about civil engineering, the pride that he expresses comes through for engineers of every kind.

Biology Taught to Engineers

Arthur T. Johnson

Appeared in IEEE Pulse, vol. 1 (2), page 61, Sept/Oct 2010.

Dear Editor,

Thank you again for a stimulating May/June issue of EMBS Magazine. And, again, your excellent editorial entitled "Have You Invented Anything Lately ?" has prompted me to respond.

Engineering involves an amalgam of scientific knowledge with creative activities to move beyond either factual knowledge or artistry in order to produce solutions to problems important to humankind. Although not all biomedical engineers invent equipment, they should all have the capacity to do so.

There are at least two characteristics of the engineering mind that are crucial to the ability of engineers to create desired products and processes. The first you mentioned in your editorial – the ability to calculate necessary parameter values. This, of course, enables the engineer to predict success for her/his design and avoids the need for a long and costly trial-and-error process that only perhaps leads to a successful design.

The other necessary ingredient is the ability to understand how things work. This ability involves vision, conceptualization, and mental connections. An engineer must know how something is supposed to work before she/he can quantitatively analyze the prospective design.

This, then, leads to your comments on the Biology for Engineers course. If you ask most engineering faulty members how a course in biology for engineers should differ from a biology course for scientists, then most would likely answer as you did in your editorial. They would say that biology for engineers must take a quantitative approach that is not included in the course for scientists.

This answer may be partly correct, but ignores the fact that engineers need to know how things work, and why they are as they are, before they break out their calculators. It is a mistake, I believe, to base a course on biology for engineers on a quantitative foundation before the essential concepts of biological workings are full comprehended. It has been my experience that engineering students are too quick to plug numbers into equations to chug out answers before they completely understand the reason for why they are using this set of equations rather than another set. It has also been my experience that I have occasionally attended research paper presentations by bioengineers who completely miss basic biological concepts and spend inordinate amounts of time and effort trying to solve technical problems without hope of solution. In both of these cases, quantitative information was available, but basic conceptual understanding was lacking.

Thus, I believe that a biology for engineers course must present biology as a set of concepts that work together. The laws of physics, chemistry, mathematics, and engineering sciences are relevant, just as are the unique uses to which they are put in living things. And, to make this clear, a biology for engineers course should deal with the entire realm of biology, not just human biology, because there are principles to be learned from microbes and plants as well as from humans and animals.

This approach to biology for engineers is not common, to say the least, but I believe strongly that it is the proper approach. By the time you see this, my *Biology for Engineers* textbook should have appeared in published form. Take a look at it, and see what you think.

Old Man River

Arthur T. Johnson

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One trait I share with many of my friends is the troublesome tendency to repeat a song over and over in my head until it long passes the tiresome stage. Once a song gets there, it stays for days at a time, often only to be replaced by some other no less catchy tune taking up semipermanent residence in the cavities of my brain. Who can resist *It's a Small, Small World*, or *My Darling Clementine* ? At least my rapacious repertoire extends to more than just these two ditties. The trouble is that they play constantly in the background of my thoughts during both day and night, and stay there long after they have worn out their welcome.

I recently suffered a bout of *Ol' Man River*-it is. Against my will, or completely independent of my will, this poignant lament reminded me ceaselessly about the distress of daily living. Every now and then, when the song worked its way into the foreground of my mind, and I was forced to pay it some attention, it occurred to me that there is more than just a song here; there are thoughts and lessons about modern day work.

Ol' man river; Dat ol' man river … He keeps on rollin' along. I remember the passion and enthusiasm that drove my early work. It was so easy then to jump out of bed in the morning and do what it was that needed to be done that day, because it was all so exciting. It was all so important. It was all so good. All I had to do to reach the promised land and snatch the holy grail was to get there, and getting there was fun.

Passion is probably the one emotion that separates the young from the old. I can see the passion and enthusiasm in the eyes of my students. They want to save the world, or at least some part of it, and they have the energy and determination to try. Just to be in the presence of this youthful energy is one of the real pleasures of teaching.

It is so easy to lose the enthusiasm of youth and trade it for the ennui of middle age. Passion and fire are hard to sustain, and few of us are able to maintain a high level of adrenaline for long periods of time. Perhaps if we did, it would kill us. *But Ol' Man River, he jes' keeps rollin' along.*

He don' plant taters; he don' plant cotton; An' dem dat plants 'em; is soon forgotten. It is so easy to become lost in the day-to-day activities of bioengineering. Even as faculty members, in an occupation that is sprinkled with variety, there are tests to compose, papers to grade, students to advise, and proposals to write. Ah, the proposals … so much depends on them … support for grad students, postdocs, summer salary, and even promotion. And yet we cannot stop there because we must always look forward to the next proposal or project. And in the end, when our careers conclude, we may look back and wonder where we were going, where we had been, and why all those things were so darned important. Planting taters and cotton might be necessary to sustain ourselves, but they may not mean much in the end.

Tote dat barge; Lif' dat bale! Git a little drunk an' you land in jail. It is so easy to be distracted by the details that come in the course of a day: the reports to write, committees on which to serve, and tests to monitor. An organization does not run by itself; there are maintenance activities that require so much time to be taken from the quest for our lifetime goals. Others depend on us, and we on others, to share the overhead demanded by our institutions to keep them running smoothly. It can be drudgery, grunt work, but it must be done. Avoid these responsibilities, and the burden falls on the shoulders of others. We don't land in jail, but we can provoke resentment.

Dat ol' man river; He mus' know sumpin'; But don't say nothin'; He jes' keeps on rollin' along. Here is where we diverge from Old man River. We can take our year's work, package it neatly into a 20 minute presentation, go to a meeting, talk and be talked to, and return to our work with renewed enthusiasm. What we have done was important to others, and we can revel in the reflection of our yearly progress. We can be encouraged t

o keep going, and perhaps have found new ideas and collaborations to sustain us. With new perspectives, and with refreshed confidence, we can be inspired to renew our efforts. We were pumped.

This is the way to rekindle the fire. This is how we sustain our efforts for the next year and beyond. This is renewal. Let Old Man River keep his thoughts to himself; let him roll silently along. What we do is important, gives meaning to our work, and reignites the spark of passion that had so many times been nearly extinguished by the grind of everyday existence.

Now if I could only stop humming that song …

Jargon is a Barrier

Arthur T. Johnson

Published in the ASEE Prism vol. 23(7), page 11 (Mar/Apr).

The statement that communication between engineers and life scientists has been difficult "because most engineers and physical scientists approach a problem more from a quantitative, numbers-based perspective, while many life scientists rely on descriptive measurements" in the January 2014 issue of *Prism* article "Culture Clash" is misleading. Engineers don't jump directly to quantitative analysis of a solution before they have created a concept for the product. Qualitative conceptualization ("the idea") is the first step in an engineering design. If not, then there is nothing to analyze, no reason to compute.

If engineers have a difficult time communicating with other non-engineering professionals, it is because of two things: first, engineers have their own set of jargon that they use as shorthand to replace complex engineering concepts that would take many words to fully explain. They develop this jargon over the four or more years of taking engineering science courses in their undergraduate and graduate educations.

Second, other professions, especially medicine and law, have rich sets of vocabulary that they acquire in their professional training. It is this mismatch of the vocabularies of engineers and other professionals that must be overcome if meaningful communication is to take place.

When I taught my Transport Process Design course, I assigned three full-blown design projects each semester. Each project required an elaborate design report of professional quality. Each report was assigned two equally-weighted grades, on for technical quality and the other for communications ability. Contributions to the second grade were clear writing, attractive and well-labeled illustrations, and orderly progressive format. I instructed the students to write so that their mothers could understand it. Jargon words were to be avoided or defined, so that, for instance, if they were to use the term "viscosity", then they should explain that viscosity could be equivalent to fluid thickness. These reports were pre-evaluated by classroom peers before I graded them, and some of their peers were harder on the use of jargon than I was.

Engineers who go through undergraduate experiences such as this should have no problem communicating with other professionals. They are taught to think about what they mean to say and to explain it in clear common language. They can use their engineering shorthand when around other engineers, but know to revert to more wordy, but understandable, explanations with others. Then, when talking to those from other professions, if the others perceive that the engineers are making every attempt to communicate clearly with them, they will often respond by reverting from their own jargon to clearly explain things that they understand so the engineer can understand as well. Communication requires offered information and response. It should not be difficult!

Part 3

Students

To All Students Everywhere

Art Johnson

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> "*It is not the critic who counts: not
> the man who points out how the strong man stumbles
> or where the doer of deeds could have done them
> better. The credit belongs to the man who is actually
> in the arena, whose face is marred by dust and sweat
> and blood, who strives valiantly, who errs and comes
> up short again and again. . . who spends himself in a
> worthy cause; who, at the best, knows, in the end, the
> triumph of high achievement, and who at the worst, if
> he fails, at least he fails while daring greatly*."

This quote by Theodore Roosevelt exemplifies two needs: 1) to recognize and celebrate those who work diligently toward good and noble ends, and 2) to become those people ourselves. The world is a tough place, and it demands toughness in order to survive. The world can be cold and ruthless, taking those who aspire to no more than to be left alone and to leave others alone, and grinding them to small pieces of subhuman protoplasm. There are victims; there will always be victims of war, starvation, fraudulent schemes, the powerful, and adverse circumstances. The most these victims can do is to subsist uncomfortably with little hope for improvement.

You are not victims; you are winners. You have advantages of family, friends, resources, and education. You could lose every material thing you have in this world, and you could rebound. You have hope, confidence, energy, and spirit. You can thrive. You are, by some miracle, in the right place at the right time to prosper, to be comfortable, and to take care of yours. Your worries are little worries, and your life is in your hands.

Such a contrast, you and the impoverished. You have everything you need and much of what you want; the impoverished have nothing, no safety, no surety, no future. You can live a life that counts for something; the impoverished barely have life.

You are hardly responsible for your advantages. You did not choose to be born who you are, to the parents you have, and in the comfortable environment that surrounds you. You have friends, who like you, are here because of circumstances they did not choose. You have physical and mental health, you are robust, you are intelligent and you are capable. But you didn't choose these things, they chose you. You are here, and that is how lucky, and how rich, you are.

There are those out there who need you. The mother who lives in poverty; the child who will nearly starve to death because of war; the victim of inhuman acts on our streets; the elderly who face uncertain futures; the driver of the other car; the high schooler harassed because of being a conscientious student; the patient with incurable genetic disease; your friend succumbing to stress. The world will never improve if you don't do all you can to improve it.

It is up to you, each of you, because there are enough problems for everyone to tackle. We are all involved, whether we like it or not. It is up to us, not someone else, to be marred by dust and sweat and blood, to strive valiantly.

We may not succeed. No one succeeds all the time. But when the alarm clock wakes you in the morning, you need to remind yourself that is a new day to make the world a better place, and you need to get going because without you the world will not be better in the unique ways that you can make it better. It is up to you to kick-start yourself to do what you can. Without you, there is one less dusty, sweaty, bloody face that the world needs right now—immediately.

And, remember, there are others who are dusty, and sweaty, and bloody because they, too, are trying. It may be convenient to associate with the powerful, the well-placed, the rich. It may even be expedient to forget those who wear rags rather than tuxedos, who are only capable of doing little things, not big things, to improve the world. But talk to those people and share a little of their dust, and sweat, and blood. They deserve respect not only for what they do, but also for what they are. Perhaps, someday, you, too will be elevated to their level.

Aspire to Greatness

Arthur T. Johnson

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"*You can go to medical school, become a physician, and save people one at a time, or you can be a biomedical engineer and save them a thousand at a time.*" I've often said this to my students; it reflects my pride in being an engineer and the good that comes from engineering endeavors. Looked at more deeply, however, both paths mentioned in the above statement lead to saving, or, at least, improving the lives of, people. There is basically no difference between the two outcomes if saving people is the goal.

Biomedical engineers, I think, have made their choice of profession, at least in part, because they care about people and want to do something to make life healthier, safer, and better for others. Yes, there is the personal challenge of engineering problems, the ability to use one's imagination and creativity to produce unique designs, and the mental reward that comes from new insights, but, behind it all, is the feeling that it can all be worthwhile because someone else will be better because of our involvement.

This sense of benevolence, compassion, and altruism is part of the fabric of most of the biomedical engineering students that I have taught. Knowing this, my stated challenge to them has always been to do their best, aspire to greatness, and aim high. I have told them that I expect that each of them will do something great, that each one has the capability to make the world a better place than it would be without them.

I once had a teacher, Professor Dropkin at Cornell University, who made it a habit to tell every one of his students in every one of his classes how special they were to be there. He told us that, because we were engineering students at Cornell, we would go on to accomplish great works. His words have always stuck with me, and have been an inspiration to perform at as high a level as I could. I want my words of expectation and encouragement for my students to be as memorable to them as Professor Dropkin's are for me.

My courses were not the easiest for my students to do well in. My course on Transport Process Design was for many years the hardest course in their curriculum. Yet, former students had many times told me that this course was the one most important course that they had taken as undergraduates. I had tried hard to give my students what they would need to become successful engineers after graduation, and I also tried to let them know of the confidence that I had in each of them once they had mastered the material in this and their other courses.

I hope that my former students will develop a broad sense of social responsibility that extends well beyond their own corner of the technical world. I hope that they will have an interest in the issues important to society, and act as leaders to interpret technical issues for people who do not have the capabilities to understand all the implications of possible solutions. I hope that they will take an interest in their professional societies, and become society leaders. I hope that they will not forget the responsibilities that they have to people even in the lowliest of circumstances.

Technology is advancing rapidly, and my students will be among those who will develop new capabilities. I hope that they will see beyond the immediate problems that they are working on to assure that their technological advances, which will probably have both beneficial and harmful potentials, are steered toward the good side. Every engineer should consider the wider implications of her or his work; enabling the positive attributes of technology is good, but not enabling the negative aspects may be just as good or even better.

Alison Gropnik, a psychologist at the University of California at Berkeley, has been quoted as saying, "*One of the things we always say is that it's not that children are little scientists – it's that scientists are big children*." Engineers, like scientists, need that open, creative mind of a child to bring new ideas to fruition. My hope is that my students can maintain a little of that child-like naitivité, good-will, humanitarianism, and benevolence to believe that they can help to fix the problem or make it better.

With all the wealth we have in the world, why are people still starving, why are some homeless, why do we have to use so many poisons, why are there parents who abuse their children, why is there so much violence, and why don't we have peace? I hope my students can someday find answers to questions like this and do what they need to eliminate these problems. Even if they don't find solutions, I hope they make the attempt.

It is not the sole responsibility for biomedical engineers to face issues such as these, but, as members of the human race, they belong as much to us as to anyone else. So, when I urge my students to do great things with their lives, I am hoping that they can do more than invent the next great medical device. True greatness comes by making a difference in other peoples' lives, whether it be one at a time or a thousand.

Choosing Good Graduate Students

Arthur T. Johnson

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Your good grades will get you into graduate school. No, not necessarily. Undergraduate students aspiring to graduate work often think that it's their grades that will get them into grad school. So, they work hard and compete for the best possible grades, usually all A's these days, and hope for the best. Well, undergraduates, that isn't the whole story.

When we faculty members are asked to provide references for graduate programs, we are asked a number of questions about the candidate: can the candidate express himself or herself orally? In writing? Will the candidate make a good teacher? Researcher? How does the candidate relate to others? Does the candidate work well in groups? Does the candidate show leadership potential? Is the candidate creative? All of these are important attributes when potential graduate students are judged.

Letters of recommendation, also, rarely contain anything remotely associated with grades. What a good letter of recommendation includes are insights into a candidate's capabilities, personality, and strengths and weaknesses (mostly strengths) in the classroom, laboratory, and when working with others. Most recommenders are asked to compare the candidate to others in their class, and these comparisons are only partially related to grades. After all, nearly all candidates for graduate school have very good to excellent grades. Grades do not distinguish one student from another very well.

Leadership is important. To be a good leader requires a combination of confidence, knowledge, and social skills. Undergraduate students who have had extensive experience working in groups, clubs, and student chapters can gain these skills. They are hardly ever taught, but they are as important to life success as any knowledge learned in the classroom.

My cohort of graduate students was, for the most part, hand picked. Before I offered an assistantship to a prospective grad student, I got to know them as well as I could. Most of my graduate students were selected from our undergraduate program in which I had taught them two or three courses. I was usually confident of their abilities by the time they had completed these courses, so I did not put much weight on their grades. Having an overall grade point average high enough to be accepted into graduate school was sufficient, and, under special circumstances, even that requirement was relaxed.

What I looked for most was the ability to fit with my grad student group. Of particular importance was whether the candidate had the social skills to get along with the others. If they all got along, they were not afraid to help and support other students in their endeavors, be it classroom work, research, or private lives. Ours was not a competitive environment, but a mutual support network. We did compete with others, but as a group, as a team. Consequently, we became the most productive group in our department. We ran the most experiments, wrote and published the most papers, and had unusual success attracting outside funding. There was always activity in our lab, which became the envy of other faculty and grad students in our department.

With any group of individuals, each had particular strengths and weaknesses. One grad student was particularly creative, and had an idea to solve every problem. Not all of his ideas were worthwhile, but enough were valuable and were used. Another student was particularly good with instrumentation. If another student had a measurement problem, this student was glad to help. Other students were especially skilled with dealing with the human subjects we often tested. They could run an experiment while being sensitive to subject needs, and I had utmost confidence that these experiments were conducted correctly and according to the approved protocols. Still other students were very good at social skills, and became the glue to hold the group together running smoothly. If there was ever a major disagreement in our group, I certainly don't remember it happening. If a difficult situation was developing, we dealt with it consensually at our weekly meetings.

Each graduate student had his or her own research project that led to a degree. Although it was their own project, they could call on the others to help out when needed. In addition, we had common group research projects to conduct. All students helped with these. As a result, students learned by experience how to conduct their own projects. They developed confidence by familiarity.

Each student's name appeared as a coauthor on the papers about common research projects, and, as a consequence, each student had compiled a fair number of published papers by the time of graduation. One PhD student, in fact, had enough publications to her name by the time she graduated to have earned tenure if she had been an assistant professor. Each grad student was given the opportunity to write the first draft of a research paper, and senior authorship went to the writer.

I also expected my grad students to participate in classroom teaching, despite the fact that they were supported by research assistantships and not teaching assistantships. Teaching a class develops important skills not developed in the research lab, so they all accepted this requirement without objection.

Returning now to the undergraduate student aspiring to graduate school, there are many more criteria for selection than just grades. The grad school experience can be much more rewarding and beneficial if the student chooses a grad program that weighs many different factors in addition to academic grades. This is, after all, a portion of your life that can set the direction for your entire later professional career.

The Effects of Technology on Diversity or When is Diversity Not Diversity?

Arthur T. Johnson and Rosemary L. Parker

Excerpted from Paper 2470-3 presented at American Society for Engineering Education 2001 Annual Conference.

The University of Maryland campus community is proud of its diverse student body. It is a campus where diversity is celebrated and nurtured, even defended before the U.S. Supreme Court. The University has invested heavily in building and maintaining a student body consisting of 12% African Americans, 13% Asian Americans, 5% Hispanic, and 4% of international origin.

The mission of the University of Maryland Diversity Initiative is to build a more inclusive community grounded in respect of differences based on age, race, ethnicity, gender, religion, disability, sexual orientation, class, marital status, political affiliation, and national origin. The presumption, then, is that if minority student enrollment increases, so does cultural diversity. However, there may be other factors that dilute the value to the campus of diversity based mostly on race affiliation.

Admissions standards at the University of Maryland have markedly increased in recent years (for example, in 1992 the average SAT score of the incoming freshmen was 1068 with a high school GPA of 3.19; corresponding statistics in 2000 are 1253 and 3.74). Imposition of these standards has resulted in cultural, as well as academic, selection. There is a much smaller difference among racially diverse students because we are now selecting from among applicants with similar backgrounds.

One of the factors that seem to be having a profound effect on the diversity of our student body is technology. Seventy-three percent of white pre-college students and 32% of African American students have computers at home. These same students are likely to have other technology (cell phones and pagers), strongly supportive parents, more than adequate family income, stable home life, and encouragement for extra curricular activities. Culturally, these students are relatively homogenous, and the technology found in their homes is standardizing the thought processes of these human beings. As we have become a more selective institution, we have sought out those students who are more technology privileged but perhaps less imaginative and creative. As we strive to select the top ten students, it is important to consider many factors so that we may have a campus that is culturally and creatively diverse as well as diverse racially and ethnically.

The effects of all this are seen in several places. The Banneker-Key scholarship is the most prestigious and selective all expenses paid scholarship at the University of Maryland. From an annual pool of 20,000 freshman applicants to the University, only 2000 applications folders are reviewed for this purpose, and only 105 students actually receive the Banneker-Key scholarship. Opinions of members of the Banneker-Key scholarship committee is that there is less creativity, imagination, and originality evident in the application materials than there one was. There are other indicators of homogeneity: out of 28 randomly-selected applications materials, there were 11 females and 17 males, with average SAT scores of 1452 and average high school GPA of 4.25

(weighted). Six of these were first generation college applicants, two were children of parents one of whom had attained a bachelor's degree or higher, and 20 had two parents with college degrees. There were 12 who listed themselves as Caucasian, 7 as African American, 8 as Asian, and 1 as Hispanic. Of the 28 folders, 25 had given email addresses. The faces of the students in a class may look different, but once they open their mouths, their voices all sound the same.

A Cultural Diversity Survey was conducted among 57 Sophomores, Juniors, and Seniors in the Biological Resources Engineering program at the University of Maryland. This program is among the most diverse at the university, but there was no attempt to select students to receive the questionnaire except that they were enrolled in either a required sophomore, junior, or senior level course in the spring semester 2000. Of the respondents, 23 were male and 34 female. Two were African Americans, 10 Asian Americans, 35 European Americans, and 6 were of other ethnicity, including Hispanic. The remainder didn't respond to this question. Their average ages were 21.3 ± 1.81 (mean ± std. deviation). The 57 respondents were asked which of these technologies they had available before coming to the University of Maryland: Television (56), Radio (56), Computer (54), Video Cassette Recorder (55), Cellular Phone (26), Pager (20), and Compact Disk Player (53).

They were asked to rate their agreement with the following statements on a scale of 1 (least agreement) to 5 (most agreement). They were told to base their answers on the years immediately preceding their entrances into the University of Maryland.

4.70 ± 0.462	I was a good student.
4.14 ± 1.11	The atmosphere at home was conducive to study.
4.61 ± 0.726	My family supported me and encouraged academic achievement.
4.12 ± 1.15	I used the computer a lot.
3.23 ± 1.30	My cultural experience was different from the experiences of my classmates in college.

When asked to rank activities by the amount of time spent on each before coming to the University of Maryland, they responded with:

3.15 ± 1.91	Talking with friends and family.
3.50 ± 2.35	Thinking.
3.80 ± 2.61	Reading and studying books.
3.87 ± 2.98	Playing sports.
5.55 ± 2.40	Using a computer.
5.91 ± 2.38	Watching TV.
6.24 ± 2.08	Writing.
6.55 ± 2.40	Crafts, mechanics, or other manual skills.
6.85 ± 2.64	Volunteer work.
7.72 ± 2.62	Playing a musical instrument.

Numbers denote average ordinal responses with standard deviations.

What emerges from the results of this study is a student body with a self-image more diverse than is indicated by the academic atmosphere, available technology, and activities that they engaged in. Despite the varied ethnic backgrounds of these students, they appeared to have very parallel and homogeneous lives before matriculation at the University of Maryland.

The data thus far supports the conclusion that as entrance requirements increase, cultural diversity of students decreases. We attempted to find some performance measures that would reflect the effects of higher entrance requirements and the cultural meanings of those requirements. In Table I are found retention rates for students in the University of Maryland Honors program, and in Table II are found retention rates for students at the other end of the academic spectrum. Retention rates and the 4-year graduation rate for the class of 1999 are all higher for the Honors students than for students not part of Honors or similar programs. This would be expected, because Honors students have the advantages of better academic records, more scholarships, probably more supportive families and friends, and access to technologies, as already discussed.

The differences between retention rates and graduation rates of the two student groups widens as time goes on. Nearly 60% of the Honors students graduated in 4 years compared to 30% of the non-Honors students.

Comparing African American students to their respective groups shows that African Americans had lower 4-year graduation rates than the averages for both student groups. However, the graduation rate of African American students was 70% of the average for the Honors students, but less than 50% of the average for the non-Honors students. A somewhat similar trend can be seen for Hispanic students, but not for Caucasian or Asian students.

We conclude from this that better students are more likely to be retained at the University and to graduate in 4 years. Therefore, the advantage of raising entrance requirements has positive academic rewards for the University.

It could be asked, “Why is diversity among students a desirable goal?” Is this just an example of social engineering, or is there a real educational benefit to diversity in the classroom? The concept of the traditional university, wherein students learn by immersion in an intellectual atmosphere of new ideas and by exposure to experiences of a multifarious nature, is enhanced by a diverse student body. Teaching in the classroom is enriched by student experiences shared with other students. Core technical material is perhaps independent of culture, but applications are not. A classroom full of students representing different cultures yields learning benefits well beyond material that appears in textbooks.

There are pressures to transform the university from a place of quiet intellectual pursuit into a competitive atmosphere of energy and vitality. These modern universities scramble to climb to the “top ten”, and once there, to become “number one”. In the quest of competitive position, real cultural diversity is sacrificed for higher SAT scores and Grade Point Averages. As these universities become more selective, admitted students seem to become more homogeneous. What is left of diversity are the vestiges of skin colors and surnames. The cultural richness that they once would have brought to the classroom has become a relative sameness. All this in the name of quality.

There are good reasons for selecting students with the highest SAT scores. These students learn fast and perform well. They are not only easy to teach, but they become an object of pride. However, the price paid for extreme selectivity is a constriction of cultural diversity. As SAT scores homogenize, so do the students.

The University of Maryland has been proud of its record on diversity, but Chaucer said, "*If the gold rusts, what of the iron?*" Indeed, if the University of Maryland, which has placed so much emphasis on diversity, is in danger of eradicating true diversity as it becomes more selective, what of those universities for which diversity is less important?

There is no answer to this question. Just as every engineering design involves trade-offs, so does the choice between true cultural diversity and selectivity. We conclude, however, that diversity is often not what it appears to be. The true diversity of students who have met or exceeded high admissions standards often does not enhance the academic environment in the way it could have. This diversity is dishonest diversity; it is a fraud.

The most imaginative and creative minds may not always have the highest standardized test scores or have access to the latest in technology. For example, through the individual admissions program, the University is able to bring in truly different students. Many of these admissions have talents, such as athletic or artistic performance, that normally would not qualify them to come to the University of Maryland. However, these students are not likely to fit the same experiential and cultural mold as those who qualify for regular academic admission. This is diversity for real; diversity that broadens the collective experience of faculty and students at the University.

We certainly do not want to lower admissions standards and recent achievements of the University of Maryland, but we do want to enhance student experiences through opportunities given to students who represent real differences in creativity, imagination, and originality.

In an article on admissions decisions, Arthur Coleman, Deputy Assistant Secretary, U.S. Dept. of Education, challenged us to think of Admissions this way: "*You are a conductor of an orchestra. You may hire five additional musicians before your fall tour. Of the twenty candidates who have applied, the five most musically-credentialed candidates are all violinists. Do you hire only violinists when you have broader musical needs*?" Clearly it is not enough to hire five violinists of different racial and ethnic backgrounds. Likewise on our campus we need students from different racial and ethnic backgrounds who bring different creative and intellectual talents to the campus community.

Table I. Percent Retention Rates for Students in the University of Maryland Honors Program (1999 data).

Year	Race				
	All	Afr. Amer.	Hisp.	Cauc.	Asian
1995 (matriculated)					
1996	96.2	98.0	90.7	96.6	95.8
1997	89.5	90.2	83.7	89.0	94.7
1998	88.4	88.2	79.1	88.4	92.6
1999 (graduated)	58.6	41.2	48.8	61.2	60.0
1996 (matriculated)					
1997	94.7	95.1	93.3	94.3	97.0
1998	91.5	92.2	93.3	90.9	93.0
1999	90.3	91.2	88.98	89.7	94.0
1997 (matriculated)					
1998	96.0	93.9	95.9	95.6	97.1
1999	90.9	87.9	85.7	91.5	90.4
1998 (matriculated)					
1999	95.7	89.7	89.2	96.4	98.0

Table II. Percent Retention Rates for Students of the University of Maryland Who Are Not in Honors or Similar Programs (1999 data).

Year	Race				
	All	Afr. Amer.	Hisp.	Cauc.	Asian
1995 (matriculated)					
1996	83.6	82.1	86.2	83.3	87.3
1997	72.1	65.7	73.1	72.8	77.5
1998	68.5	58.0	67.7	70.6	72.6
1999 (graduated)	30.3	14.2	15.4	37.1	26.4
1996 (matriculated)					
1997	83.8	80.0	77.8	84.7	89.3
1998	73.6	68.5	70.6	74.3	82.1
1999	68.7	60.5	65.9	70.2	78.2
1997 (matriculated)					
1998	84.7	83.2	76.9	84.9	89.8
1999	75.5	71.4	61.2	77.1	81.8
1998 (matriculated)					
1999	88.4	81.8	85.8	88.2	91.9

Letters to Zen

Arthur T. Johnson

Zen Liu is a graduate student in Biomedical Engineering at Columbia University. She writes a regular column in the IEEE-EMBS Pulse magazine about her experiences while in graduate school. These emails were sent to Ms. Liu in response to several of her columns.

Sent Jan 22, 2013:

Zen,

I have been reading with interest your columns in Pulse. They are very good columns. This last column of yours, Bad Science, has prompted me to respond to several issues you raise.

First, you should be aware of the fact that people who serve as references for graduate student candidates are asked their opinions on a number of questions not directly related to a student's academic performance. We are asked about the candidate's potential as a teacher or researcher, how the candidate relates to other students, and about the candidate's ability to write or speak English. So, the judgment of a potential engineering graduate student is not based solely on her or his technical skills. You may not have known this from your prospective, but softer skills and abilities are definitely in the mix for selection of a graduate program candidate.

Second, you compared the treatment of science and medicine in two TV shows, and you selected Grey's Anatomy and Big Bang Theory. I do agree with you that the medical profession is usually held in higher regard on TV than is science, but what about Scrubs? There is a spoof of the medical profession for you. And, in many ways, CSI is about scientists. So, your example can be countered by other shows that do not conform to the stereotypes that you have presented. Incidentally, I really like Big Bang Theory, and I don't mind the show making fun of physicists.

If you read my column in the same issue of Pulse, then you would have discovered that I make a large distinction between science and engineering. Indeed, I have a great pride in the fact that I am more than a scientist. Engineers solve problems important to humanity using, among other things, tools provided by science. All too often, especially in biomedical engineering it seems, this distinction between science and engineering is not inculcated in the students, and I find that to be a shame on BME teachers. I don't think you are a scientist, but an engineer. You will do things to improve the lot of people around you, and you will belong to societies such as IEEE-EMBS that are engineering societies. You will find that medical personnel are in awe of your abilities, just as you admire theirs. There is no reason to hang your head low, because, as I have said to my students, "You can be a medical doctor, and save people one at a time, or be a biomedical engineer and save them a thousand at a time". That is your privilege.

Art Johnson

Sent Jan. 22, 2013:

Zen,

Please don't take my comments as criticism, because I do appreciate reading about your experiences. I was editor of the BMES newsletter when Matt Canver was an undergraduate student, and always looked forward to receiving his columns the same way I enjoy reading yours.

I agree that medicine can be much more exciting than science or engineering, except if you consider the mundane parts of medicine, such as seeing tens of patients a day with the flu, or burning a keratotic cell from someone's skin. However, engineers in the design process are much more mentally involved than are medical doctors in their typical practices. So, continue on with your studies and remember that you may someday give the medical doctors the tools they need to look like heroes.

Art Johnson

Sent on Nov. 12, 2013:

Zen,

I thought the essay that you had in the Sep/Oct issue of Pulse was one of the best that I have ever read. I am sorry to learn about the death of your grandfather, but the message that you conveyed separating the more immediate but trivial issues in life from the most important thing that life itself is priceless was very well illustrated.

I find that I am amazed by what we mean by life, and by self-awareness. Nobody really knows why or how, but in any case, life itself in all its forms is precious. You made this very clear in your excellent essay.

Art Johnson

Sent on Feb. 25, 2014:

Zen,

Once again your column has prompted me to respond. Your column about women in leadership was both poignant and honest, but I think you reached the wrong conclusion. Instead of resigning yourself to what you see as the inevitable bias against women in leadership positions, I think you are capable of rising above it. What you have gone through in perhaps your first major leadership position is really no different from what others go through in the same situation. Leadership is about taking personal risks. Many of us want to be liked by everyone around us, but sometimes leaders must face the dilemma of doing what needs to be done versus what is most popular. A real leader makes the first choice at the expense of the second. Realizing that some decisions will not be popularly received, one can steel oneself against the inevitable criticism, whether spoken or not. I can remember similar feelings when I first assumed a leadership position.

I, of course, am not a woman, so I can't speak directly to the issue of bias. I can say that many of us men today have been trying to eliminate such feelings from our psyches. Perhaps, I suggest, that a good part of the pressure that you felt was generated internally rather than from outside yourself. Perhaps that is one difference between men and woman: women are more sensitive to the feelings of others and to themselves than are many men. Consequently, women may be more cognizant of small unspoken cues radiated from those around them. Even if the cues are not meant to be critical, they can be interpreted that way.

Now that you have had that experience, you know more about what to expect the next time. That is where rising above perceived bias comes in. You know what to expect; now you must be able to deal with your own sensitivities. If you can do that, you can be the leader you had aspired to be.

One more thing: I had observed in others, and had experienced it myself, that it is sometimes easier to be on the fringes of leadership than to be the top dog. I can easily support some policies or procedures if I am a secretary or even vice president. When I am president, however, I must be careful to represent all views in my organization; I do not want to alienate entire segments of my organization. Thus, I must tone down my advocacy as president. You will find the same thing.

So, in conclusion, don't give up. Your dreams are worth fighting for. Be the person to whom others look up to and inspire other women to follow your lead. You can do it if it is important enough to learn how.

Art

Part 4

Teaching

The Noblest Profession

Arthur T. Johnson

Published in the ASEE-BIO Biomedical Engineering Newsletter, Fall 2012.

As an engineer who is proud of my profession, one of my favorite quotes is from Herbert Hoover, himself educated as a civil engineer:

It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege.

The great liability of the engineer compared to men of other professions is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope the people will forget. The engineer simply cannot deny he did it. If his works do not work, he is damned.

On the other hand, unlike the doctor, his is not a life among the weak. Unlike the soldier, destruction is not his purpose. Unlike the lawyer, quarrels are not his daily bread. To the engineer falls the job of clothing the bare bones of science with life, comfort, and hope. No doubt as the years go by people forget what engineer did it, even if they ever knew. Or some politician puts his name on it. Or they credit it to some promoter who used other people's money. But the engineer himself looks back at the unending stream of goodness which flows from his successes with satisfaction that few professions may know. And the verdict of his fellow professional is all the accolade he wants.

I have used this quote in several of my books and read it every year to my students in my Transport Process Design course. All too often we forget to express to our students the pride that comes with the positive accomplishments made by engineers, and how lucky they are to have chosen a college course of study leading to a profession associated with problem-solving, creativity, and good works. After my one lecture on ethics and professionalism, students have come to me and commented how appreciative they were that one of their professors had talked of such things. These comments reminded me of how much I was moved while myself a student at Cornell University by one of my teachers who repeatedly told his classes how privileged they all were to have a degree in engineering from that great university.

But, as proud I am of engineering, I am more proud of being a teacher. Teaching, I am convinced, is the noblest profession. Teachers of all kinds and at all levels impart knowledge and ability to their students. A great teacher influences her or his students in innumerable ways, all positive. That same teacher can be one of the most influential people in a student's life, and that influence can last a lifetime. There is not much in a negative way that can be said about teaching; even the worst of teachers can have good outcomes; there is hardly anyone who can't learn something that a teacher tries to teach.

The result of teaching is that the student is better able to be a valuable and productive citizen. The student learns how to channel energy and creativity in acceptable ways. The student learns how to become an individual who can make her or his way in this world, not becoming a burden on others, but contributing in some measure to the needs of society.

Who else but a teacher has the nearly unfettered opportunity to urge young people to accomplish great things with their lives? To make a difference because they were here? To change history for the better? To become the best that they can possibly be? Teachers are in a position to influence entire generations of great scientists, engineers, humanitarians, poets, lawyers, politicians, artists, parents, and even the next generation of teachers. Teachers can urge and inspire, enable and encourage, and stimulate creative and imaginative endeavors. What could be a better lot in life than this?

We have all had teachers who we remember fondly for the positive influences that they had on our lives. We remember the teachers who were tough, but fair. We remember the teachers who knew their materials amazingly well. We remember the teachers who were interested in us as individuals, despite the fact that we acted so immature at times. Good teachers are like that: they are competent at teaching, they like their students and get to know them as individuals; they are less interested in showing off how much they know than in seeing to it that we learn what we are supposed to; they are interesting to listen to, both in and out of class; they are open to learn, as well, from their students; they earn respect rather than obsess about popularity; they treat everyone fairly and equally; and they challenge each and every student to perform at the highest level to which they are capable. Good teachers are gems, and not to be taken for granted.

Many of us in college teaching also engage in research activities. We must write proposals, manage money and lab activities, publish papers, and, perhaps, even find important breakthrough results that can change the course of technology. But, as important and engaging as research is, and as much importance is attributed to research by our administrations, the most influence most of us will have in our careers, the greatest accomplishments that we will ever see, is in the students who have learned valuable lessons from us and, in turn, will pass these on to others. As teachers, our high privilege is not the things we produce, but the people who are better because of our efforts, and the investments we have made in their futures.

Threshold for Plagiarism

Arthur T. Johnson

Published in the IEEE Engineering in Medicine and Biology Magazine vol. 29(2) March/April 2010

The editorial on plagiarism (*"Don't Play It Again, Sam"*) in the September/October issue of *IEEE Engineering in Medicine and Biology Magazine* hit on several subjects for which I have much interest. I have served for many years on Student Honor Boards at the University of Maryland, and student dishonesty cases mostly concerned either exam cheating or plagiarism.

I found myself sympathetic towards freshmen accused of plagiarism when it was clear that high school teachers had encouraged them to include verbatim excerpts in their own papers, and no instructor at the University had yet explained to them what constituted plagiarism. On the other hand, upper class students who plagiarized certainly should have known better, and, consequently, they were given grades of "XF" in the offending courses ("F" for failure and "X" indicating dishonesty). They could have the "X" removed from their transcript by attending an Academic Integrity Seminar. Thus, the emphasis for the punishment was to teach them to modify their behavior for the better. Once the seminar was successfully completed, they could retake the course if they wished. The "F" would still remain for the first time they took the course.

I think that plagiarism needs to be defined differently for science and engineering compared to the arts. In the arts, words are used to convey feelings or particular interest in the arrangement of words; science and engineering use words to describe products or processes. It is difficult to achieve clear and adequate descriptions of products or processes without using the same words as previously used. The value of these words lies in rational interpretation rather than irrational emotion. Therefore, I would want to see lines from a poem included in quotation marks and given an acknowledgement of their source, but I would want neither quotation marks nor source attribution for the description of a hemostat.

It's similar to brand-name usage. Some brands, like "Jello", have become part of the common use vernacular. Other brands have not because their owners have taken great pains to protect the integrity of their brands. Once they transition into common usage, brands are no longer considered exclusive. Scientific and engineering descriptions usually carry with them the assumption of common usage.

That's why one must use duplication-search software with caution. There is no clear limit as to how many words can be duplicated before it is defined as plagiarism. Identical strings of two, three, or more words are not at all rare in descriptive writings. Identical strings of one hundred words would clearly indicate plagiarism. Somewhere between these limits is the threshold for plagiarism. In the arts, an identical pair of words not in quotes could well be plagiarism. It is hardly ever so in science and engineering.

There are other issues, too, that are more difficult to detect. Figures and drawings can be plagiarized as well as words. How much different does one drawing have to be from another in order that the two not be considered legally identical? My publisher says

40%, but it is really hard to recognize a 40% difference in a drawing. This is especially true, again, for a common-use, vanilla-type drawing.

So, it is good that we don't look too closely at the issue of plagiarism in the *IEEE Engineering in Medicine and Biology Magazine*. There is only quicksand on the path to the muck, and it is always better to begin with an assumption of honesty rather that a suspicion of guilt

Fostering Creativity

Arthur T. Johnson

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In this issue of the *Bulletin* appears the second of two articles by Dr. Paul Fagette about partnering with museums to give students experience with creative projects. Paul has in the past, shared stories about reverse engineering Willem Kolff's original hemodialysis machine and building reproductions of historic medical equipment. Paul's efforts are to be commended.

Engineering and science are not equivalent, as most of you realize. Engineering is first and foremost a creative profession, intended to solve problems of importance by using scientific knowledge to control outcomes in ways for which science is not primarily intended. Once the idea has been formed, science can be used for implementation. So, scientific knowledge is the means to the end of creating something real from an inspiration.

Look at engineering curricula. They are filled with physics, chemistry, mathematics, and engineering science courses. All of these courses are intended to establish and reinforce logical and rational thinking patterns in the minds of future engineers. These courses impose discipline on the unfettered creative mind.

Where in typical engineering curricula are the courses to exercise creative thinking, the courses that teach how to avoid limits, the courses that show how to recognize self-imposed box walls and to find means to think outside those walls? We have a few of these: capstone design experiences are meant to serve this purpose, as are underclass design projects. But are these really enough—can we begin to produce better engineering graduates if we put more emphasis on fostering creative spirit?

There are those who would argue that creativity is innate, and one major result of schooling from kindergarten through college is to substitute rules for creativity. Indeed, some of the most creative students cannot thrive in the engineering curriculum. The list of legendary drop-outs includes some of the most successful inventors, businessmen, and artists, topped, perhaps by William H. Gates. The list also includes far more people who have never achieved success. I do know, however, that some of my best communicators and imaginative students struggled in my courses. They went on to become lawyers and business leaders. Their talents did not match well with logical and rational thinking.

Like most of you who are faculty members in bioengineering or biomedical engineering, I have students in my classes who are capable of very high achievement. However, they seem to be more capable at researching and retrieving information than in generating it. They grew up in an environment where everything they wanted to know is available somewhere in the webosphere, and so they can write papers and lab reports that are superior to anything students could produce even a decade ago. Nevertheless, they can't distinguish between the shapes of the curves given by $e^{-t/\tau}$ and $(1- e^{-t/\tau})$, and I think that's because they haven't developed the ability to visualize information. This, to me, is a very real shortcoming for engineers.

Perhaps it is time to look at what talents we should foster in engineering, and to support industrial design, creative writing, sculpture, drama, and dance for our engineering students. Free thinking, by itself, is not guaranteed to solve engineering problems, but it can start the process. Maybe we should all talk to Paul Fagette and hear what he has to say.

Allowing Them to Fail

Arthur T. Johnson

Published in the BMES Bulletin, vol. 33(2), 2009.

I have long appreciated self-reliance. You do what you have to do, and you do it with what you have. You do the best you can, and, when that is not enough you dig deeper into your reserves. You do this to avoid failure, because you have experienced failure and have learned what it feels like to fail.

One of life's most important lessons is to learn the feeling of failure. A second lesson is to learn to overcome failure. A third is to learn the depths of one's own strength that can be called upon when failure is a real possibility. These lessons, and others like them, should be part of the educational process in which many of us are involved.

Without the possibility of failure, it is unlikely that one would learn to reach beyond his or her capabilities, to perform superhuman acts, and to accomplish much more than us mere mortals. It is the possibility of failure and the determination to avoid failing at all costs that moved the gymnast Kerri Strug to overcome ankle pain, and the swimmer Jason Lezak to set fatigue aside and to beat Alain Bernard by 0.08 seconds in the 2008 Olympics. I have been awestruck by the performance Jennifer Hudson gave in the movie "Dreamgirls," and by Wagner's Tannheuser. I have appreciated an elegant electronic design or an ingenious piece of computer code. Watching the A-10s piloted by members of our Maryland Air National Guard as they pass overhead, or seeing the beauty of a new car as it glides down the highway are to me amazing sights. They all have something in common, these arts and crafts; they all are examples of humans reaching for perfection, knowing that the wrong choice, a slip of a hand, or an unattained goal could doom them and their projects, perhaps even their entire futures, to failure. Those who match up against perfection, who run the risks of failure but are determined to succeed, who can find reserves of intellect and strength that they didn't know they had, who are on familiar terms with the penalties that failure brings, but who persevere anyway to overcome adversity, that's who I want on my team.

Success and failure are two sides to the same coin. Taking that coin from your pocketbook does not guarantee which side faces you, but, unless it is a trick coin, each side will emerge face up about half of the time.

We like to talk about success. Success inspires; success progresses. Bioengineering successes are what make us feel good about our profession and about our own works. Yet, we know that each success was hard-won. We know that we have failed many times, only to try again until the winning combination was found. We have been motivated by success, but goaded by failure. That is why we revise and resubmit those research proposals, why we rewrite those papers, and why we spend long hours in the lab perfecting techniques or many tedious hours trying to make those computer models come out as we think they should.

Those who haven't failed haven't tried anything, and there are those who nearly always make the safe choices that lead to neither failure nor success. Their idea of success is to avoid failure, but they will never really know success.

It is not uncommon that bio-based engineering programs in colleges and universities attract the brightest and most ambitious students. These are students who have known at least some measures of success. By the time they get to college, they have fine-tuned formulas for avoiding failure: try things they are good at, study hard, associate with similar-minded students, and figure out their instructors. Because of this, they are expected to succeed.

These are excellent students in my classes. They have excelled during every one of their scholastic years. They have succeeded at nearly all of their endeavors. They have played varsity sports, been first chairs in All-State bands and orchestras, elected as class leaders, edited newspapers and yearbooks, published scientific papers, and achieved Eagle Scout ranks. They were expected by the families, their friends, and their teachers to succeed. And succeed they did.

But sometimes expectations can be self-fulfilling. Sometimes the best and the brightest are cut some slack that the second tier are not. Sometimes, the best opportunities are given to those who one expects can make the most of them. Sometimes deadlines are allowed to slip if it is known that past project results have always exceeded expectations. Sometimes favors are given even without thinking about them. Sometimes failure doesn't happen because we don't let it.

That may be good for school, but the world is not like that. We know former colleagues who were denied tenure; we know consultants who lost contracts; we know people who have lost jobs to overseas outsourcing. Even the best baseball slugger misses hitting the ball two-thirds of the time, and at least one political candidate comes up short each election. The world is full of failure. Because of this, they are expected to succeed.

Many of us don't push these students hard enough. We don't offer the real possibility that they could fail despite their formulas for avoiding failure. We don't make it likely that they will find the depths to their capabilities because we often don't expect them to plumb these depths. The result is that we all avoid failure: the students because they have passed their courses and the faculty because we have successfully made it to the end of another term. As a result, our students find out that good enough is good enough.

It is easy enough as faculty members to take this path. After all, success for us is determined more by our number of funded proposals than by our teaching prowess. If we failed to give our brightest students A's or sprinkled a few D's and F's into our grades, the time we would have to take to explain to students, parents, and administrators why these grades were justified would be that much less time to devote to research.

Students need the real possibility of failure in order to find their mettle. They need to know that their fined-tuned formulas to avoid failure are sometimes not enough, that at times they need more, and they need to know assuredly that they have more if need be.

I am not saying that the bar must be placed so high that no one can succeed. Higher education is a time to revel in learning opportunities that lead to lifetime goals. It is also a time to grow and mature, and to meet challenges in the relatively benign environment of the classroom as practice for life after graduation, where penalties for failure are ever more severe.

Too much failure can be discouraging. No failure can lead to complacency. The real possibility of failure can spur motivation, and that is the type of failure that we should make possible for our students.

There are a lot of facts, figures, skills, and techniques that need to be learned before a college degree can be earned. There are soft skills, too, like learning to live on one's own, operating in teams, and managing one's time. Learning to cope with at least the possibility of failure should also be one of these, and it's best to learn this skill in the controlled confines of the classroom, before the stakes get too high later.

Excellent students can learn how to dig deeper, how to go beyond the comfort level, and how to cultivate grit when faced with the real possibility of failure. And, if they have given their utmost and failure still resulted, then they can learn how to live with that and move on to the next challenge. They can only do this if failure is a real possibility for them despite their histories of academic successes.

Last year I gave a design project at the end of my Electronics Design course that required students to meet a set of analog and digital specifications for the proper functioning of the circuit. Students typically spend a lot of time in the electronics lab learning to apply what they were taught during the semester. When successful, the circuit works as specified, but students don't always succeed at making the circuit work. One student, who had already spent all night trying to make the circuit work the way it was supposed to, asked what would happen if they were not able to successfully complete the design. I told him that as an engineer with an assignment that went unfulfilled he would not be paid for the job. He needed results; he needed to succeed or he would fail the project. He realized that failure was a real option and redoubled his efforts. He ran out of time, but was very close to finishing the project at the deadline. Later, he thanked me for being honest with him about the penalty for failure and that he found out that he could reach deep to produce a successful outcome.

It may be hard for students to accept that teachers are willing to let them hang until they either drop or rescue themselves, but in the long run most will be grateful. That's what tough love is all about. There is no greater gift that a teacher can give to his or her students than the gift of knowing themselves. Socrates talked about it thousands of years ago, and so did Edmund Hillary when he said he climbed Mount Everest "because it is there." If you let students know that what they do is serious, that the lives and health of present and future people will depend on their best efforts, then students may find new strengths and abilities to test themselves against the best. And there is no better way to instill seriousness than to have them realize that failure is an option that they must learn to avoid while the stakes are not overwhelming.

We all want our students to succeed. We are amazed with their abilities and accomplishments. We are all sure that they will someday discover new cures, save lives, become brilliant surgeons and Nobel laureates. Our own selves live on in our students. We really need to prepare them now for the challenges they will face later in life.

What Does it Take to Be a Good Biological Engineer?

Arthur T. Johnson

Appeared in the IBE Newsletter, vol. 12.2, Summer 2008

The story is recounted in the *Phi Kappa Phi Forum* about a Harvard University conference entitled "Keeping Kids in the Achievement Game" (Malone, 2008). John Merrow, President of Learning Matters, Inc., and a renowned education reporter for PBS and NPR, gave a compelling speech about the importance of quality teachers, holistic education, and the care and nurturing of our inner-city students. No sooner had he finished than a male high school student stood up and asked, "*Well, if all this is so important, how come my art got cut, and how come I haven't had a music program since the fourth grade?"*

How come, indeed! Apparently, the No Child Left Behind policy, with its formal standardized testing and rating of successful and unsuccessful schools has caused there to be increased instructional time in reading, writing, math, and science. What suffered was time devoted to arts, foreign languages, and social studies.

Without science and math, reading and writing, our students cannot be expected to survive in the 21st century world. Aren't they also at a disadvantage without art, history, music, and social and cultural legacies? The world is facing globalization: shouldn't we prepare the next generation to adapt with languages, global history, and appreciation for foreign contributions?

Emil de Cou, Associate Conductor for the National Symphony Orchestra, has said, "*I have yet to meet a teacher who thinks excluding the arts is a good idea. If you just memorize facts and figures, you're not contributing to society. You're a maker of widgets. The arts can be a divine spark that grows*." (Express, 2008).

Biological engineering, as some of us like to think, is a very broad integration of science, engineering, and biology. Not only do we expect biological engineering practitioners to be familiar with principles from fundamental physics, chemistry, engineering sciences, mathematics, and biology, but also much more. Biological engineers who truly represent the entire profession, and not just a small segment of it, should also know about ethics, aesthetics, emotional satisfaction, group dynamics, ecology, history, music, art, economics, and law. In other words, they should have some holistic view of the world; some systems concept of the grand scheme of things and how various parts fit together.

We have had several successful IBE meetings with myriad technical papers that reflect the reductionist segmentation of the field. I have gone to many of these presentations and wonder exactly what the speakers were talking about. I wondered why I was there, when I expected perspective and yet got only detail. Perhaps that is the nature of the game, but it makes me yearn for something more complete.

Perhaps that is what we can expect in the future as more and more of our high school students become more and more proficient in math and science, and less and less in cultural diversity. With art and music squeezed out, what chance do we have to maintain a broad view of biological engineering? How can we expect future biological engineers to be adept enough to anticipate reactive maneuvers and unintended consequences characteristic of living things?

Perhaps art and music do not directly contribute to versatility, but they help people to break the chains of constrictive thinking. The box that biological engineers need to operate in should have walls that are far removed from one another. Outside the box thinking should be the norm rather than the exception. If biological engineers cannot do this, then who can?

My Biology for Engineers course reflects this philosophy. It is not a cellular biology course; it is not an ecology course; it is not biomechanics, electrobiology, genetics, or biophysics. It is all of these and more. The reason for this is that just a little exposure to group ecology, beauty, human factors engineering, language, and others goes a long way toward expanding the box. Understanding of genes as only one possible intergenerational information legacy, and of birth as a resetting of a chaotic system to a common starting point gives new perspective on biological details repeated so many times in other courses that one loses a sense of the wonder about the completeness of the biological world. Looking at biology as a source of solutions to be worked with rather than a source of problems to be conquered offers hope that biological engineers can truly add to universal progress rather than to false starts and technological pitfalls.

We want us to be positive contributors. We want us to be appreciative of all the world around us and what it can offer. We need those who come after us to maintain this legacy of hope, vitality, and expression. We need to impart to them familiarity and appreciation for a broad education. We can do this in the home, in school, and in life, but we cannot condone extremism that excludes cultural appreciation.

Very few of us will win the Nobel Prize. I haven't given up hope yet, but there is nothing that I have done thus far to deserve such an honor. And it's not likely that I will ever achieve anything even close. But, as Arlo Guthrie has said, "*everyone's good for something*." I think it is more likely that the something that someone is good for depends strongly on the education and experiences they have in their formative years. Perhaps the something that we can be good at is to help the next generation to achieve greatness.

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Mr. or Ms. Janitor et al.

Arthur T. Johnson

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Toward the end of my Transport Processes Design course, between the times when all the necessary transport material had been taught but the final design project was not yet due, there was a day that I took to talk with the junior-level students about professional issues. I used as a framework for the discussion an old version of an IEEE code of ethics. Most professional engineering societies have codes of ethics, and some of them, including the present IEEE code, have become quite elaborate; the one I used was relatively simple.

In this presentation, I talked about professional responsibilities for practicing engineers; I talked about keeping their knowledge current and joining societies; I talked about whistle blowing, working for adequate compensation, and conflicts of interest; I talked about the actions of the Morton Thiokol engineers in the Challenger space shuttle disaster, and I talked about why engineering firms in Maryland found it cheaper to give kickbacks to then Baltimore County Chief Executive Spiro Agnew than to incur the overhead expenses of unfunded engineering proposals. I also talked about the engineer's responsibility to the public, and how an engineer was expected to give service to the public for free despite the fact that elsewhere in the ethics code it states that engineers shall perform their professional activities for fair and adequate compensation. I illustrated this provision by reminding the students that the tuition they paid for their excellent education at the university, as expensive as it was, covered only a portion of the costs, and that their educations were being underwritten in part by taxes paid by the citizens of the state of Maryland. Thus, they had a responsibility to the public to give of their expertise whenever it was appropriate.

But, more than that, I said, even the janitor who they see sweeping and mopping the floor each day, emptying the trash can, and cleaning the bathrooms, is helping to educate you the students. Students owe something to the janitor and to the others whose service is often overlooked.

As faculty members, we can easily point to some of the people and organizations without which we could not have achieved as much as we have. Some that come to mind are the National Science Foundation, National Institutes of Health, Howard Hughes Medical Institute, and other local, regional, and national funding agencies. We know that our graduate students and post-doctoral associates have also contributed important energy and ideas to our work. If we are lucky enough to have laboratory technicians or graduate teaching assistants, then they, too, are usually admittedly given a portion of the credit for our successes.

But what of the invisible people whose labors are often forgotten? Without them, conditions would become intolerable or, in the extreme, impossible. Yes, the janitors are part of that forgotten cohort, but so are the people who change the light bulbs in our offices and labs, or the plumbers who fix clogged toilets, or the painters who keep our facilities looking decent. There are the grounds people who beautify our campuses, or the highway people who patch the streets so that we can come to work or go home in our automobiles without a teeth-jarring ride. Even harder to appreciate are the police who occasionally give us tickets for infractions but who also protect our parking spots from interlopers. There is the waiter or waitress who serves us lunch, or the counter person at the fast-food joint, or, when we brown-bag our lunch, there is the janitor again who empties our garbage from the trash can.

These are just the people who we encounter directly. Of course, there are others who help supply our electricity, our clean running water, and the food that we eat. Let's not forget them. We depend on so many.

Everyone knows how good it feels to be complimented for the good work we have done. Recognition from the boss or from colleagues has very positive and salutary effects. There are people, such as the janitor or garbage collector, who are so far down on the social ladder that they don't often hear appreciation for the work that they do. They are, sadly, often ignored.

It only takes a short amount of time out of a busy schedule to take notice of the nice job that the janitor or the groundskeeper or the painter is doing. A word of recognition and encouragement is certainly in order. A little "thank you" can be important, not only for the recipient, but also for the one who says these words. These people not only make our lives easier, but, through their taxes, they may also be helping to pay our salaries. They deserve recognition. Oh, incidentally, my father was a janitor.

Math Aversion

Arthur T. Johnson

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Students in my Basic Electronic Design course had a difficult time distinguishing between the graphical representations of $e^{-t/\tau}$ and (1- $e^{-t/\tau}$). They had no gut feeling for either term; they didn't really know that the first decreases with time asymptotically to zero, but the second increases with time asymptotically to 1. These are very basic functions to electronics, chemistry, physics, and biology, and knowing what they mean is important to understanding of the world as it is. It took many quiz questions, and many wrong answers, before the majority of students could identify one from the other. Some students just memorized the answers.

Moving on to transfer functions, these juniors, who had completed three calculus courses plus differential equations, were flummoxed by the meanings of the equations; they had seen many of the terms before, but had no facility to visualize what they actually stood for. Many of them couldn't comprehend that the equations represented actual responses in the frequency and time domains because they couldn't translate from one to another. It took laboratory exercises to demonstrate to them what they could not comprehend in lecture. Again, some resorted to memorization.

Students in my Transport Process Design course would do anything they could to avoid having to deal with simple differential equations. We are talking here about first and second order differential equations with constant coefficients; they were not that complicated. Start talking about any calculus math at all, and students' eyes would begin to glaze.

I could relate somewhat to this attitude. When I was in high school, mathematics fascinated me (so did history, but that's not relevant here). I could calculate numbers easily in my head (a largely forgotten talent), but when I moved on to college, things started going a little flat. I was put in an advanced-level introductory calculus course, but it proved beyond me at the time. Once I dropped back to the normal-level course, things again righted themselves.

In those days, we engineering students were proud to walk across campus with our slide rule cases swinging to and fro from our belts. Those were the days before handy-dandy calculators, and we lived and died (not literally) by our slide rule prowess. We learned how to estimate numerical answers in our heads so that we knew where to place the decimal points in the answers that came up on our slide rules. Pi could be approximated by 3.0, and factors in the numerator were canceled with similar, but not identical, factors in the denominator. I became rather proficient at this, and still retain enough of this ability that I can sometimes use it to impress my calculator-dependent students, especially when I can approximate an answer before they can key in all their numbers.

I loved differential equations. There were rules and strategies that one could follow to find solutions of many of the more common types of differential equations, and I really liked the order and structure of the process. Because I liked this course, I developed a facility to solve these fun equations, even finding trigonometric substitutions and integration by parts relatively easily within my grasp. I disdained my fellow students who had to use integral look-up tables.

Things started turning for the worse when I took a statistics course in the math department and the only way that statistical tests were introduced was with equations; there was no reality to the course, no explanation of what these tests meant and how they could be used, and I sought out other mathematics majors in the course to inquire if they knew what it all meant; they couldn't tell me. Later, as a graduate student, I took advanced calculus with its Green's functions, kernels, and tensors; these baffled me, because I had no idea about where they could be used or why I should be studying them. In advanced heat transfer, with its Bessel functions, error functions, and Legendre polynomials, I longed for some basic and real understanding. I could not visualize how these higher-level monsters behaved, so they remained foreign to me. I started using look-up tables.

Skip now to a time when I had come to be a university professor. Two lessons occurred that helped me understand how mathematics is really practiced. Once, when I encountered a differential equation unfamiliar to me, I had to go to a fellow faculty member, a math professor, for help. I had tried to bone up on my rules and strategies for solving differential equations, but the solution to this equation still eluded me. Instead of following the ordered procedure toward a solution that I had learned many years before, he proceeded to guess at the answer and worked backward to see if his guess satisfied the equation that I had brought to him. I learned from this experience that familiarity with mathematical solutions made finding new solutions much easier. This mathematics expert was operating just like my engineering students when they worked backward from the answers to solve their homework problems. From that point on, when faced with a new mathematical modeling problem, I tried to start with a simplified permutation of the problem, one that I understood and could be confident of the correctness of the solution, and then add complexity one step at a time.

The second lesson came up when composing a worked example to include in my second book, *Biological Process Engineering: An Analogical Approach to Fluid Flow, Heat Transfer, and Mass Transfer in Biological Systems.* The problem involved conduction with temperature-dependent heat production, but the temperature-dependent part threw me. Anyone knows that the rate of biological heat production depends on temperature, so it was important to me to include this problem in the book.

Following the procedure learned from lesson number one, I simplified the problem and found answers that I was confident were correct. However, I couldn't get around the temperature-dependence difficulty. After many tries, I gave up, walked down to the math department, and consulted a professor there. He listened as I explained the problem, and once he understood what it was that I was asking, he did something I was not prepared for; he tried to look up the solution in *Mathematica*. Not finding the solution there, he declared that he could not help me. I left his office, disappointed that it had come to this, when even the math professors had to use look-up tables. I included this example in my book anyway, but it has no solution given there.

With the insights that my own experiences had given me, I had sympathy for my students with math-aversion. I have firmly convinced myself that it is a mistake to introduce an engineering subject purely mathematically. Before they have to deal with the strange language of mathematics, they need first to understand the concepts important to the subject. They need to develop the ability to visualize, if possible, or at least understand to a fundamental degree mechanisms or ways that things work. After that, mathematical descriptions can be taught as correlates to the basic concepts. Equations are just one possible description of the ideas making a product or process happen, although an efficient description at that. With this two-step approach, students can start to understand better both the basic concept and the mathematics.

For that reason, I have tried to incorporate conceptual thinking as the first step in my courses and in my books. You will see in *Biological Process Engineering*, that I have relied on a very visual conceptual approach to transport processes, and in *Biology for Engineers* that the mathematics is kept to a minimum. Engineers need intuition to invent new solutions, but they also need mathematical discipline to assure that these solutions are realizable. There is no substitute for either.

Why Biomedical Engineers Should Study Biology

Arthur T. Johnson

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Is it a waste of time for biomedical engineering students to study biology? A lot of BME educators seem to think so. In their opinions, physiology is sufficient; biomedical engineers should be thoroughly familiar with physiological processes of the human body, but there is little need for biological knowledge if it has no direct relevance to human physiology.

I can agree in part with these educators. There certainly is a lot of material taught in traditional biology courses for which it is hard to see relevance. After all, who needs to know about the ecosystem of an ocean reef, or the relationships among various segmented worms, or how plants convert sunlight energy and carbon dioxide into sugars? Having to spend time learning these seemingly irrelevant pieces of information, at the expense of not learning other, more pertinent facts, can be an unnecessary extravagance when there is only so much material that can fit into an already overcrowded undergraduate curriculum.

If the only thing that biomedical engineers did was to build cardiac defibrillators or MRI imaging systems, then these educators would be correct – taking biology would be a waste of time. However, the field of biomedical engineering is expanding rapidly into new applications hardly ever dreamt of several years ago. So called “personalized medicine” requires new DNA tests, detection of specific biomarkers requires knowledge about enzymes and biochemistry, neural engineering requires familiarity with emotions and personality, and holistic approaches require comprehension of ecological interactions. One cannot fully understand the full nature of these and other interrelated biological tendencies by taking only human physiology. There are some biological principles more basic than those found in a physiology course, and these can be learned in the right biology course.

The problem with many biology courses is that they are taught by biologists for biology students. These courses are taught largely the way they were taken as students by those now teaching them (of course the material has changed, but the paradigm remains largely the same). And that is fine, for biology students.

But engineers, not just biomedical engineers, but all engineers, need to know about biological principles in the same ways that they know about transport process principles, mechanical principles, electrical principles, or biomaterials principles. These principles form the concepts basic to engineering applications, and, when dealing with anything biological, it is good to know the likely outcomes for an idea before one spends much time or effort developing it.

Hence, the biology course that biomedical engineers should take is not the same biology course usually offered at the university. Rather, this course should emphasize basic biological principles, at all hierarchical levels, with an eye toward ultimate applications in engineering designs. The biomedical engineer should take from this course an appreciation for how biological systems work together. Developed correctly, this could be just as much an engineering science course as statics or heat transfer.

Certain biological principles are important to know about: competition, cooperation, optimization, communication, energy transformations, adaptation, and environmental interactions among them. Further, because biomedical engineers deal with whole human beings, some human psychology should be included. This course, similar to other courses taken at the undergraduate level, can present enough of the subject matter to be a useful terminal course, or could be an introductory course to subsequent courses taken later on. Certainly, such a course would make human physiology easier to teach and understand if taken after biology.

Every educational institution that I know has a list of required general education courses or categories to help round out a student's education and contribute to their worth as educated citizens. These courses have been derided by some as a waste of time. However, they add to student perspective, and are often appreciated more with time as careers progress. The general biology course that gives understanding of the biological world around us can give the same basic perspective that persists throughout an entire career.

What is the most desirable outcome of a biomedical engineering design? Certainly that design should include effectiveness, efficiency, biocompatible materials, acceptable operational features, easy installation, and a host of others. But one desirable feature is that it would work cooperatively with the intended biological system (usually human, including associated microbiome) rather than imposing upon that system. A good course in biology could help biomedical engineering students achieve better designs and realize more successful careers.

Is It Name or Content that Counts?

Arthur T. Johnson

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It just goes to show that not everyone knows what Biological Engineering is. The working definition that some of us use is that Biological Engineering is the discipline of engineering based on the science of biology, similar to Chemical Engineering and chemistry, Electrical Engineering and electricity, and Mechanical Engineering and mechanics, without any particular application in mind. But that's not the way the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET) sees it. Let me tell you how I know this.

In 2005, the Biological Resources Engineering (BRE) program at Maryland was reviewed under the Biological Engineering criteria and given a full six year accreditation in 2006. The program was apparently able to meet Biological Engineering requirements. In 2006, the undergraduate program was renamed "Bioengineering" and a few minor changes were made in required courses. The program still retained the broad and general flavor of the previous BRE program. All of the course requirements that I taught remained exactly the same. For those of you who know what I teach (Biology for Engineers, Basic Electronic Design, and Transport Process Design), you know that there is a little agriculture, a little environment, a little biotechnology, and a little biomedicine in each of these. That still remains.

We added an imaging course, a biomechanics course, and a physiological modeling course. We convinced the instructors of these courses that they should include material drawn from a wider range of applications than just medicine. We did the same for the bioinstrumentation course that was carried over from the previously-named BRE program.

We made such minor changes that our University Senate approved the changes locally without sending them to the Maryland Higher Education Commission. Our academic program code (CIP) remained the same as it was before (09030), designating the program academically as agricultural, biological, or biomedical engineering.

The change of name was prompted, as it often is, by local conditions, and because the students greatly preferred "Bioengineering" over "Biological Resources Engineering." Student interests may have changed somewhat with the different name, but even under BRE, 80-90% of our students had designated Biomedical Engineering or biotechnology as their primary interest. We presently describe our Bioengineering program to be Biological Engineering (broad, science based) and Biomedical Engineering (major application in health care). I know there are other Biological and Biosystems Engineering programs with similar profiles.

The next step was to request ABET to transfer our new BRE accreditation to the Bioengineering program. That is when we found out that it is name alone, and not content, that matters to ABET. The letter of refusal seemed to be self-contradictory:

"….this program as named now invokes a set of program criteria against which the program was not evaluated during its last comprehensive review." What does *name* have to do with *program criteria*? A lot, as it turns out; no, everything.

Something is wrong when ABET can presume to dictate acceptable names of programs. Something is wrong when Biological Engineering cannot include an application in human health care. Something is wrong when our ASABE (American Society of Agricultural and Biological Engineers) and BMES (Biomedical Engineering Society) representatives accept arbitrary distinctions that don't exist in many programs.

The refusal letter went on to say that because of our name, we cannot be accredited under the Biological Engineering criteria. ASABE, which is the lead society for Biological Engineering accreditation, and which in the past has sent program evaluators and gained a certain loyalty because of it, will no longer be the lead society for our accreditation. That seems to be very shortsighted and not a good omen for the society's future, because we tried as hard as we could to maintain the spirit and historical strengths of Agricultural and Biological Engineering. We doubt whether these will be understood by our new BMES accreditors, either. We have no choice but to be accredited according to our name and not our content. Goodbye ASABE, hello BMES. We hope you understand our unusual combination of curricular objectives.

The Obvious Answer

Arthur T. Johnson

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In his book titled "*Everything Is Obvious. Once You Know the Answer*", Duncan Watts posits that what we value as worthwhile is often determined by chance. He cites the case of the famous painting *Mona Lisa* that is now considered among the world's masterpieces, and hangs in a special place in the Musée du Louvre in Paris. For centuries, the *Mona Lisa* was of no particular interest, and was thought of as no more than an obscure painting by a second-rate artist. It was not until it was stolen from the Louvre in 1911 that attention was drawn to this work of art. Once it was seen to be valuable enough to be stolen, its popularity soared to its revered position today.

Watts also cited studies that showed that the popularity of music, books, or videos from among many possible competitors depends strongly on an accumulation of a few early samplings by others; once a trend starts to become apparent, later patrons want to see what the fuss is all about, and so add to the apparent popularity of the item. In positive-feedback fashion, early success begets later success.

That life is chaotic in the mathematical sense is well known. Later outcomes depend very strongly on the many choices, some quite insignificant at the time, that are made earlier. Environment, and its consequent variations, determines, to a large part, what are the final outcomes. In my own career, a series of choices about where to go to college, who to marry, where to live, and how to express my urge to activism led to becoming President of the Alliance for Engineering in Medicine and Biology (AEMB – the forerunner of AIMBE), of the Institute for Biological Engineering, of the International Society for Respiratory Protection, and the Secretary of the Biomedical Engineering Society, among others. When I look back over my career, I can see how some choices made earlier, if chosen differently, could have changed my life pathway completely. What happened earlier mostly determined what happened later.

MIT's Dr. Nam Su once said that individual birth is a resetting process, that each life begins anew at the basic genetic potential of the species without the corrupting influence of environmental options. For the most part, this seems likely. However, with the important discovery of epigenetic changes in gene expression, it has become apparent that birth is not completely a reset. Agent orange exposure in Viet Nam, and now asthma, have been shown to affect several subsequent generations. Our progeny can also be affected by our own choices.

There is one rather mundane application of the ideas in Watts's book. If the obviousness of what we know is determined by prior knowledge, then it would seem that we can improve our teaching if we disclose to our students the problem solutions before we show them how to arrive at the answers. I had tried a little of this in my book, "*Biological Process Engineering. An Analogical Approach to Fluid Flow, Heat Transfer, and Mass Transfer Applied to Biological*

Systems", where I gave some illustrative examples of applications of basic transport concepts to fluid flow, heat transfer, and mass transfer at the end of the first chapter on basics and before the subsequent chapters dedicated to each of the transport topics. Once they know the answers, students can often figure out their own methods for arriving at the known answers, as we all know. Knowing the answers ahead of the methods is also what makes so effective the technique of teaching starting with case studies.

Another application of Watts's conjecture is the mistake made by many presenters at technical meetings; they give their oral presentations in the same order as the written papers that they publish. Listen to these, and you will hear: 1) introduction, 2) methods, 3) results, and 4) conclusions. This is a mistake; the audience does not have the luxury of flipping a page or two to read of the outcomes of the study before focusing on the methods. They need to know the answers before the methods to be able to follow the presentation well. Instead of the typical presentation scheme, the presenter should give: 1) introduction, 2) conclusions, 3) methods, 4) results, and 5) conclusions repeated. The presenter could say something like, "These are my conclusions, and this is how I arrived at them". In this way, the gentle audience can know where the talk will end up and be more attentive as a result.

Knowing the answer ahead of the means to arrive at it is important when there are so many possible choices that guidance is called for. With this in mind, we can all become better writers, teachers, speakers, and even life planners. Setting of long-term goals is, in some sense, knowing the tentative answers to a long process of achieving them. Then, all that's needed is to figure out the choices to make to get there.

The Raving

Arthur T. Johnson

Given as a final examination in a graduate Instrumentation Systems course.

Once within my research meeting, while my thoughts were weak and fleeting,
Over many a quaint and familiar host of forgotten lore -
While I nodded, nearly napping, suddenly there came a tapping,
As from my advisor rapping, rapping at my vision's door -
"'Tis some revenant," I sputtered, "tapping at my vision's door –
Only this and nothing more."

Ah, distinctly I remember it was in the bleak December;
And each musing's dying demur wrought its part into my snore.
Eagerly I wished the ending; - vainly I had tried mind bending
From my psyche pulling, rending - rending of my thoughts galore –
To that rare and radiant moment when this meeting be no more –
Endless here for evermore.

Presently the noise grew stronger: hesitating then no longer
"Sir," said I, "I am pained, truly your forgiveness I implore;
But you caught me lightly napping, and so gently you came rapping,
And so faintly you came tapping, tapping to dissolve my bore,
That I scarce was sure I heard you - now my eyes are wide once more;
No need there is to shout and roar."

Returning to the world around, speaking no longer any sound;
Pensive, and receptive to instructions given twice before.
He towered before me glaring, moving not and stiffly staring,
Uttered words no longer sparing, shaking me unto my core, -
"Your assignment measures knowledge that you've taken into your core -
It's that simple, and no more."

"Out in Utah there's a lake, its elevation you need to take;
Fluctuating with sporadic rainfall events that came before –
Digital data sent through space from such remote a place
Removed, distant from the base; location of our laboratory door
Power consumption must be small, far from our laboratory door;
Save that power evermore!

"Transmit data every fortnight, when request it, as you might;
From past diurnal events; use computer, I implore,
Show how to do this thing; block diagram, specs, and everything;
Written solution you need to bring, bring to my office door
In seven days at noon without excuse bring to my office door –
Or it's up a creek without an oar."

As I sat engaged in guessing, but no syllable expressing
To the prof whose fiery words now burned into my very core,
This and more I sat divining, with my head no more reclining
Fully aware of my new assignment to be brought to his office door.
How I loathed that unkempt office with the hard wood office door
The sign attached says: Nevermore

The Shaming of the True

Arthur T. Johnson

Given as a final examination in a graduate Instrumentation Systems course.

Dramatis Personae

C LORD
B LORD   Persons in the Inducti
A LORD
BAPTISMAL, a rich gentleman of Paddock
PINOCCHIO, a wooden-headed gentlemen of Pizza
ENGINEIRIO, a stalwart technologio, played by the ENBE 601 student
KATHERINIO, feeder of the shrews
MARK ANTONIO, character from another play who changes his first name to "San" and adopts a surname moniker of TEX.
SAGGITARIO, the hunter
SERVANTS, quite a few

SCENE - Paddock, a large country estate in central Italio.

INDUCTION

Inside an alehouse
A LORD, B LORD, AND O LORD sit before the hearth.

A LORD. 'Tis a wager the rogues may bet; Before he tire
And gently to his bed doth go.
That within a week or so,
Bethink of a means to salve old Sire's woe.

B LORD. And a more weighty burden cannot be so,
For the wealthy inhabitant of that great estate
Has seen fit to be the unwitting host to guests of great number,
Although the shrews acknowledge not his hospitality.

O LORD. What can be done to tame his troubles?
Solv'd in a blink as time goes.
Yet, my Lord, as the ale is clear'd before the glass is fill'd
I'll take your wager that the scholar, looking on with consternation,
Has the means to employ a correct response,
To this final examination.

A LORD. Should the Heavens be aligned so regular that nary an error wilt be made?

Nay, your wager is on. My shekels support the pessimist
foretelling inappropriate rejoinment.

ACT I.

Paddock. The Villa
Enter BAPTISMAL and PINOCHHIO walking together

BAPTISMAL. Pinocchio, since for the great desire I had
To see fair Paddock, from fruitful Lombardy,
The pleasant garden of great Italy,
And, by my father's love and leave,
Have stay'd these years within these villa walls,
Remov'd from the merchants of Venice in another play.
Yet my offspring Katherino has habits
Undesirable for my quiet years.

PINOCHHIO. Say it again, Sam.

BAPTISMAL. Nay. Who can remember? But Katherino
Consumes crackers in her bed.
Her crumbs she drops beneath the sheets
In slobbery, disarray,
Leaving them for servant hands to clean,
With no thot to the attraction she poses for villa vermin.

PINOCHHIO. Can you not arrest her untidy habits, my friend?

BAPTISMAL. Wait. You have not heard all.
When by her hand she has made one bed discomfortable,
She moves to another, and yet another,
Until all one hundred one rooms of the villa
Have succumbed.
Villa vermin are everywhere!

PINOCCHIO. Uncouth habits indeed.
She is so headstrong,
That even young Petruchio cannot crack her.
My sympathy for your plight.

ACT II.

Paddock. The Villa.
BAPTISMAL sits in his chair.
SAGGITARIO knocks on the door.

BAPTISMAL. Who is there?

SAGGITARIO (from outside the door). Comand.

BAPTISMAL. Comand, who?

SAGGITARIO. Comand open the door.

BAPTISMAL. I am glad to see you, Saggitario.
Here to rid the villa of vermin.
Ye'll have no trouble finding your prey.
They are omnipresent I fear.

SAGGITARIO. Cas'd the villa, I did.
'Twill be a difficult hunt.
For the vermin scute hither and yon,
Moving from pile to pile and room to room
Full of cracker crumbs and comfy sheets.
Before I ply my trade,
And rid this villa of vermin,
We must know if they are German.
I know what I'll do;
I'll call my buddy Engineirio.

ACT III.

Paddock. One room in the villa.
SAGGITARIO and ENGINEIRIO are talking.

SAGGITARIO. And this I propose to you,
To monitor these villa vermin
Sense the presence of each tiny mouse,
And where it is within the house.
Keep track of movement this way and that
As they try to avoid the cat.

ENGINEIRIO. How do you wish me to begin?
It seems like a job t'me.

SAGGITARIO. Sense mouse movement as cheaply as you can,
In all one hundred and one rooms.
Monitor in one location in the far wing,
With special alarms for animal activity in the pantry or library.
I must know whereabouts of the scum,
Before I can rid them from this place.

ENGINEIRIO.How large are they?
Can they scute thru the walls?
To see or not to see?
Shall I nuc'em where they stand?

SAGGITARIO.All kinds are here and all sizes too.
They are in the walls and on the floor.
'Tis not necessary to see'em.
Nay, no nuc, leave the fun for me.

ENGINEIRIO and SAGGITARIO.
[This dialog is ad libitum in the classroom setting.]

ENGINEIRIO.I think I can.
I think I can.

SAGGITARIO.Sir, we will be victorious, in this villa.

[Exeunt]

The Red Hombre

Arthur T. Johnson

Given as a final examination in a graduate Instrumentation Systems course.

Captain First Rank Marko Ramirez of the Paraguayan Navy was dressed for the special occasion to occur later that day. Five layers of louse-infested castaway uniform parts enclosed his slightly-bloated body. A filthy harbor tug sputtered its engines as it pushed ever so gently against the *Red Hombre*. It was the first mission for the first submarine in Paraguayan history. On its decks was a diverse collection of ragtag paramilitary adventurers who would soon discover that the decks of submarines do not stay dry for long.

"Engines ahead slow, Karlos," he ordered. Karlos fumbled. Ramirez frowned. Karlos was not quite sure he knew where the engine control was located. Ramirez frowned on, afraid that Karlos would ask the question of him. With a frown on his face, Ramirez looked formidable. Karlos never asked.

The submarine slid from her contact with the filthy harbor tug and began slowly plying the waters of filthy harbor. The *Red Hombre* was a sight to behold. Made from scraps bought at yard sales around the world and smuggled into Paraguay, the submarine was at once majestic and cobbled.

The sub was the same inside. Where instrument panels would have been found in other ships, large areas of emptiness presented themselves. Karlos did not know what to make of it. Ramirez knew that nothing had been made of it.

"Get me some assistants," said Ramirez. "This sub needs instruments. Without them we're lost." Karlos obeyed quickly. He contacted the ENBE 601 class, knowing that help could be gotten there cheaply.

"Never mind that you have a final examination coming up," he intoned. "We need your help with some instrumentation issues. What we need are the answers to some problems that I know you can answer. Without them, we can't hope to escape from filthy harbor. With them, we can move to new places and you can escape from ENBE 601. Neither you nor we can lose. Here is the list:"

1. Propose a means to measure the volume flow rate of a liquid flowing through a pipe using transit time ultrasonic flow measurements. Diagram the system completely, using only components that you studied in this course. Fully describe the operation of each element and interfacing considerations between components. The system should terminate in a digital display of flow rate.
2. Describe the three means to transmit separate data values: separating values in time, space, and frequency. What types of hardware are required for each? Compare their merits. Show where each is more advantageous than the others to use.
3. Discuss impedance issues. What care needs to be taken that impedances of two connected components are not mismatched? Give examples of

nonelectrical impedances that are important in your work.

4. If you were to purchase a digital data acquisition system, what are some of the important details that you should consider before buying?

Part 5
Professional Societies

American Institute for Medical and Biological Engineering (AIMBE)

Medical Engineering Societies and Organizations

Arthur T. Johnson and Patricia I. Horner

Excerpted from Medical Engineering Societies and Organizations, in Encyclopedia of Medical Devices and Instrumentation, J. G. Webster, ed., John Wiley and Sons, NewYork, pp. 311-321 (2006).

Introduction

Modern technology has transformed the practice of medicine. We can now see where we could not before, conduct surgery with minimal trauma, intervene at the genetic level, replace whole natural organs with functional artificial ones, make rapid diagnoses, and peer into the workings of the brain. More patients are surviving, and those who do are living better. Much of the credit for these advances goes to the engineers, physicians, and physiologists who together decided what needed to be done, the science required to support it, and how it could be made practical. Medical engineers are now very much involved in the process of developing medical advances. They bring to medicine the abilities of conceptualization, computation, and commercialization. They use varied tools such as biophysics, applied mathematics, physiological modeling, bioinstrumentation and control, imaging, and biomechanics to accomplish their advances.

The result is that there are nearly as many subspecialties of medical engineering as there are medical specialties. Tissue engineers, for instance, grow bioartificial tissues and organs as replacements; metabolic engineers find means to adjust cellular metabolic pathways to produce greater quantities of biochemicals and hormones; and rehabilitation engineers design new prostheses or modify existing units to reestablish adequate function in patients who have lost ability usually as the result of trauma. There are medical engineers working with biosensors, bioprocess optimization, multiple imaging modes, pancreatic function, vascular replacement, and drug delivery. Biomaterials engineers have produced materials that can function in different regional corporal environments. Indeed, there is no part of the human body that has not been studied by medical engineers to improve or replace lost function.

As the body of medical knowledge has increased overall and has been repeatedly split more and more finely into specialties, there has been a concomitant proliferation of organizations to communicate, share, and advocate action related to their particular specialties. Some of these would be recognized as chiefly engineering organizations with application interests in medicine; some are medical societies with significant engineering contributions. There is almost no significant human disease, physiological system, organ, or function without a group or organization representing associated interests. There is even a group interested in developing synthetic biological forms that, although it is too premature to link with medicine, may someday have a profound effect on medicine. All of these groups can be found by searching the Internet, and any attempt to enumerate them here would be outdated very quickly.

Definitions

Progress in biological science and engineering has not been made with a clear distinction between medical and non-medical applications. Advances in human medicine often find applications as well in veterinary medicine. Genetic coding techniques have been applied equally to humans and fruit flies. Prospective biomaterials are modeled on computer without regard for the ultimate specific application, and they are tested in animals, plants, or fungi before approval for human use. Progress toward better nutrition through science, and toward purer environments through improved pollutant detection monitoring, have resulted in better human health for most humans living in the developed world. Biology is biology, whether applied to human health care or not, so a convergence of basic knowledge and methods between medical and biological engineers is expected to continue.

Several relevant definitions attempt to distinguish among various fields where engineers have and will continue to contribute.

The U.S. National Institutes for Health (NIH) has the following definition of bioengineering:

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 U.S. National Science Foundation program in Biochemical Engineering and Biotechnology (BEB) describes its program in the following 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).

The Whitaker Foundation definition of biomedical engineering is as follows:

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.*

And, finally, the Institute of Biological Engineering (IBE) defines biological engineering as follows:

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 emerging discipline of biological engineering lies at the interfaces of biological sciences, engineering sciences, mathematics and computational sciences. It applies biological systems to enhance the quality and diversity of life.

Historical Developments

In 1948, in New York City, a group of engineers from the Instrument Society of America (ISA) and the American Institute of Electrical Engineers (AIEE), with professional interests in the areas of X-ray and radiation apparatus used in medicine, held the First Annual Conference on Medical Electronics. Soon thereafter the Institute of Radio Engineers (IRE), joined with the ISA and AIEE, and the series of annual meetings continued. Subsequent years witnessed a remarkable growth of interest in biomedical engineering and participation by other technical associations. By 1968 the original core group evolved into the Joint Committee on Engineering in Medicine and Biology (JCEMB), with five adherent national society members: the Instrument Society of America (ISA), the Institute of Electrical and Electronics Engineers, Inc. (IEEE), the American Society of Mechanical Engineers (ASME), the American Institute of Chemical Engineers (AIChE), and the Association for the Advancement of Medical Instrumentation (AAMI), who jointly conducted the Annual Conference on Engineering in Medicine and Biology (ACEMB).

Professional groups responded vigorously to the demands of the times. Attendance at the annual conference by natural scientists and medical practitioners grew to approximately 40% of the total; medical associations requested formal participation with their technical counterparts on the JCEMB. New interdisciplinary organizations were formed. New intrasociety and intersociety groups, committees, and councils became active; meetings filled the calendar; and publications overflowed the shelves.

In 1968, a document was prepared that read as follows:

WHEREAS:

1. Common interdisciplinary purposes cannot be well served by individual groups working independently from each other;
2. Certain associations have developed in attempts to meet the need;
3. Conferences and publications have proliferated in attempts to meet the needs;

4. At present, no mutually satisfactory mechanism exists for the coordination of the relevant groups and functions;
5. There does exist an annual meeting and proceedings publication sponsored by a limited number societies through the Joint Committee on Engineering in Medicine and Biology (JCEMB);
6. The JCEMB is formally structured with a constitution, plural societal representation, and an established pattern of operation. This structure and pattern of operation, however, are not deemed adequate to fulfill present and future needs. To the best of our knowledge, there exists no other single organization that seems capable of fulfilling these needs.

THEREFORE, it is appropriate that a new organization be established.

On July 21, 1969, at the 22nd ACEMB in Chicago, Illinois, representatives of 14 national engineering, scientific, and medical associations founded the Alliance for Engineering in Medicine and Biology (AEMB). It was incorporated on December 24, 1969, in Washington, D.C. Lester Goodman, Ph.D., served as Founder President in1970-1971; Arthur C. Beall, MD (1972); Alan R. Kahn, MD (1973); Harry S. Lipscomb, MD (1974); Anthony Sances, Jr., Ph.D. (1975); Charles Weller, MD (1976-1977); Edward J. Hinman, MD MPH (1978-1979); Paul W. Mayer, MD (1980-1982); Francis M. Long, Ph.D. (1983-1984); Arthur T. Johnson, PE, PhD (1985-1988); and Alfred R. Potvin, PE, Ph.D. served as the final President in 1989-1990.

The Alliance operations were determined by an Administrative Council composed of delegates from each of its affiliates. Later the Alliance was to consist of more than 20 such organizations:

Aerospace Medical Association (ASMA)
American Academy of Orthopaedic Surgeons (AAOS)
American Association of Physicists in Medicine (AAPM)
American College of Chest Physicians (ACCP)
American College of Physicians (ACP)
American College of Radiology (ACR)
American College of Surgeons (ACS)
American Institute of Aeronautics and Astronautics (AIAA)
American Institute of Biological Sciences (AIBS)
American Institute of Chemical Engineers (AIChE)
American Institute of Ultrasound in Medicine (AIUM)
American Society for Artificial Internal Organs (ASAIO)
American Society for Engineering Education (ASEE)
American Society for Hospital Engineers of the American Hospital Association (ASHE)
American Society for Testing and Materials (ASTM)
American Society of Agricultural Engineers (ASAE)
American Society of Civil Engineers (ASCE)

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)
American Society of Internal Medicine (ASIM)
American Society of Mechanical Engineers (ASME)
Association for the Advancement of Medical Instrumentation (AAMI)
Biomedical Engineering Society (BMES)
Institute of Electrical and Electronics Engineers (IEEE)
Instrument Society of America (ISA)
National Association of Bioengineers (NAB)
Neuroelectric Society (NES)
RESNA – Rehabilitation Engineering & Assistive Technology Society of North America
Society for Advanced Medical Systems, now American Medical Informatics Association (AMIA)
Society for Experimental Stress Analysis (SESA)
SPIE – International Society for Optical Engineering
Alpha Eta Mu Beta – National Biomedical Engineering Student Honor Society, established under the auspices of AEMB.

The Alliance headquarters office opened on November 1, 1973. John H. Busser served as the first Executive Director. Patricia I. Horner served as Assistant Director, as Administrative Director, and succeeded Busser as the Executive Director. Among its goals, is the following excerpted in part from its constitution, bylaws, and recorded minutes:

To promote cooperation among associations that have an active interest in the interaction of Engineering and the physical sciences with medicine and the biological sciences in enhancement of biomedical knowledge and health care.
To establish an environment and mechanisms whereby people from relevant various disciplines can be motivated and stimulated to work together
To respond to the needs of its member societies, as expressed by their delegates, rather than to seek authoritative preeminence in its domain of interest…
To support and enhance the professional activities of its membership…

The 23rd ACEMB in Washington, D.C., in 1970, was the first held under the aegis of the Alliance. From 1979 to 1984, the IEEE Engineering in Medicine and Biology Society (EMBS) held their conferences immediately preceding the ACEMB. The Society for Advanced Medical Systems, later to become AMIA, and the Biomedical Engineering Society also held their meetings for several years in conjunction with the ACEMB.

The accomplishments of the Alliance far outstripped the expectations of its founders. The Alliance more than fulfilled responsibilities for the annual conference inherited from the predecessor JCEMB, but the Alliance made important contributions through a variety of studies and publications ranging from a 5-year ultrasound research and development agendum to a guideline for technology procurement in health-care institutions:

- First International Biomedical Engineering Workshop Series held in Dubrovnik, Yugoslavia, under the sponsorship of the National Science Foundation. This project was in cooperation with AIBS and the International Institute of Biomedical Engineering in Paris. Five workshops were held, and planning handbooks were completed.
- Assessment of selected medical instrumentation; Tasks 1 – 4, ultrasonic diagnostic imaging; Task 5, radiologic and radionuclide imaging technology.
- Summary guidelines and courses on technology procurement; practices and procedures for improving productivity in research and health-care institutions.
- Information exchange and problem assessments in medical ultrasound, including preparation and distribution of a directory of federal activities, conducted instrumentation conferences, delineated training needs, assessed technology transfer potential, and prepared guidelines for the establishment of clinical ultrasound facilities.
- Joint U.S. – Egypt international technology transfer project in medical diagnostic ultrasound, including international workshops and the design and support of a focus laboratory for ultrasonic diagnosis at Cairo University Medical School.
- Short courses for continuing education at the annual conference on engineering in medicine and biology.
- International directory of biomedical engineers.

Before long, the proliferation of medical engineers, and competing interests among societies, led to a fragmentation of the field. It became clear that the Alliance no longer represented positions of the entire field. No organized group could speak for the entire profession, and the spirit of unity that had led to the development of AEMB no longer existed. It was time for a new beginning.

American Institute for Medical and Biological Engineering
In 1988, the National Science Foundation funded a grant to develop an infrastructure for bioengineering in the United States. The AEMB, jointly with the U.S. National Committee on Biomechanics (USNCB), was to develop a unifying organization for bioengineering in the United States. The co-principal investigators were Robert M. Nerem and Arthur T. Johnson, and Patricia Horner served as Project Director. The AEMB/USNCB Steering Committee consisted of Robert M. Nerem, Arthur T. Johnson, Michael J. Ackerman, Gilbert B. Devey, Clifford E. Brubaker, Morton H. Friedman, Dov Jaron, Winfred M. Phillips, Alfred R. Potvin, Jerome S. Schultz, and Savio L-Y Woo. The Steering Committee met in January and March 1989, and the first workshop was held in August 1989. Two more Steering Committee meetings were held in December 1989 and March 1990, and the second workshop was held in July 1990. The outcome of these two workshops was to establish the American Institute for Medical and Biological Engineering (AIMBE). All AEMB members voted to cease operation of the Alliance for Engineering in Medicine and Biology in 1990 and to transfer the AEMB assets and 501c3 status to AIMBE in 1991.

AIMBE opened an office in Washington, D.C., in 1995 with Kevin O'Connor as Executive Director. He was succeeded by Arthur T. Johnson in 2004 and Patricia Ford-Roegner in 2005. AIMBE Presidents have been as follows: Robert Nerem(1992-1993), Pierre Galletti (1994), Jerome Schultz (1995), Winfred Phillips (1996), Larry McIntire (1997), William Hendee (1998), John Linehan (1999), Shu Chien (2000), Peer Portner (2001), Buddy Ratner (2002), Arthur Coury (2003), Don Giddens (2004), Thomas Harris (2005), and Herbert Voigt (2006).

Representing over 75,000 bioengineers, the AIMBE seeks to serve and coordinate a broad constituency of medical and biological scientists and practitioners, scientific and engineering societies, academic departments, and industries. Practical engagement of medical and biological engineers within the AIMBE ranges from the fields of clinical medicine to food, agriculture, and environmental bioremediation.

AIMBE's mission is to

- Promote awareness of the field and its contributions to society in terms of new technologies that improve medical care and produce more and higher quality food for people throughout the world.
- Work with lawmakers, government agencies, and other professional groups to promote public policies that further advancements in the field.
- Strive to improve intersociety relations and cooperation within the field.
- Promote the national interest in science, engineering, and education.
- Recognize individual and group achievements and contributions to medical and biological engineering.

AIMBE is composed of four sections:

- The College of Fellows – 1000 Persons who are the outstanding bioengineers in academic, industry, and government. These leaders in the field have distinguished themselves through their contributions in research, industrial practice, and/or education. Most Fellows come from the United States, but there are international Fellows.
- The Academic Council – Universities with educational programs in bioengineering at the graduate or undergraduate level. Currently there are approximately 85 member institutions. Representative to the Council generally are chairs of their departments. Many also are members of the College of Fellows. The Council considers issues ranging from curricular standards and accreditation to employment of graduates and funding for graduate study.
- The Council of Societies – The AIMBE's mechanism coordinating interaction among 19 scientific organizations in medical and biological engineering. The purposes of the Council are to provide a collaborative forum for the establishment of society member positions on issues affecting the field of medical and biological engineering, to foster intersociety dialog and cooperation that provides a cohesive public representation for medical and biological engineering, and to provide a way to coordinate activities of member societies with the activities of academia,

government, the health-care sector, industry, and the public and private biomedical communities.

- The Industry Council – A forum for dialog among industry, academia, and government to identify and act on common interests that will advance the field of medical and biological engineering and contribute to public health and welfare. Industrial organizations may be members of the Industry Council if they have substantial and continuing professional interest in the field of medical and biological engineering.

Current members of the Council of Societies are as follows:

American Association of Physicists in Medicine
American College of Clinical Engineering
American Institute of Chemical engineers; Food, Pharmaceutical and Bioengineering Division
American Medical Informatics Association
American Society of Agricultural and Biological Engineers
American Society for Artificial Internal Organs
American Society for Biomechanics
American Society of Mechanical Engineers, Bioengineering Division
Biomedical Engineering Society
Controlled Release Society
IEEE Engineering in Medicine and Biology Society
Institute of Biological Engineering
International Society for Magnetic Resonance in Medicine
Orthopaedic Research Society
Rehabilitation Engineering and Assistive Technology Society Of North America
Society for Biomaterials
SPIE: The International Society for Optical Engineering
Surfaces in Biomaterials Foundation

Current members of the Industry Council are as follows:

Biomet, Inc.
Boston Scientific Corporation
Genzyme Corporation
Medtronic, Inc.
Pequot Ventures
Smith + Nephew
Vyteris, Inc.
Wright Medical Technology, Inc.
Zimmer, Inc.

The AIMBE Board of Directors oversees the work of the College of Fellows and the three councils. The Board consists of a President who is assisted by two Past Presidents, the President-Elect, four Vice-Presidents at Large, a Secretary-Treasurer, and the Chair of the College of Fellows – all of whom are elected by the Fellows. The Board also includes chairs of the other councils and chairs of all standing committees. AIMBE's day-to-day operations are supervised by the Executive Director in the Washington headquarters.

AIMBE's Annual Event each winter in Washington, D.C., provides a forum on the organization's activities and is a showcase for key developments in medical and biological engineering. The annual event includes a 1-day scientific symposium sponsored by the College of Fellows, a ceremony to induct the newly elected Fellows, and a 1-day series of business meetings focused on public policy and other issues of interest to AIMBE's constituents. For additional information about AIMBE's mission, memberships, and accomplishments, visit http://www.aimbe.org.

The AIMBE has focused on public policy issues associated with medical and biological engineering. The AIMBE enjoys high credibility and respect based on the stature of its Fellows, support from constituent societies, and its intention to be a forum for the best interests of the entire field. The AIMBE has taken positions on several important issues and advocated that they be adopted by various agencies and by Congress. A few of the AIMBE's public policy initiatives that have met with success are as follows:

- National Institute of Biomedical Imaging and Bioengineering (NIBIB) – Created in 2000 with the help of AIMBE advocacy, the NIBIB has received strong support from the AIMBE and other institutions that value the role of technology in medicine, particularly the Academy of Radiological Research. The NIBIB has experienced rapid growth and development in all areas, including scientific programs, science administration, and operational infrastructure. The prognosis for the near future is continued growth and development especially in bioengineering, imaging, and interdisciplinary biomedical research and training programs.
- FDA Modernization Act (FDAMA) – Enacted in 1997, this legislation amended the Federal Food, Drug, and Cosmetic Act relation to the regulation of food, drugs, devices, and biological products. FDAMA enhanced the FDA's mission in ways that recognized the Agency would be operating in a twenty-first century characterized by increasing technological, trade, and public health complexities.
- Biomaterials Access Assurance Act – The 1998 legislation provides relief for materials suppliers to manufacturers of implanted medical devices by allowing those suppliers to be dismissed from lawsuits in which they are named if they meet the statutory definition of a "biomaterials supplier".
- National Institutes of Health Bioengineering Consortium (BECON) – This is the focus of bioengineering activities at the NIH. The Consortium consists of senior-level representatives from all NIH institutes, centers, and divisions plus representatives of other Federal agencies concerned with biomedical research and development. The BECON is administered by NIBIB.

The AIMBE Hall of Fame was established in 2005 to recognize and celebrate the most important medical and biological engineering achievements contributing to the quality of life. The Hall of Fame provides tangible evidence of the contributions of medical and biological engineering during the following decades:

1. 1950s and earlier
    - Artificial kidney
    - X ray
    - Cardiac pacemaker
    - Cardiopulmonary bypass
    - Antibiotic production technology
    - Defibrillator

2. 1960s
    - Heart valve replacement
    - Intraocular lens
    - Ultrasound
    - Vascular grafts
    - Blood analysis and processing

3. 1970s

- Computer-assisted tomography (CT)
- Artificial hip and knee replacement
- Balloon catheter
- Endoscopy
- Biological plant/food engineering

4. 1980s

- Magnetic resonance imaging (MRI)
- Laser surgery
- Vascular stents
- Recombinant therapeutics

5. 1990s

- Genomic sequencing and micro-arrays
- Positron emission tomography
- Image-guided surgery

The AIMBE has now turned its attention to Barriers to Further Innovation. It is providing forums and platforms for identification and discussion of obstacles standing in the way of advances in medical and biological engineering. Barriers could be procedures, policies, attitudes, or information and education, anything that can yield when AIMBE constituents apply pressure at appropriate levels.

What Is AIMBE All About?

Arthur T. Johnson

Appeared in the AIMBE News vol. 2004(1) September 2004.

When we first set up AIMBE, we had a vague idea of bringing together all the professional and technical societies representing medical and biological engineering. What was needed was a unified voice representing the entire field; until that voice was heard, there were many voices, each assuming to represent all or part of the field. So, after a seemingly long and arduous process, AIMBE came into being.

Today that central core of AIMBE is represented by the Council of Societies (COS), which has been more or less successful in bringing together the major players in medical and biological engineering. It was through the COS and its interests that AIMBE took on various public policy issues of interest to the field. In concert with other allies, we had major successes in federal legislation dealing with biomaterials and the establishment of the National Institute for Biomedical Imaging and Bioengineering (NIBIB). It took efforts by the combined membership of all the constituent societies of AIMBE to achieve those successes. So, if pressed to give the major function of AIMBE, most would say “public policy”, and they would be correct.

However, it doesn’t stop there. So after it looked like AIMBE would be formed, it was suggested that there be a recognition function for AIMBE. There would be a College of Fellows, representing the most distinguished 5% of the field of medical and biological engineering. These Fellows could serve as a technical and professional oracle for the field. An AIMBE Fellow was distinguished by the fact that she or he was selected by the entire field, and not just one segment or another. Soon, it became apparent that there was also a need for a very distinguished award coming from the entire field. That led to the establishment of the Pierre Galletti Award, in honor of the distinguished recipients, and also memorializing our second AIMBE President. Hence, AIMBE has also assumed an important recognition function for the entire field of medical and biological engineering.

The Academic Council (AC) was the next to be suggested. There already was a Council of Chairs of ABET accredited undergraduate biomedical engineering programs. That group had been able to discuss issues of common concern and coordinate responses. Wouldn’t it be useful if there could be a body within AIMBE that was representative of all the programs, accredited or not, undergraduate or graduate, in medical and biological engineering? Such a body could be used to share ideas, discuss common problems, and contribute to improvement of the effectiveness of medical and biological engineering academic issues. The AC publishes its annual job survey, has dealt with NSF funding of academic research, has caused *US News and World Report* to modify its rankings of biomedical engineering academic programs, has discussed curricular issues, and is looking into problems of entry into the US of foreign graduate students. The AC has been a very active organ of AIMBE that has expanded greatly the activities and functions of AIMBE.

The Industry Council (IC) was conceived as an organ to represent the common positions of the industrial segment of medical and biological engineering. In particular, the positions of the medical device industry have been made known. It was thought that the IC should not duplicate other representative industry organizations, but could be effective by representing industrial positions filtered through the non-self-serving perspective of the entire AIMBE organization. The health of industries in medical and biological engineering is important for us all, so the IC can be an essential part of AIMBE. Over the years, the IC has contributed to the biomaterials effort, to technology transfer, to FDA regulatory reform, and to refuting junk science in the courtroom.

Let us not forget the AIMBE Annual Event. Originally conceived as a forum that went beyond the technical meetings of AIMBE constituent societies, the Annual Event has become the premier venue for discussion of the interplay between technology and policy. Perspectives gained during the two days of the meeting are important for formation of appropriate legislation, management of research efforts, and appreciation of the effects of technology on our society.

AIMBE thus has a number of important functions that one could expect from an energetic organization that coordinates an entire field. It has accomplished a great deal, but the best is yet to come. There are a number of issues that are to come before the AIMBE Board that are bound to reinvigorate AIMBE and make it much more effective. This will take your support; please consider the AIMBE Capital Fund Campaign about which you can read elsewhere in this newsletter. Also, we need your energy and expertise; please volunteer them.

What is AIMBE all about? It is about issues that concern all of us, that together we can make a real difference.

A Matter of Balance

Arthur T. Johnson

Appeared in the 8 June 2006 (2006:1) issue of the AIMBE Newsletter.

Back when Bob Nerem (as Chair of the U.S. Committee on Biomechanics) and I (as President of the Alliance for Engineering in Medicine and Biology) were given the charge from NSF to come up with a plan to unify the many voices claiming to represent bioengineering, the biggest hurdle as we saw it was to bring the many interested technical societies together in a non-threatening way. The new organization, if there was to be one, had to be clearly distinguished from member-oriented technical groups. And so, after many long and tenuous negotiations, AIMBE was formed as an organization without open membership and centered on public policy rather than technology.

Of course, the public policies that were of importance were those related to medical and biological engineering (MBE), and so had a technical foundation. Although AIMBE is primarily *not* a technical society, technical issues still had to be understood to propose and support the best public policies of that time.

The largest group of AIMBE members, the Fellows, were by and large selected based upon their technical accomplishments. Just reading Fellow induction citations confirms that very few Fellows are selected for achievements other than technical works. Some Fellows have moved on to interests of a more public affairs nature, but many still retain their primary interests in technical issues. This, then, forms the inherent paradox within AIMBE's mission: the role of the organization is to be primarily public policy, but the interests of a large portion, if not the majority, of its members are technical.

Very few of us are conversant with the wide range of technical issues pertinent to MBE public policy decisions. In recognition of this fact, past AIMBE meetings have been highly technical, but with a difference. Presentations given at AIMBE meetings have been more similar to keynote addresses at technical society meetings than to individual papers. The very reputation of AIMBE has allowed us to hear from preeminent experts in particular fields, and their talks have included perspectives on history, future, and implications of their subjects. So, AIMBE, a public policy organization, has conducted some of the best technical meetings that could be found.

The bylaws of AIMBE state that the purposes of the organization shall be to:

1. Promote public awareness of medical and biological engineering.
2. Establish liaison with government agencies and other professional groups.
3. Improve intersociety relations and cooperation within the field of medical and biological engineering.
4. Serve and promote the national interests in science, engineering, and education.
5. Recognize individual and group achievements and contributions to the field of medical and biological engineering.

As I read them, the bylaws neither prohibit technical interests and activities nor limit AIMBE to public policy issues. Indeed, as set forth in the bylaws, the purposes of AIMBE are closely aligned to education, cooperation, and recognition related to MBE.

AIMBE shall not infringe on the technical activities of its member societies, but neither should it ignore the technical foundations upon which our econotechnological society rest. Like living systems themselves, somewhere between the extremes of technology divorced from its public implications and public policy unrelated to technology lies the most fertile ground for survival and growth.

I have heard comments reacting to Annual Event content: some say that they are not interested in all this public policy stuff. Others say that we need to have more public policy and fewer technical talks. These reflect the breadth of MBE as well as its elite.

Under the heading of "you can't satisfy all the people all of the time," neither of the above commenters is likely to be completely satisfied. AIMBE must strive for a balance incorporating the technical issues of the day and their public policy implications. It is this tie that makes AIMBE unique. We cannot afford to stray far from the middle ground, because to do so would lose distinctions we have from other successful and well-established groups.

AIMBE's public policy goals make it effective, but so do its non-partisan technical experts. With this unique combination of interests, we may come to agree with Melvin Kranzberg, who said "*Technology is neither good nor bad, nor is it neutral.*"

AIMBE as the Reliable Source

Arthur T. Johnson

Appeared in the September 2007 issue of the AIMBE News.

The AIMBE Federal Symposium, sponsored by the Council of Societies, had presentations from industry, including one on the beneficial effects of pharmaceuticals in modern health care. As far as I recall, he did not refer to pharmaceuticals as "drugs," nor did he present any data that disparaged the industry he represented or the products that they dispensed. For slide after slide he wove a wonderful tale of success and health through chemistry.

His message was so glowing, so convincing, that I nearly rushed out to the nearest CVS Pharmacy to fill myself with the elixirs of which he spoke. It was only the fact that I was occupying an interior seat and next to me was the most comfortable medical and biological engineer in the whole room that prevented me from pushing my way past. I am not so good at the vault.

But the more I listened, the more I wondered about the source of his data. Let's see: he was talking about pharmaceuticals and he represented Pharma, the organization representing the pharmaceutical industry. I'll bet the source of his information was the very companies that manufactured and marketed the drugs that he spoke about

And there is the rub: if we had gone the next day to talk to our Congresspeople and had parroted the message we heard, 1) I don't think it would all have been believed, and 2) that would have weakened the believability of everything else we said. And it's not just pharmaceuticals; Advamed, representing medical device industries, has a similarly-glowing report about the use of medical devices in health care; BIO, the Biotechnology Industry Organization, would tell you only the best things about genetically-modified organisms. Wonderful as they are, they are not the final answer to all the questions we need to ask.

Messages coming from an industry group may or not be self-serving, may or may not be biased, and may or may not misrepresent the entire picture. They may or may not be these things but they certainly arouse suspicions that there is another side not being told.

AIMBE has an Industry Council, but AIMBE does not represent an industry segment. AIMBE also has a College of Fellows, Council of Societies, and Academic Council, and, because of that, it can be an effective independent organization to present reliable information concerning medical and biological engineering (MBE).

I cannot say that AIMBE has an unbiased stance, because AIMBE exists to promote MBE. But AIMBE should be able to present the warts along with the wonder workings of any particular MBE technology.

To view AIMBE as a quality-assurance organization that can substantiate effectiveness claims stretches the role of AIMBE, at least operationally. We have never in the past have had anyone working for AIMBE who could spend a considerable amount of time researching claims, independently checking data, and writing reports based on the findings. Congress used to have its Office of Technology Assessment (OTA), but that is long gone. There is a void that AIMBE could usefully fill. If funding can be found to employ such a person, AIMBE might garner additional attention and respect from the government, the media, and the public.

To maintain a reputation of honesty and reliability, however, AIMBE must be careful that funding for this person can come with few, if any, strings. Like Caesar's wife, there can be no reproach, no besmirching of reputation. AIMBE cannot become another Pharma, Advamed, or BIO. Information coming from AIMBE needs to be correct, verifiable, and believable. This can be done. It is a role AIMBE was meant to play.

The Weak Sister

Arthur T. Johnson

Appeared in the 10 January 2007 issue of the AIMBE News.

Joe Bronzino used to argue that the name "biomedical engineering" was all-inclusive, because it included both "bio" and "medical." Thus, he used to say biomedical engineers were those who deal with either/or both medical or non-medical biological applications. In those days I thought that names were important, so my retort to him was that, practically speaking, whenever people said "biomedical engineering," they meant medical applications.

When AIMBE was still in the process of development, we had a number of workshops wherein we invited a number of leaders in the field to discuss how a new organization could be formed to bring everyone together despite the Balkinization that was occurring. One of the most divisive issues we discussed was what this new organization would be called. Of course, one of the favorites included the term "biomedical engineering." Another favorite was "bioengineering." The discussions were heated, animated, and repetitive, as one can imagine. Every argument and counterargument was articulated at least three or four times. After a good long while it was suggested that we use as a model the International Federation for Medical and Biological Engineering. What better way to include everyone?

As with all good compromises, nobody liked this one. And so it was, when we broke for lunch.

I was not there when it happened, but, somehow during that break, a number of people got together and decided that "medical and biological engineering" was about as good as it was going to get. So, shortly after lunch the "American Institute for Medical and Biological Engineering" was agreed upon. Al Potvin was assigned the duty to design the logo (which was changed in 2005), and the conversation turned to mission and mechanics. As chair of the bylaws committee, I was to capture the essences of comments made about mission and reduce them to reasonable form.

Nowhere in AIMBE foundational documents will you find the term "biomedical engineering." Everywhere you will find "medical and biological engineering." The intention was to bring groups with similar interests together, and similar interests meant a substantial and continuing interest in medical and biological engineering (MBE); no more, no less.

In the first few years of AIMBE operation, the concern was inclusion of medical doctors (MDs), and we struggled with Fellow nominations to fulfill our goals. After a few years, concern shifted to industry representation, and since then we have tried to establish means to augment the number of industry Fellows.

I think our efforts should now turn to biological engineers. This group is seriously underrepresented in AIMBE (especially considering that biological engineering is linked equally with medical engineering in the AIMBE name and foundational documents). We have relatively few biological engineering Fellows, AIMBE meeting topics are all slated to medical engineering, and the term "biomedical engineering" creeps into AIMBE literature more than it should.

Just as a reminder about who we are talking about, biological engineers are those who engineer with living things that are not likely to have a direct link to medicine. They are biochemical engineers, environmental engineers, agricultural engineers, metabolic engineers, human factors engineers, and food engineers, just to name a few. They contribute to the nation's health and safety by assuring safe food, clean air and water, proper sanitation, alternative fuels, and environmentally-sustainable industrial products produced from living things. They keep people out of hospitals rather than treat those who are unfortunately in hospitals. They prevent diseases and accidents, and contribute in untold ways to the health of our surroundings as well as to the health of each human being. They develop new technologies and test ones that can't be used on humans until proven safe and effective. They deal with animals, plants, microbes, and derivatives. They have a lot to say to us, and we have a lot to tell them. We need each other.

As the field of biology continues to permeate more and more of our lives, the economics of biological engineering grows rapidly. At some point there will be a biological engineering industry with a net worth greater than medical engineering.

AIMBE needs more biological engineering involvement. AIMBE needs to be a catalyst to promote discussion and cooperation among medical engineers and biological engineers. AIMBE needs to be involved in regulating and public policy discourse related to biological engineering. It needs more biological engineering Fellows and biological engineering industry representatives. It also needs to seek out more professional societies representing biological engineering.

Enzymes act to bring biochemical components together so that they can react and be joined. AIMBE should be the enzyme for medical and biological engineering. That's the way we thought it should be.

Fostering Biological Engineering

Arthur T. Johnson

Published in the AIMBE News, 2007.

Medical and biological engineering—the phrase is beginning to catch on. It took quite a few years for AIMBE to accept the biological engineering part of this phrase, but right now it is drifting in the right direction. There is a lot of overlap between the two, and it should be part of AIMBE's mission to educate the world that we are not representing two fields, but one. Medical engineering really is what most of us routinely call "biomedical engineering" when we speak of engineering applied to human health care delivery. As such, it is an applications discipline, specifically directed to the particular use of human health. Biological engineering is the more generic term, an engineering discipline based upon the science of biology with many possible applications. As such, it is a science-based discipline. So, medical and biological engineering represents an engineering discipline that rests upon the science of biology with its major application in human health care.

And now the first disclaimer: I have been around long enough to know that there are those who have other definitions for all of these terms, and others besides. So, it wouldn't surprise me if a few of these grab my lapel when they see me and point out the errors of my ways. I shall not be moved.

Now permit me to suggest how AIMBE can assert leadership in the field of medical and biological engineering, and that is to promote the message that these two are one and are inseparable in the holistic view of human health.

Take the National Institutes of Health, for instance. NIH, with "Health" in its title, really is concerned with *restoring* health, not *guarding* it or *maintaining* it. But health to the vast majority of Americans is maintained through adequate diet, sanitation, and exercise. Sure, there are millions who contract disease, suffer traumatic accidents, or are prone to genetic weakness. But, there are hundreds of millions of Americans who don't because they eat healthy food, have flush toilets, and move around a bit. We have gotten so inured to these commonplace things that we take them for granted. When a few of us get sick or die from tainted spinach, it's a big deal. When the toilets don't flush, we are quick to show disgust. When we don't exercise enough, we all become fat ("obese" is the acceptable euphemism), and throw our hands up in resignation.

Yet, as dependent as the health of this nation is on nutritious food and clean water, the National Institutes of Health barely notice. If there isn't a named disease, there is scant attention. AIMBE should act to fix that.

Looking at the other side of the coin, the United States Department of Agriculture and the Environmental Protection Agency both give some recognition to the importance of their activities to maintain human health. USDA sponsors human food nutrition research and EPA regulates pesticide use on human food. AIMBE needs to support these agencies and help the public realize their importance.

Making a more nutritious steak is not nearly as glamorous as allowing a disabled person to walk again or as restoring sight to the visually impaired. But glamour and rock-steady dependability do not easily walk hand-in-hand. AIMBE can help people realize that there is importance in the seemingly mundane, and a great, big payoff for those who contribute to keeping people out of hospitals.

There are volunteers in the AIMBE organization who apparently still do not know that biological engineering includes applications remote to human medical care. Recent Fellows nominations have been rejected because the nominees' activities were not closely enough related to biomedicine. There was no indication that nominees' credentials were searched for substantial and continuing activity relating engineering to biology. AIMBE still has a lot of education challenge in-house.

Why can't a biological engineer working with biofuels be an AIMBE Fellow? Why not someone who works to remove nitrates from groundwater? Why not a protector of exotic species? Why not someone who develops biomimetic adhesives (as Geckos use to climb walls)?

Now the second disclaimer: although I have strongly advocated the biological engineering side of MBE, my own teaching and research has been more biomedically oriented. I have taken the positions I have because I believe enough attention has not been directed to biological engineering and that biological engineers deserve more recognition than they have gotten. I believe that looking at the whole system has advantages for understanding, and biological engineering, at least as far as I understand it, gives an opportunity to look at the entire system.

Several years ago, AIMBE gave special recognition to Dr. Norman Borlaug, the father of the green revolution. Because of the work of Dr. Borlaug, more people in the world are eating healthy food. AIMBE could follow up this recognition by establishing an award to honor those whose MBE activities have helped to keep us safe and healthy every day, day in and day out. And, with such an award could come press releases that tell of the overwhelming successes that such people have had to keep us safe and well. Now that's a message all should hear.

Who Should Belong to AIMBE

Arthur T. Johnson

Appeared in the January 2005 issue (vol. 2005:1) of the AIMBE Newsletter

"*Our perception is that AIMBE is primarily an academic and research-oriented organization*." This is what I was told by an officer of one of our constituent societies, and it stung more because his society members were mostly practitioners. I suppose an academic and research society is fine for academics and researchers, but we have lots of those societies in our field. AIMBE, to me, should be more.

AIMBE is not the American Institute for Academic Biomedical Engineering. It is, instead, the American Institute for Medical and Biological Engineering, founded to serve the needs (especially public policy needs) of a broad constituency comprising biomedical engineering research and education, biological engineering, biotechnology, medical and industrial practitioners, and all others with a substantial and continuing interest in the broad field of medical and biological engineering.

Have we lost touch with our roots? Maybe a little bit. When AIMBE was first established, we worried about including MDs in our Fellows and in our Board of Directors. I haven't heard even a smidgen of this concern in recent years. We have also lost touch with some of our member societies, especially those outside the biomedical engineering mainstream. I have tried to rectify this a bit by contacting each of our societies and talking about improving relations. There are other societies that should be brought into the fold to make AIMBE a more effective umbrella for the broad field of medical and biomedical engineering.

Oh, and did I mention industry? I belong to two practitioner societies and five others largely populated by academics. There isn't an academic society that isn't concerned with bringing in more industry folks. AIMBE is doing somewhat better than most of these, and that indicates that AIMBE has not yet contracted into an organization of academics and researchers, but we must be energetic in our efforts to keep from doing so. We have been extremely fortunate to have had some very dedicated industry leaders who have seen value in AIMBE and who have kept the Industry Council alive. People like Al Potvin, Dane Miller, Paul Citron, and Vince DeCaprio come to mind. If only we could multiply their numbers. . . .

The point of all this is that AIMBE is an organization with a complex set of goals and objectives. It is needed because we have to synergize efforts related to our common interests. We need energy and dedication from all of engineering related to medicine and biology, including academics, practitioners, and industry. And, whether our immediate goal is to influence public policy to remove barriers to innovation, or to compile information about employment opportunities, or to enhance technology transfers from lab to industry, representation from each of our constituencies is necessary to make AIMBE effective. I hope we can all agree on that.

One Little Step for an Engineer

Arthur T. Johnson

Appeared in the 18 April 2007 issue of the AIMBE News.

Without a doubt there was a lot of energy at the AIMBE meeting this year. But, there always is. Now that we are all back home and in our normal comfortable environments, whatever passion we had for the commonweal has cooled and we are back in our own little worlds. But, it always happens that way. If only we in AIMBE could sustain our drive on behalf of medical and biological engineering (MBE), how much more AIMBE could do, and how much stronger our influence would be. But, that does not appear to be the natural order of things.

There was, however, something new at this meeting. Jonathan Moreno mentioned something about getting involved at a very personal level, about the dirth of real science and engineering expertise in organizations such as the think tanks of the Washington, D.C. area. He explained how these organizations write papers, give advice, and guide public policy related to science and engineering without themselves being constrained by real expertise in these subjects. Then he casually mentioned that we in the audience would all be very welcome to submit our CVs to organizations of our choice—be they on the political right, left, or in between—and act as consultants on science and engineering issues.

This idea has appeal. For many of the gray-haired folk listening to him, their careers are at the stage where they could seriously consider such a move. Their research, teaching, administrative efforts, and professional lives have come to the point where there is not a lot more to be proven. Experience and expertise have amassed to the point where they clearly form the major portion of their ongoing professional contributions. Wouldn't it be great to use these skills and judgments where they are in short supply?

For those of us who heard Dr. Moreno, the message he delivered had a lot of appeal; I heard a number of conversations where the idea of joining some of these organizations was being seriously discussed. For those of you who weren't there, perhaps it is time for you, too, to make a modest change in direction of your professional life.

But, now the AIMBE Annual Event is over; we are all back in our comfortable familiar environments. There is no sense acting upon feelings that were aroused at AIMBE, because the world of mundane issues has closed in again. Excitement, inspiration, and passion have again been pushed aside, to remain in the background until the next AIMBE meeting next year.

But wouldn't it have been fun for us, and great for AIMBE, if we had just taken that next step.

When Scientists Get Involved in Public Policy

Arthur T. Johnson

Published in the BMES Bulletin vol. 33(3) 2009.

Daniel Sarewitz has written that "*the notion that science can be used to reconcile political disputes is fundamentally flawed*." He writes this is an *American Scientist* article in which he posits that scientific testimony on public policy issues often does not clarify the issues, and in many cases makes them more poorly understood (Sarewitz, 2006).

He goes on to say that disagreements among scientists over methods, data, and conclusions are commonly caused by differences in values held by scientists. Whether a policy should be enacted depends also on the point of view. Views on whether or not to allow genetically altered crops in agriculture would depend on whether the scientist is a nutritionist, an ecologist, an economist, or an agronomist, for example.

Scientists who testify at hearings before a public policy is enacted will almost always bring their values to the table and support them with legitimate facts. It is almost unheard of that all scientists will agree totally on any issue, so the appearance that is presented to the public is "dueling scientists" who are not a lot of help.

It is to the credit of politicians that they are able to establish meaningful public policies when all the facts are not known. Scientists, says Sarewitz, may be able to alert the public to an impending problem of which they have no prior notice, but otherwise should probably be involved in support of public goals after consensus is reached through public discussion. Scientists can then help chart the way toward achieving these goals.

One major difference between science and engineering is that engineers must reach conclusions about product or process design despite incomplete knowledge. The scientific literature is replete with conclusions that, at best, represent tentative outcomes based on the measured data. It is only after many such papers, with sufficient replication of essential data, that scientific conclusions are respected as reflections of truth. Even at that, scientific conclusions can still be influenced by the point of view of the writer.

There is no question that AIMBE must advocate positions of interest to its members when public policy is being formulated. However, forming completely independent positions on the issues can replace "dueling scientists" with "dueling advocacy groups." To be effective, we have already found coalition and cooperation to be invaluable. Forming alliances with other groups with interests similar to our own must continue to be our best strategy. Likewise, we must mobilize our member organizations to speak out on the issues with coordinated voices. This is the strength of AIMBE: it is not the organization itself; rather it is the amalgam of many independent voices chanting the same chorus.

Reference

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American Society for Agricultural and Biological Engineers (ASABE)

What Does It Take to Become a Vampire?

Arthur T. Johnson

Published as part of NABEC paper 13-078 (2013).

When I was a kid, I wanted to be something really cool for Halloween. Among my friends there were going to be many hobos, super heroes, Hollywood starlets, and clowns, but I wanted to become something threatening, something that would scare the pants off all the little tykes we would see trick-or-treating around the neighborhood. No siree, I did not want to be at all friendly; I wanted to be as terrifying as I could. So, I decided to be a vampire.

I went to the store and bought one of those cheap little sets of false front teeth with the long incisors. They certainly did make my teeth look like what I expected from a vampire. Really scary! And that would have been as far as I had to go if I only had to show my mouth. But the rest of my face was the same as it always was – maybe ugly to some, but much too familiar to me. It didn't look like a vampire's face, even with the sharp, pointy teeth.

Back to the store I went. This time I had to look harder to find some green- and black-colored grease paint. They were a lot more expensive than were the false teeth, but I bought them anyway. Bringing them home, I applied them liberally to my face in what I thought should be the way a vampire's face should look. Yes, that made my face look a lot more scary. Along with the teeth, I was definitely going to scare those little kids. Ah, what fun I was going to have that Halloween.

But still, my costume was wrong. I could only muster up a dark tee-shirt and one set of jeans that didn't have too many holes worn in them. They would never do. Vampires did not spend their unholy existences looking like some poor farm boy with a face green from tasting his first cigarette out behind the barn. No, vampires wore cool outfits with high collars and capes. I tried taking a clean sheet from the linen closet and making a cape from it. First, it wouldn't stand up around my collar; second, it was white, and what I needed was something dark, black if I could get it; third, I managed to get green grease paint all over it. I was going to be in big trouble once Mom found out. I hid the soiled sheet in the bottom of the clothes hamper for now. We'd have to take the consequences later. Anyway, back to the stores.

Well, not quite. I needed first to remove the grease paint from my face before appearing in public. I didn't want store clerks to run screaming from me when I needed their help. Broad daylight would not have helped, maybe even made matters worse. Besides, I didn't want to ruin my Halloween surprise by letting anyone see what I had in mind.

Unfortunately, that's when I realized that in my eagerness to coat my face with green face paint, I should have applied a layer of cold cream first. That grease paint was so hard to remove. Perhaps the extra sweat from all the scrubbing helped. All I know is that it took six clean wash cloths to get most of it off. My raw face looked like it had been scorched in the sun all day, and the wash cloths looked all green. The bottom of the clothes hamper was beginning to fill up and there was going to be a very nasty scene once Mom found out. Still, I had to persist.

I broke into my savings. The costume with the shiny black pants, black shirt, vest, and black cape lined in red was very expensive, but I had to have it. I came home without a lot of money, but carrying a believable vampire outfit.

Now, I was ready. When Halloween came, I gathered all my costume parts, painted my face (over cold cream this time), inserted my pointy false teeth, and donned my black clothes with the sexy red-lined black cape. A little black shoe polish in my hair slicked it back just the way it was supposed to look. I was really finally ready.

That dark night I hid in the bushes, ready to jump out and scare the bejesus out of all those little kids. But, it didn't work. My voice was too high and I couldn't scream just right; I didn't have the right kind of moves. The little kids may have been a little scared, but not enough to justify all the money and trouble I put into becoming a believable vampire.

So, I learned my lesson: if you want to become a vampire, you have to act like one.

And the same is true of ASABE: if you want to be a society of biological engineers, you have to act like one.

ASABE as the Biosystems Engineering Society

Arthur T. Johnson

Published in the ASABE Resource September/October 2012 issue, vol. 19, no. 5, p. 4.

Dear Editor,

Regarding the article by Jeong-Yeol Yoon in the May/June 2012 issue of *Resource* (Who We Are and What We Can Do), much of what he writes is right on the mark. ASABE has a very strong history of dealing with biological systems. As agricultural engineers, we had been educated to view the entire system of inputs and outputs, mostly biological in nature, but not always. We had courses in machinery, but those courses were different from machinery courses taken by mechanical engineering students; they included mechanical properties of plants and animals. We had courses on soil and water topics, but these were different from water courses taken by civil engineering students; they included water needs of plants growing in soils. We took courses in structures and environment, but these courses were different from structures and environmental courses taken by mechanical engineers or civil engineers; they included environmental interactions between plants, animals, and physical conditions.

There is need for a society, some society, to represent the field of engineering related to biological systems at all levels. The best positioned society to fill this need is ASABE. We have people who are experts in plant modeling, animal modeling, and insect modeling, all related to environmental conditions of the real world. There is no other society that has as large a concentration of expertise in engineering of the complete system of biology as has ASABE.

There are three other primary societies with the words "biology" and "engineering" in their names (not counting AIMBE, which is a secondary society). The first is the Institute of Biological Engineering (IBE). IBE was formed as a community of ASAE (as was its name at the time), but differences arose between the ASAE Board of Directors and the IBE Council, so IBE split from ASAE. Some hope that IBE could one day reconcile with ASABE, but that is not going to be possible. Despite having foundational statements that it serves biological engineering in the broadest possible sense, the strength of IBE papers and publications is in biological engineering at the cellular and tissue level, areas that do not significantly overlap those of ASABE, and certainly not the engineering of biological systems of interest in ASABE.

The society with interests closest to IBE, and the second society with the words "biological engineering" in its name is the Society for Biological Engineering (SBE), a society formed by chemical engineers with interests in biomolecular, cellular, and tissue engineering. It is federated with the American Institute of Chemical Engineers (AIChE) as a technical community. Despite the name of SBE, its interests do not include the engineering of biological systems at all hierarchical biological levels, as they do in ASABE.

The third society is the Engineering in Medicine and Biology Society (EMBS), part of the Institute of Electrical and Electronic Engineers (IEEE). EMBS is federated very closely with IEEE, and is almost exclusively concerned with engineering related to human medicine. EMBS does not represent the broad perspectives that are found within ASABE.

Of all the societies with engineering related to biology, the only one representing a broad, all-encompassing perspective of engineering related to biological systems at multiple biological levels is ASABE. That is our strength, and that is what we should promote.

At one time, engineering in agriculture was the keystone of our society, and we did it well. Times have changed, however, and agricultural research has metamorphosed into biological systems research. Funding sources reflect this change. At the same time, our society has changed, our students have changed, and the word “agriculture” is no longer attractive. It certainly is not as attractive as “biology” or “medicine”. If we are honest about it, it wasn’t even as attractive as a field of employment to us. Fred Wheaton, our former and late department chair, who grew up on a dairy farm on Michigan’s Upper Peninsula, used to tell me, ”I’ve had good days as department chair, and I’ve had bad days , but I’ve never had a day so bad that I wanted to put up hay”

Our problem in ASABE is letting go of “traditional interests” and positioning ourselves for a future that attracts the new breed of student, that feeds on the strengths that we have built over the years, and that positions ourselves as the go-to society for understanding the interconnectiveness of biological systems, environment, and human activities. We have promised our students that they will learn about engineering, learn about biology, and be able to deal with interesting challenges when the two are put together. They don’t want to be labeled as agricultural engineers, and they see little reason to associate with agricultural engineers. If ASABE is to have a strong future, which it most certainly can have, it needs to begin to seriously attract graduates of the new academic programs and give them what they need. There is no reason to abandon traditional interests of ASABE, but they do need to be de-emphasized and made subordinate to the more inclusive term of “biological engineering”.

As to whether we should permanently banish biomedical engineering from the interests of ASABE, the response needs to be nuanced. Let the engineering of diagnosis, prognosis, and treatment of human medical needs be recognized as the purview of EMBS and BMES. But we cannot abandon human interests entirely. Let us embrace human safety, preventative health measures, and human interests in environmental preservation. The human being was, is, and always will be the motivation for much of what we do. Besides, looking at biology as a whole means that we cannot ignore the human as an important source of biological research information. It is appropriate that we recognize the human element in engineering related to biological systems.

This country and the world need a professional group with expertise concentrated at the overall, global, systems level. Someone needs to understand how everything fits together. This is an exciting prospect for ASABE; it could be exciting for its present and future members, for funding agencies, and for society as a whole. We have this strength, and it is time. As Dr. Yoon has said, “*What are we waiting for?”*

ASABE Biological Engineering Initiative

Arthur T. Johnson

Appeared in ASABE Resource, vol. 9, number 11.

Let me begin by complementing you on an excellent issue of *Resource.* The September issue certainly supports the intention of the Society to emphasize biological engineering. The Update section was chock-full of examples illustrating applied biology, and these can be very useful in class. The McLeod Harvest article also was good because it looked at some of the biologically-broader issues of harvesting. Norm Scott's article on sustainable communities was also consistent with the applied biological themes of the previous pages. This article, however, brings up a number of issues related to the ASAE biological engineering initiative.

An important aspect of biobased sustainable communities is the socioeconomic phenomena mentioned but not further elaborated in the article. A potentially sustainable community may be possible in China with its limited resources, generally compliant population, and its high degree of sensitivity to common purpose. In the United States, however, we have a population that is egocentric, opportunistic, and not so limited by available resources. Now, if biological engineers are going to try to establish biobased sustainable communities in the United States rather than China, they need to be able to deal with vastly different socioeconomic realities.

So, this relates to the ASAE biological engineering initiative because it illustrates that the technical and not-so-technical issues of interest of ASAE members must broaden considerably. Not only must biological engineers know about dealing with standard biological systems, but they must also know how the context affects expected responses.

In order to be the Society representing biological engineers, new associations and new liaisons must be established. Not only need we, as ASAE members, be concerned with what is going on with agriculture but also with biomedicine, genetics, psychology, biochemistry, and a whole bunch of things we never thought about seriously before.

The world in which we find ourselves as biological engineers is different from the world of agricultural engineering. The opportunities are different, the competition is different, and the interested groups are different. One big step toward playing a role in biological engineering is to step out smartly and start talking to the other players in this field. I think that it is starting to happen with the Biomedical Engineering Society on the issue of ABET accreditation of programs. It needs to happen also with other groups about public policy, research interests, and professional issues.

This is not only about borrowing from other groups, because ASAE members have a lot to offer as well. It has been my experience over the last 30-35 years that the other groups do not know the strengths represented by ASAE. It is time to represent our strengths to other groups with interests in biology and engineering.

We will find that the field of biological engineering can be very broad, and we do not have serious interests in the entire field. That is fine; we must be able to know where our core interests lie. Certainly, we will want to retain agriculture, food, and the environment as some of these interests. But, who better than we can deal with some of the connections between environment and human disease just coming to light these days?

I would urge the Board of Trustees and the other officers of ASAE to consider the details of the biological engineering initiative, because the details will be what define ASAE and its interests. Such things as annual meeting keynote speakers, sponsorships of meetings, presence at sister organization events, biologically-related standards, and cooperation with other groups speak very loudly about who we are and what we can contribute.

So, if we model ASAE as a sustainable community, we must account for the total environment in which we find ourselves, and learn as much as we can about all the external influences that can determine whether or not we achieve our goals.

Back Track on Dual Track

Arthur T. Johnson

Published in the ASABE Resource, August 2005.

The May 2004 issue of *Resource* had been lost on my desk. After liberating it from beneath unruly and obsolescent detritus, I read with interest the interview with ASAE Past President Harmon Towne. Asked what he would do if he were chairperson of an agricultural engineering department and had to plan for the change to biological engineering. Towne responded that he would propose parallel tracks of agricultural engineering and biological engineering. Coincidently, in the same issue was an article by Ajit Srivastava in which he discussed agricultural engineering at Michigan State University. One of the lessons learned from his MSU experience was that "a department cannot be everything to everybody". Another was that a transformation of agricultural engineering into a biology-based discipline was underway. It seems to me that these two lessons auger against the parallel track approach.

Although there are universities that maintain dual tracks of agricultural and biological engineering, there is also indication that such dual tracks are part of the transition from one to the other, and that the one will supplant the other in many locations. In these days of limited resources, and with the need to have an easily identifiable identity on campus, agricultural engineering departments simply cannot afford to maintain dual-track diversity.

If we truly believe that agricultural engineering is an application of biological engineering, then agricultural engineering should be a graduate-level option just as other applications are. At the graduate level, specialized knowledge is absorbed and small class sizes are expected. There is the possibility that specialized agricultural engineering classes could be given in the last year or two of the undergraduate curriculum, but graduate-level offerings could be attractive for students coming from other degree programs.

There is nothing like farm experience for an agricultural engineer. For years, agricultural engineering programs assumed that their students had farm experience. That experience contributed to educational efficiency, because practical aspects of crop handling, animal husbandry, irrigation, and machinery did not have to be taught at the elementary level. That efficiency is rapidly being lost as smaller proportions of matriculating students possess practical farm experience. So, even if ag engineering were maintained as an undergraduate track, courses would have to change to accommodate backgrounds.

One important attribute of the old ag engineering curricula, and one I appreciate to this day, is the range of technological topics. That same broad outlook is what makes agricultural engineers well suited as biological engineers. There is nothing as broad and pervasive as the field of biology. There are no more diverse opportunities than those ranging from electrophysiology of individual cells, to toxic reactions, to environmental contaminants, to prosthetic limbs. From imaging to harvesting, from swarm intelligence to bioreactors, from individual strands of DNA to macroecological systems, there is diversity, if nothing else. No matter what strengths or interests are expressed by a student, there is a biological engineering topic that can fit, and agricultural engineers should be able to appreciate that better than anyone else. We should be careful to maintain that broad and fundamental view as the transition to biological engineering unfolds.

Assuming the role of biological engineers means much more than just a shift of technical focus, we must embrace many potential applications areas traditionally ignored. Fortunately, many departments are doing just that by including human medicine, biotechnology, and ecology within their domains. We must also reach out to new associates and encourage new approaches. While we maintain our ties with traditional agricultural organizations and personnel, we must also find opportunities with those working in other applications of biological engineering.

Perhaps the most radical change of association will be the colleges administering our departments. As long as we are administered in colleges of agriculture, we will be agricultural engineers. Our transition will not be complete until we change our affiliation to the colleges of engineering where our fellow engineers are all located. This change does not mean abandonment of ag engineering, but establishing new ties and accommodation to new educational cultures. This will not be an easy transition, but it will be necessary. Without it, the transition to biological engineering will be stuck halfway, and we know from biology that organisms that cannot adapt are eventually replaced and forgotten.

If I had been coaching Mr. Towne, I would have urged him to consider all of the above. Unfortunately, his answers would not have fit in the required space. But, then again, how can you explain a vision in a few short words?

Biomedical Engineering Society (BMES)

A Tribute to Pat Horner

Arthur T. Johnson

Published in the BMES Bulletin, vol. 34(1), February 2010.

Pat Horner had one strong spirit. She was a whirlwind with the strongest will of anyone I've known, who not only was in the center of the action – she was the action.

I met Pat in the early 1970's – I don't remember the exact year – when the American Society of Agricultural Engineers asked me as a young bioengineer to investigate their involvement in the Alliance for Engineering in Medicine and Biology. I had recently returned from a tour as an Army captain in Vietnam, and had taken a job at Edgewood Arsenal, in Maryland.

Washington, DC wasn't too far away, so I made an appointment to visit the Alliance office. There I met John Busser, the Executive Director, and Pat Horner, his deputy. I was favorably impressed, and reported back to ASAE that I thought there might be something there for ASAE to be interested in. I don't quite remember the details, but I was named ASAE representative to the Alliance Council.

I was impressed. Around the Council table were bioengineering pioneers such as Francis Long, Dick Gowan, Dick Johns, Les Geddes, Les Goodman, Charlie Weller, and, of course, Pat. I was among giants, and I was just starting my career.

Pat soon became Executive Director of the Alliance, and it soon became obvious that it was she who made the organization tick. The Alliance was a cooperative amalgam of member societies with interests in medical and biological engineering. Pat spent long hours on the phone with the movers and shakers in biomedical engineering. She knew everybody and everybody knew her. She was the centerpiece of the Alliance, the one person who kept the organization running. She was excellent at forming consensus, but, to tell the truth, it was usually her position on issues that prevailed. She was very strong-willed. I knew when I picked up the phone and heard that familiar "Hel-low, Arthur", that I was going to be on the line for at least an hour.

We hit it off pretty well, and her relationship to me that began as a mentor, after a while became advisor, and after that, ally. The progression reflected my growth and maturity, not Pat's. She had early cut her teeth on Republican politics in Pittsburgh, and she knew the ropes. It was I who learned a lot from Pat.

After a few years, I was elected Treasurer, and then Secretary of the Alliance. It was Pat who made sure I was nominated.

When the Nominations Committee passed over me to nominate another person for Alliance Vice President, Pat was not pleased. I asked her advice, and she assured me that, if I petitioned to be on the ballot, she would support me. That was all I needed. I got all the petition signatures I needed, and called all the Council delegates to let them know that I was interested in their votes. I won the first and only contested election for Alliance Vice President, and I won unanimously. I'm not aware of the part Pat played behind the scenes, but, whatever it was, I'm still grateful.

After two years, I was elected Alliance President, and was the first President to serve a term of four years. During that time, it was becoming apparent that the Alliance was in need of major overhaul. Member societies were terminating membership, and the Alliance was developing financial troubles.

Pat, still the resourceful manager that she was, managed to pare expenses. That meant buying office supplies when they were on sale, reducing office staff and doing more work herself, and getting the best deals at hotels where our meetings were held. There wasn't a hotel manager who could stand up to her. She knew what she wanted, and she knew how far to push to get even better than the best price breaks that they were prepared to offer.

When money was plentiful, Pat could put on the most lavish party at her meetings. When money was scarce, she could put on a party that looked as lavish as the other one, but cost half as much. She was amazingly talented at running a society.

Because of the financial woes of the Alliance, Pat was forced to look for society management employment elsewhere, and went to work for Smith-Bucklin, a firm that managed several societies. Pat took on other society management duties.

It was during this time that we were meeting to form a new organization, the American Institute for Medical and Biological Engineering (AIMBE). Pat was the Project Director of that effort. Although she didn't become directly involved in AIMBE, she was highly supportive. Her loyalty was with the field of biomedical engineering that she loved, and she wasn't about to give up on it. I still got the calls from her.

We maintained contact through those years, and, when Eric Guilbeau came to me to ask what I thought about Pat as Executive Director of the Biomedical Engineering Society, I told him that there was nobody more qualified. I also told him that Pat had such a strong personality that she would have her own ways to do things. But they would be done well. She was chosen as the second Executive Director of BMES, and the first to manage a BMES office. There she stayed until her retirement in 2005.

We stayed in touch, and had an occasional lunch together. In these years, it was becoming clearer that Pat the physical person was weakening. I once asked her how she liked retirement, and she responded, "To tell the truth, retirement is hell." I think what she really meant was "old age is hell". Despite her physical limitations, she still had the same fire, the same spirit, but her will was not enough to push her body to the extremes that she had been used to earlier in life.

Pat was indomitable. This is the characterization of her I will always carry with me. She had her likes and dislikes, and she made no secret about either. She believed strongly in what she was doing, and the word "strongly" is an understatement. She was a positive force in the early days of biomedical engineering, when the field was just being formulated. She was loyal and consistent, and I shall admire her for that for the rest of my life.

She touched many lives, and nobody came away from an encounter with Pat Horner without being impressed. I can just see her now – telling St. Peter who to let through the Pearly Gates and who to reject. That would be Pat – in the middle of the action.

Attracting Industry

Arthur T. Johnson

Published in the BMES Bulletin vol. 32 no 1, 2008.

Of all the themes that I have heard over the many years of engineering society membership, one of the most persistent is the wish to attract new industry involvement. The motivating force behind this wish is often, although not always, the hope that industry would provide additional resources for society activities. Usually, although again not always, this hope takes the form of cash.

This theme has been singularly unsuccessful for many of these societies, and the reasons are many. Aside from a fairly clear idea of what industry could bring to a society, exactly what benefits industry would derive from such an association is not as clear.

Perhaps the biggest mistake we academicians make when talking about industry is that we assume all industry is the same, has the same procedures, and has the same needs. As one who is beginning an NIH phase II SBIR, I can tell you that there are segments of industry that have tremendous start-up needs and that are essentially broke. I don't think societies are talking much about wanting to associate with this portion of industry, although it is this portion that probably has the most needs that society associations could satisfy.

The contexts of Board of Directors' conversations about industry involvement usually suggest the idea that industry could contribute to solving society financial woes. Indeed, the worse off the finances of a society, the more intense are the conversations about attracting industry. By this, we usually mean *profitable* industry, with *very profitable* industry preferred.

So, after assuming that all industry is the same, and that individual representatives of this monolith would be eager to contribute to society welfare, if only given a chance, what do we do now?

I have had extended conversations with only a few industry representatives about this topic. There were no general conclusions that I can point to, no magical aphrodisiac identified to attract industry to society membership. Each person I talked to had a different opinion on why their company was associated with BMES. Sometimes it was exposure, sometimes being in the presence of potential customers, and sometimes wanting to hire excellent students were reasons given for their presences. What was not mentioned were the need to disclose the mechanics of their latest products, the need to make contact with closely-associated academic experts, or even society publications. Industry reps did not need a place to publish, a platform for speaking, or credit given for attending workshops. Some did come to find out about the latest research, but other times that wasn't important. In other words, industry folks may have ideas and needs alien to the academic way of thinking.

Dr. Al Mann gave one of the plenary talks at the 2007 BMES meeting. As part of this talk he listed the 10 most important considerations for success. The first three of these were all the same: "Money." It was only when he got to number 10 that he named the "Idea." One might then rightly conclude that one major industry interest is money, and that is *getting* money, not giving it away. In that sense, the interests of industry and societies are competitive. Just as exergonic chemical reactions require that activation energies be overcome before energy surpluses become available, industry and societies must find mutual benefits before the two can cojoin to form useful associations.

With this general discussion as background, let me make several concrete suggestions. First, if industry representation is so important to BMES, then let's restructure the bylaws to guarantee that there will be industry representatives on the committees and the Board of Directors. Instead of industry people running against academics in a general pool of candidates, have industry representatives run against other industry representatives to guarantee that at least some will win. This is not such an undemocratic move as long as we democratically decide on this course of action. The American Society for Agricultural and Biological Engineers constitutionally mandates that every other President will come from industry. The system has worked for many years and is generally accepted by ASABE members.

Second, let's program industry into our meetings. The Institute for Biological Engineering holds what it calls an Industry Nexus at each of its meetings. In these sessions (not held in parallel with any other sessions), industry speakers are invited to present talks on some general topic. Speakers always seem to refer to their products or their companies when reaching for examples to illustrate their points, but these are not product showcase sessions as such. IBE has found a way to engage industry without making the assumptions of homogeneity or potential ATM machines. BMES could do likewise and thus build a foundation for future society-industry interrelationships.

Third, we can provide useful publications. Research journals are often seen by academicians as places to publish, show their progress, and receive credit towards their next promotions. These types of publications do not serve industry very well in many cases. I had suggested that BMES establish some kind of translational research journal, geared toward applications and real uses of advancements in the BME field. Rick Waugh took this further by suggesting a kind of *C&E News* for BMES. Neither of these is likely to happen soon, but we can ask that a paragraph be appended to each published paper in ABME explaining why the work is important and how it can be applied. Even this may not happen soon, if at all. In the meantime, I will attempt to make the Bulletin serve the translational purpose as much as possible. Contributions to the Bulletin will be welcome, but they must be short (about 2000 words) and they must emphasize background, context, and practical application. I invite you to submit contributions within these guidelines.

It would be good to see more industry involvement. If you have any additional ideas about how this can be done, send them along. Who knows? They may be just the keys we are looking for.

Finally Begun

Arthur T. Johnson

Appeared in volume 31, number 2 issue (2007) of the BMES Bulletin.

A lot was accomplished at the Spring BMES Board Meeting at the end of February, but, as far as I was concerned, the biggest accomplishment was the passage of a motion to support progress toward registration of bio-based engineers. I have really thought that this step would be the one that defines our discipline as separate and distinct. I have written before about the formation of a new discipline with biology and engineering at its central core. It has not been easy, especially because there are so many opportunities these days in bioengineering that the field is attracting lots of attention from those in other disciplines who begin working with medicine or biology, but who have not had the core of bioengineering education given to those who have been in bioengineering from the start. With this constant influx of participants who are not themselves bioengineers by training, it has been difficult to reach consensus about what constitutes a bioengineer and what expectations there are for them.

A separate discipline is distinguished not only by scope of technical knowledge, but also by methods. We have only recently begun to agree on the essential technical knowledge part (as evidenced by Rob Lindsenmeyer's surveys), but I doubt whether many people have even thought about methods. Nonetheless, an exam to license bioengineers gives legal recognition of bio-based engineers as a separate field of engineering practice equal in the eyes of the law with mechanical, electrical, chemical, and civil engineering. It is a rite of passage, and we are on our way.

The licensure process has several steps. The first is the fundamentals of engineering (or FE) exam that is supposed to test engineering knowledge common to the first two years of engineering education (that is, before splitting into discipline-specific tracks). There may not be any bio-based questions on the FE exam, except if we push for some to be included. I personally think that biology is so important these days that all engineers should have at least one course in basic biology (and, preferably, a biology for engineers course that gives them biology useful for understanding systems of living things and their responses to the physical, chemical, and biological environment in which they are found—but that is the topic for other discourses). Anyway, there may be a few biology questions on the FE exam, but we can't expect many.

The next step in the examination process is the engineering practice exam taken after at least four years of certified engineering experience. Two parts comprise this exam: a common part, usually administered in the morning of the exam day, and a specialized part given in the afternoon. There is a lot of commonality in the knowledge base for all bio-based engineers, and this common knowledge should fulfill the a.m. requirements. I have written previously about what I think should constitute some of this material. No matter whether the prospective engineer has interest in medicine or biofuels, systems biology or ecology, there are principles and facts that would be expected to be known by all.

The afternoon portion of the exam could be filled with applications-specific questions. It would be here that we distinguish among agricultural, biochemical, bioenvironmental, biological, biomechanical, biomedical, or the myriad of other bio-based engineers and their areas of application. I assume that all interested professional societies would cooperate on content for the first part of the exam, but perhaps separately produce the second part.

All this is years in the future. Between now and then there is much work to be done and details to be worked out. Several levels of approval are required. However, we have taken the first definitive step—it is a step that clearly looks to the future and a time when biomedical engineering and bioengineering will have come of age, achieved the recognition that we have so desired, and can proudly mark this as our domain.

Choosing to Play with the Big Boys

Arthur T. Johnson

Appeared in the January 2011 issue of Biomedical Engineering News.

"*We love all of our students; we care for every one of them."* This statement, made by BMES Historian and Board member Paul Fagette summed up his reason for advocating the recent Board decision to support further actions toward establishing a Professional Engineers licensing exam for Biomedical Engineers. The decision was not made without opposition; a significant number of Board members were not convinced that professional registration for Biomedical Engineers was warranted; they pointed to the facts that Biomedical Engineering had been practiced just fine in recent years, and that there was a decided lack of enthusiasm for BME PEs in industry. Resources, meaning real money, is necessary to support the PE exam, and, they said, BMES could better spend the money on other projects.

Those points being made, there are more transcendent reasons for the Board to support professional licensure of Biomedical Engineers. Perhaps the most idealistic of these is to realize that, for Biomedical Engineering to be considered professionally equal to the older and larger engineering disciplines, it must demonstrate that equality. Professional registration is one of those means.

BMES took a big step toward recognition of its role as the professional society representing Biomedical Engineering when it assumed the role of lead society for ABET accreditation of BME programs. BMES has now taken the second big step by leading the way toward legal recognition of our profession.

Biomedical Engineering, according to data supplied by the American Society for Engineering Education, is now the fastest growing engineering discipline in the US. Thus, the exposure of Biomedical Engineers to the public, with all its positive and negative ramifications, is bound to increase in the coming years. There will be more opportunities for Biomedical Engineers to be held accountable for public health and safety outcomes of their professional activities. Professional registration is necessary for other engineers who directly affect public health and safety; it will be the same for Biomedical Engineers.

On a more pragmatic level, at least for BMES, is the retention of membership of BME students after they graduate. Only a very small percentage (roughly 30%, based upon experiences of other societies) of the 3600 student members (out of a total of 5600 BMES members) decide to transfer to full membership after they receive their degrees. No one knows exactly why this percentage is so small, but I would guess that student members see a number of positive reasons to belong as students, including enthusiastic fellowship with other students, but do not see BMES as providing needed benefits after graduation. This professional posture on the part of BMES may change that. I fully expect that BMES will offer refresher courses, continuing education course, and PE examination preparation courses that not only provide desirable services for post-graduate Biomedical Engineers, but also provide additional revenue for the society. We can win on all counts.

Steve Schreiner did a wonderful job shepherding the PE proposal through the labyrinth of BMES Board questions and requirements. One of the things he did was to poll students about their desire to become professionally registered as Biomedical Engineers. Fully 78% of the undergraduates polled favor a PE for BME, 74% agree that the PE benefits the profession, and 70% of the students questioned showed interest in taking the exam. This is a large enough segment of our student population that we cannot ignore them. It is for this reason that Paul Fagette made his pronouncement appearing at the beginning of this piece.

This is a great move for BMES and for Biomedical Engineering. Folks, we’re becoming big-time.

Walking Around Hollywood

Arthur T. Johnson

Appeared in volume 31, number 4 issue of the BMES Bulletin.

Walking in the neighborhood of the Renaissance Hollywood Hotel where the 2007 BMES meeting was held brought a rush of thoughts about life and things in general. Here was an interesting mixture of sights and sounds not completely unexpected in a city as cosmopolitan as Los Angeles. The location immediately surrounding the Renaissance was glitzy and unreal, with Grauman's Chinese Theater, the Hollywood and Highland Center flashing bright lights, and faux-Hollywood happenings. This area could be described as exciting, unreal, glamorous, and glitzy. A block or two away in any direction, and the scenery changed drastically. There were houses and shops that could only be described as commonplace, ordinary, or even downright seedy. The Hollywood Walk of Fame, composed of stars embedded in the sidewalk dedicated to famous and accomplished personalities extended from the Renaissance area along Hollywood Boulevard farther than I was inclined to walk. Some stars seemed to shine in the sidewalk while others farther away seemed out of place in front of the cheap shops nearby.

On Franklin Street near the Renaissance was the Magic Castle Hotel that looked like a fairyland compared to its surroundings. Up Highland Avenue from the Renaissance was the Hollywood Bowl amphitheater that looked quite ordinary from the street but revealed an impressive entertainment complex farther up the hill.

This juxtaposition of the glamorous with the mundane was interesting. I could imagine Walt Disney saying to himself that if he could select all the glamorous edifices and concentrate them in one location, excluding the run-down apartments and stores, then he could transport visitors from their ordinary worlds to a fairy land devoid of cares and troubles. And so, Disneyland could have been conceived.

Our biomedical engineering world is like that. We have the mundane, the ordinary, and the commonplace. We have hard work, unsolvable problems, and so many distractions. But we also have sublime moments when we realize that we have made progress, that what we are doing is important, and what we are doing is good. We have our teaching with so many tedious details, but we also have inspiring classes when we have just given performances so perfect that the endorphins flow like rivers through our heads.

We can dwell on the commonplace, on the tedious details, and on the ordinary. Or we can inspire and be inspired by those significant achievements in our careers and those of others. We can be guided by the highest aspirations and advancements. And, if we put them all together, we can create our own professional Disneyland of glowing achievments. That's the purpose, after all, of the BMES Annual Meeting.

Institute of Biological Engineering (IBE)

A Noble Activity

Arthur T. Johnson

Published in the 2007 IBE Newsletter.

Among the issues that I'd like IBE to take up is a definition of life. What is life, and how can it be distinguished from non-life?

Such a question certainly isn't trivial, and many great minds have been brought to bear on the topic. Elsewhere in this issue is an excerpt from *Biology for Engineers* that relates the musings of others. But IBE members are intelligent and knowledgeable. They should be able to craft some sort of definition that works at least most of the time.

We have heard the term "synthetic biology" used at our last couple of meetings. This conjures up images of living things developed from scratch using materials and rules different from those used by natural (unsynthetic) living things. Instead, what are described in synthetic biology presentations are severe modifications of subcellular processes to result in designed organisms to produce certain goals. They are not completely synthetic and it is questionable whether they are biological or biochemical.

A useful definition of life could find its way into the legal, social, and scientific fabric of our society. Coming from an engineering viewpoint, it would be a useful tool directed to solving problems. Incorporating the latest biology research results, it would anticipate shortcomings that could require premature revision. And it would put IBE on the map.

A Call To Arms

Arthur T. Johnson

Appeared in the volume 7.1 (spring 2003) issue of the IBE Newsletter

They say an expert is someone who carries a briefcase and comes from more than 50 miles away. Maybe that's because the people we know from around here we know too well to admire. We know all the mistakes they've made and we know as much about any subject as they know. An expert must know more than we do, so the folks from around here can't be experts.

It seems that there are a lot of experts about biological engineering from more than 50 miles away. Jim Dooley just told us the other day about an electrical engineering professor from MIT who came to talk to the ABET council about biological engineering. His talk was supposed to stimulate thought about this new field.

And then there is the observation that, at least for a time, whenever an educational department wanted to strengthen its biological engineering efforts, faculty from chemical engineering were hired. This isn't meant to be a diatribe against chemical engineers, because they really have a lot to contribute, but do they really know more about biological engineering than we do?

The chemical engineering definition of biological engineering is really tripped toward the subcellular, cellular, and tissue engineering side of biology. It's a definition that fits its chemical engineering roots very well. People pushing for this definition of biological engineering have, over the years, become influential in various governmental agencies and educational institutions through professional activities. Because of this, we now see their definition of biological engineering becoming the core of officially-recognized definitions.

What is missing from these definitions of biological engineering is the overall systems concepts that take into account the myriad of responses of biological units to the integrated environments in which they find themselves. Cells and tissues are treated as unit operations rather than as players in microecological complexes.

When people such as the MIT professor first become introduced to biological engineering concepts, they think they have found virgin territory. Without full appreciation for the thoughts, words, and actions taken by, for instance, members of IBE, they believe that they can contribute to the formation of this new field without extensive research.

It is time for us to realize that the experts in biological engineering do not come from (figuratively) 50 miles away. The experts are our fellow IBE members, and the society that possesses the most thoughtful, well-developed concepts about biological engineering is IBE.

It makes no sense to invite keynote speakers to the IBE meeting to speak about what is included in biological engineering if the speakers know less about the subject than we do. Also, it makes no sense to sit and listen to an electrical engineering professor talk about biological engineering as if it were an entirely new field. Additionally, it makes no sense for us to accept as definitions of biological engineering anything other than the definition that Norm Scott so painstakingly led us to agree on.

This is not meant to criticize any individual member of IBE. However, it is meant to be a call-to-arms. IBE must begin to act as the repository of biological engineering information. We should act as if we are the experts in biological engineering, and that the others have a ways to go to catch up to us. We must begin to assert that what we know about biological engineering is what needs to be known. We must be confident about this.

We must have literature that defines biological engineering and includes numerous examples from all kinds of applications. We must make sure that we don't forget the literature that we have already developed, including definitions, DNA of Biological Engineering, Proceedings of Annual Meetings, recruiting brochures, and Newsletters. And we must confidently introduce others to this literature. If it all can be archived on the IBE website, then all we need to remember is www.ibeweb.org.

So, I urge IBE members to:

1. Become involved in other circles where biological engineering topics are likely to be discussed.
2. Act confidently as the experts in biological engineering.
3. Use the literature that we already have developed rather than wait for new.
4. Remember that it took a lot of time, effort, and discussion to get to where we are; let's not minimize what we have accomplished.

The Age of the Cowboys

Arthur T. Johnson

Published in the IBE Newsletter vol. 12, no. 3 (2008).

Biological engineering has now entered a new phase. Gone are the wild ideas, the era with few, if any, rules and regulations, and where any imaginative fantasy relating engineering to biology was completely fresh. Here with us today are more mundane products and product improvements, Institutional Review Boards or Animal Care and Use Committees, and empiricism. In other words, the Technocrats have replaced the Cowboys.

The Age of the Cowboys was truly a golden era. Funding was loose, laws were looser, and excitement was in the air. Expectations were at once high and higher, and every success was a big success. Very few ideas had been tried before, so the Cowboys could try almost anything to see if it would work. Opportunities were seemingly limitless. There was some vague notion about what might be able to be done, but no one knew for sure. Technology was in its infancy, and it was like the California gold rush all over again.

The Cowboys were an interesting bunch. They had visions of biological engineering breakthroughs, and the means to try almost anything imaginable. They were explorers, magnates, and tinkerers all rolled together. They believed in themselves and the technology they thought they knew, but they had little idea about the chances of success. They were optimists, every one, and their collective motto was: "Let's try it!"

I was fortunate to have known some of the early Cowboys. People like Francis Long, Lester Goodman, Allen Kahn, Les Geddes, Pat Horner, Wilson Greatbatch, William Kolff, Michael Debakey, Adrian Kantrowicz, Otto Schmitt, and Dick Gowan. Many of these were biomedical device guys, for that's really where it all started. Soon after, the biological engineering visionaries appeared – people like John Ogilvie, Pat Hassler, Bill Splinter, Bill Fox, and Jan Jofriet.
They would probably admit their lack of biological engineering knowledge, but they were true pioneering giants.

On their shoulders stand the Technocrats of today. These men and women know as much about biology as they know about engineering. They compete successfully for funding and they are familiar with NIH rules and regulations. They are adept at getting the most from their creations involving living things, and their improvements are measured in tiny steps rather than in giant strides. They have and use vast amounts of empirical data so that they can overcome secondary limitations of their devices and systems. Just saving a life is not necessarily their goal; adding quality to a long lifetime is their goal.

You can tell that a field has reached maturity when the Cowboys are gone and the Technocrats abound. The field becomes much more specialized and fragmented because the Technocrats generate specialized data and have limited ranges of interest. They are less interested in broad connections than they are in deep progress.

The original vision for biological engineering (and IBE) was that it would remain in the nascent state forever. It would bring biomedical engineers together with ecological engineers, and they would both be able to converse intelligently with metabolic engineers and food engineers. There would be no separation for synthetic biology, wetlands reconstruction, biomaterials, or bioreactor design. We would all appreciate the commonality that we share, and emphasize general laws at the expense of empiricism. We would all share enthusiasm for the system and appreciate its wholeness.

Something happened on the way to the corral. Our own generalist Cowboys have largely been replaced by our specialist Technocrats. Our meetings are dissected along specialty lines, and we hardly ever see a paper that cuts across these lines. We don't talk to each other in the hall as we once did, because we have little in common. We don't understand general connections because we are too interested in narrow research topics. The success of the IBE meeting is based on numbers of papers and attendees, and not on the discussions that we once had.

When did we lose the foundational vision of IBE? Perhaps it was when we had to face the prospect of writing funding proposals that required specialized expertise. No matter – IBE is now as balkanized as any other society.

I would suggest at least one non-concurrent session at each meeting to host papers of a generalized nature that cut across specialties. There needs to be no other theme for this session than its generality. Papers for this session would be selected, perhaps even invited, from the Cowboys among us. They should be selected to bring back the excitement that the discovery of new knowledge can generate. When the session is finished, we should have a party. With Cowboy hats.

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The Care and Nurturing of Biological Engineering

Arthur T. Johnson

Appeared in the volume 8.1 (spring 2004) issue of the IBE Newsletter.

Biological engineering is so delicate right now. I'm talking about the broad, science-based biological engineering for which IBE was founded. That concept of biological engineering has yet to be accepted by the rest of the world. Sometimes, it seems, it even gets lost within IBE.

AIChE has been dealing with a crisis of mammoth proportions over the last year. Membership was down, and finances were overwhelming. It was possible that the society would close its doors; it was that serious. Grasping for solutions, chemical engineering and chemical engineering departments have seriously begun to look at their relationships with biology (see http:/bio.aiche/org). Many have decided that Biological Engineering is the panacea that they need. So, look for many departments to change their names to Chemical and Biological Engineering over the next few years. Note when this happens, however, that there will be little, if any, corresponding curriculum changes. Sounds like agricultural engineering and ASAE a dozen years ago, doesn't it?

ASAE is in the midst of a campaign to change its name to include Biological Engineering. Whether that is appropriate for ASAE is up to its members, but we can at least ask if ASAE is talking about the same broad and fundamental Biological Engineering that is the purpose of IBE.

Do all IBE members agree on the Biological Engineering of its founders? That is hard to answer, because, looking at the pronouncement and programs of IBE, it is difficult to discern what we stand for. Several years ago, President Norm Scott worked hard to get us to agree on a definition of Biological Engineering. It's not readily apparent that we continue to agree with it.

Then, let's look at programs from our last few meetings. We have tried very hard to include a breadth of possible applications. But, in trying to think outside the box, have we not replaced the big box with a lot of little boxes? Where is the unity in our programs?

When IBE was founded, there was a suggestion that specialty groups be allowed to form within IBE. That suggestion was rejected because we could not afford to fragment the unity of purpose of IBE.

I have written before about the tendency of IBE to look outside its ranks for experts in Biological Engineering. When it comes to keynote speakers, we look for those with established reputations in other fields to come and tell us about our own field. There must be someone in IBE who could qualify as an expert in Biological Engineering. And, if having this someone speak to us about Biological Engineering is monotonous to us old-timers, perhaps the message is needed for those who weren't around at the founding of IBE.

I strongly believe that IBE should be the bastion for broad, fundamental, Biological Engineering. We need to decide among ourselves what that really means:

what are the technical areas covered and what methods are to characterize the entire field. If we are to foster different specialized applications areas, we need to focus on the common themes among them. That is, a requirement for each paper given to and each article published by, IBE should be a consideration of how this technical information relates to the entire broad and fundamental field of Biological Engineering.

Then, with that commonality of purpose, we need to sell this concept to others. We need to show chemical engineering that they have a legitimate part of Biological Engineering, but only a part. We need to remind ASAE that the Biological Engineering talked about there still appears to be applications-based. We need to take advantage of liaisons with AIMBE, ABET, and other groups to spread the news that what they need is what we have spent so much time developing. IBE may never develop into a huge society convolving all engineers interested in biology with all biologists interested in engineering, but at least it could serve an extremely important purpose. That purpose is a vision of what Biological Engineering is and can be. We must keep that vision alive and not take it for granted.

The Next Big Thing

Arthur T. Johnson

Appeared in volume 10.2 (summer 2006) issue of the IBE Newsletter.

"*Technology is neither good nor bad. Nor is it neutral*." This quote by Melvin Kranzberg expresses the idea that technology is all-affective. No matter what technological advance we talk about, the advance, once made, changes life for all. The change may be good, and it may be bad, but its bottom line is very often dependent upon how we are willing to use new technology.

At our 2006 IBE meeting in Tucson we learned about artemesinin, synthetic-biology, standard genetic parts, biology-inspired design, and ethics. It was an interesting combination. As you might imagine, lots of people had things to say about ethics, especially when prompted by the winning essays in the student bioethics essay contest that IBE had sponsored. You can read these essays for yourself in this and subsequent newsletters.

Bioethics discussions almost have a life of their own once they get started. The discussion at the IBE meeting was no exception to this, and had to yield to time constraints before it had run its course. Most of the comments were about genetically-modified organisms and how they were either good or bad, acceptable or unacceptable, and there was a certain smug tone to remarks about "others who don't understand about GMOs."

Of course there is really never any resolution to these discussions because absolute right or wrong answers are generally conceded not to exist. However, hubris often accentuates irony and many in the room did not really realize that GMO issues were now out of the hands of the developers. GMOs are now able to be patented, so there is nothing we can do about that. Commercial interests have trumped scientific and altruistic interests, so that is largely out of our hands. Promises of less herbicide use have proved to be false, blocks of non-GMO crops that were supposed to have been planted to kill pests in the conventional way (and so delay evolved immunity to genetic modifications) were not planted), and farmers growing plants that show evidence of commercialized genetic modifications must pay whether they planted the crops or not. Legally and commercially the GMO-bioethics game is over.

On the other hand, there are issues on the horizon for which ethical discussion is more than hot air. The case of artemesinin is an example. Our keynote address was about producing this drug to cure malaria by genetically-modified microbes. Producing this drug in this way is not an issue. However, what happens after the drug becomes plentiful and cheap? Will it be abused? You bet! Will it eventually lose its effectiveness? You can count on it! Are there other drugs that can be used in its place? None known. The bioethics discussion therefore, should concern the way the drug is used to maintain its effectiveness for the longest possible time. Biological engineers should know enough about biology (and human nature) to avoid the unintended consequences inherent when dealing with living things.

Or take the winning bioethics essay (appearing in this issue). That essay emphasizes the centrality of human free will. However, recent research results have shown that human actions were actually planned before they were consciously known. The only choice, then, is whether or not to carry out preplanned actions. This has been termed free-won't rather than free-will. Furthermore, there are now being designed prosthetic neural devices meant to correct defects in basic brain processes. It doesn't take much imagination to see where this is headed: with time, higher level brain functions may be performed by complex electronic circuits. At the same time, there are scientists and engineers trying to produce computers with emotions. As the human becomes more machine-like, and the machine becomes more human-like how are they to be distinguished? What are the ethical issues in this *Deus ex machina* situation?

Are technology advances, and especially advances in bio-technology always good? How do we know? What will give us the ability to judge?

IBE as an organization should be looking for those issues and those realms for which ethical discussions could make a difference. There are the issues of tomorrow, the realms largely unknown to an unimaginative public, the questions where real leadership is necessary to guide the directions of bio-technology. It is here that IBE can make a real difference.

Part 6

Biology

A Horror Story

Arthur T. Johnson

Appeared in the Spring 2008 issue (vol. 12.1) of the IBE Newsletter.

Once upon a time there was a microbe that lived on the skin of humans. Its favorite place to reside was in the warm, humid environment of the nostrils, an environment that it shared with many other microbes of other species. The microbe of which I speak would have liked to have multiplied in number so that it could have this warm, cozy place all to itself, but the other microbes had the same idea, so they all coexisted in an uneasy equilibrium. This arrangement suited them all, because they each had their fair share of space, but, if one microbe moved just a little bit, there followed a melee of jostling to claim the empty territory. Jabbing and elbowing at each other kept them all on guard and gave none an advantage. No microbe dared sleep lest other microbes push him out of the way to claim his space. And so they remained alert, and it kept them busy and tired them, but it was the best they could do.

This constant competition for advantage made all these microbes opportunistic. Should there be a new territory, or a weakened competitor microbe, or a change in the environment more to the liking of one microbe compared to the others, and "Shazam!," that microbe would transform quickly into Capt. Marvel microbe and would take over the joint. In most cases, the human who supplied the nose would never notice. At worst he would sniffle a little more than normal until the balance was restored.

On occasion, however, one of the more dangerous and aggressive microbes would find itself with a rare chance to have some fun. It may have been a cut or skin abrasion, or it may have been a weakened human immune system. Whatever it was, this particular microbe, with its skills sharpened by constant microbial competition over the years, would go crazy. It would grow and multiply in numbers until there were so many they were beyond counting. They were all family and they were all intent on making the most of the situation.

If you get a whole bunch of brothers and sisters working together, then they can do marvelous things. What these microbes could do would be to control their own environment; baking, and making, and staking their collective claim to this new space. Each helped the others, and soon they could become unstoppable. Of course, this did no good for the human upon which they were growing.

So other humans stepped in. Humans are a proud people, and they do not like to admit defeat to a bunch of lowly microbes, no matter how well organized the microbes are. These other humans spied on microbes originally in competition with the deadly microbes and learned their secrets. They learned that one tactic the competitive microbes used was chemical warfare: they produced biochemicals that could kill microbes on contact.

It didn't take these other humans long before they duplicated these chemicals, and they patented them, and they called them "antibiotics." If the competitive microbes had known all this, they would have objected to human use of their innovations and hired lawyers to argue their cases. But, as luck would have it, lawyers don't listen to microbes, especially ones in their noses who can't afford retainers.

So, these other humans used these antibiotics against the runaway deadly microbes. Yikes! They were very effective. They killed every microbe in sight—the deadly ones as well as all others. The crisis was over and life went back to normal.

But wait! Lurking in a far corner somewhere was a sinister deadly microbe who had somehow avoided deadly contact with the antibiotic. He survived, and he vowed to get even. So, he went to his lab and cooked up a potion. In his mind was a vision of all his brothers and sisters who had been caught unawares by the antibiotic attack and had succumbed to the deadly chemical onslaught. This thought gave him the will to find the antidote.

If the antibiotic strategy was the only weapon used by the competitive microbes, then they would not have been very competitive at all. There were many such tactics used and they were very successful because they acted as one-two-three punches. One would not be very effective but three might knock out a neighbor microbe.

Unfortunately, the humans did not appreciate this fact, and so relied exclusively on this one chemical punch. And, for a while, this punch continued to be an effective weapon for humans against microbes not to their liking. All too soon, however, the microbes found out how to thwart human intentions. Some developed tougher skins; others changed their habits of hanging out together; still others put on rain coats to keep the deadly biochemicals at bay.

And, when this happened, the humans noticed, and sought other poisons deadly to microbes. The pattern repeated itself over and over: poison discovered, poison used, poison effective for a while, and poison overcome by the microbes.

Eventually, the microbes developed the skills to play this game very well, and considered it to be a challenge to test their mettle. They became so good at it that, for each and every new poison discovered by humans, it took the microbes less and less time to deal with it.

Fortunately, most of the microbes inhabiting the warm, cozy recesses of humans were not particularly dangerous, and so did not draw attention to themselves. When they overcame the challenges thrust upon them by their human hosts, they merely played among themselves or caused a few sniffles, or maybe even produced a few extra vitamins for their human. They were hardly noticed at all by the human.

There were, however, some microbes that liked to cause trouble. When just children, they played malicious pranks, and one prank led to another until they joined gangs and fought with each other and with their neighbors. They painted graffiti on their tenement walls and damaged anything that looked good. They littered in all the open spaces, for they cared not for order and cleanliness. They disdained authority. What they didn't destroy, they stole, and sold for cash. They learned how to make drugs and to use them in bad ways. These were *bad* microbes, and humans soon became aware of their ill natures, and the dangers they posed to the human sense of order and health.

When humans tried to subdue these bad microbes with their antibiotic poisons, they found that they were no longer effective. There was hardly anything that humans could do to beat back these ruffians, and the humans began to be afraid. Some humans even panicked, and cried, and threw up their hands and sought help from the authorities. The newspapers and TV and radio began to call these "flesh-eating microbes," and this caused even more hysteria among the humans who envisioned painful and horrible images of their flesh dropping away upon the ground while the microbes laughed at the expense of their human hosts.

The humans had one more devastating weapon in their arsenal. This was a doomsday weapon developed for the ultimate purpose of destroying all life should the need ever arise. These substances the humans called "disinfectants," and no creature had ever survived being doused with a disinfectant.

So, authoritative humans suggested that disinfectants be used to destroy all the bad microbes in places where they lived. They called for disinfecting hospitals, and locker rooms, and homes wherever these flesh-eating microbes were likely to live.

And so the people were relieved. Disinfection would save the day; disinfection would solve the problem. They relaxed.

But there were two lessons that humans still had not learned. First, microbes and all life is resilient, and when a single weapon is pointed at them, they can duck and avoid being shot. Disinfectants had been used for many years by humans in their homes, in their soaps, in their toilet-bowl cleaners, in their refrigerators, in their deodorants, and in their mouthwashes. The obsessions that people had with cleanliness threatened to make disinfectants just as ineffective as antibiotics. Overuse leads to uselessness. Any microbes not killed by a disinfectant could come back and show the rest how to survive the attack. Any microbe not killed by a disinfectant would find fertile ground not occupied by any other living thing upon which to grow and reproduce.

The second lesson not learned is that these battles against horrible microbes are not waged alone. Humans have always had help from the natives—other microbes that also want to overcome the bad bugs. There has always been a civil war among microbes, and humans have chosen sides based upon the effects these microbes have upon humans. Using disinfectants knocks out human allies as well as human enemies. And so, it is hard to see anything but a temporary victory for humans if they haven't learned these two lessons.

There is no absolute level of safety in the world of biology. There will always be disease and death, because this is how competition works. While humans can move the balance toward their favor, they can't escape the fact that they are still biological creatures subject to many of the same rules and limitations governing all others. And that may be the biggest lesson still to be learned.

A Lot to Think About, A Lot to Understand

Arthur T. Johnson

Appeared in volume 30, number 2 issue of the BMES Bulletin.

You will see in this issue a contribution from Mohammed Kiani in which he asserts that an understanding of evolution is an important and necessary part of biomedical engineering education. The conclusion that Dr. Kiani reaches is well reasoned and unequivocal.

I, too, teach evolution in my Biology for Engineers course, but permit me to give a few slightly different angles to the need for bioengineers to know and understand evolution and evolutionary principles. These are further explained in my book, *Biology for Engineers*, freely available on my web page, www.bre.umd.edu/johnson.htm.

In order to deal successfully with living things, bioengineers must understand that the biological objects of their attention are not passive objects like their books, glasses, or cell phones. Living things have the ability to react, to change, and to adapt, and even to attempt control of their immediate environments. The paramount objective of any living thing is to survive and reproduce, and it does so by any possible means at its disposal.

Adaptation passed on to succeeding generations is what we call evolution. It involves a semi-permanent change in essential characteristics of an organism. I say semi-permanent because nothing that I can think of in biology is permanent (not even death, on some levels).

If the characteristics of the living things you are dealing with change, then you had better understand the process of change: how it happens, why it happens, what contributes to it happening, and the results of it happening. There is no more of an issue here of *belief* or *non-belief* than there is with understanding that electrical current flows through a wire if I hook it to a battery. Evolution is a description of what can be expected when a population of living things is challenged over a transgenerational time span. Just as any living thing will adapt within limits of its capabilities, so will a population of living things evolve within its capacity to change.

Three necessary conditions for evolution to occur are: 1) genetic variation, 2) constant environment, and 3) a differential reproductive advantage. Without genetic variation, the capacity to change is limited or nil. Without a constant environment the necessary selection pressure will not be felt long enough for reproductive advantages of certain genes to be manifested. Going back to the paramount object of biology, we are talking about survival and reproduction, and the better the survival and the more fecund is the reproduction, the more dominant a certain genome will become. Again, there is no issue of "belief," just a mechanistic description of a long-term input-output relationship for living things.

Not only microbes have been induced to change. Fishing regulations in the Pacific Northwest have changed the median size of salmon, and our fruits, vegetables, and flowers are all much different from their native forms. Our cows are beefier and our lab mice have been selected to exhibit specific traits. Evolution, whether caused by human or nonhuman influences, has affected every part of biology.

What has gotten many evolutionists in trouble is their insistence that genetic variation comes about entirely as a result of random processes. They seem to have flaunted their own unbelief that there could be some creator behind this whole scheme of things. Well, genetic variation isn't entirely random. There are locations within the genome where mutations are more likely to occur compared to other locations. The places where mutations are more likely also appear to be the places where, if mutations do occur, they would lead to a disproportionate chance of a survival and reproductive advantage. So, it appears as if there are at least several levels of evolution at work: a level that selects for a tendency for advantageous outcomes and a level that selects for the advantageous outcomes themselves. Who knows if it is even more complex than this?

All of this I find fascinating, and like the laws of physics, a marvelous schema of predictability.

Lastly, I want to address the issue of human evolution, not in the past, but in the future. Recent evidence has pointed to improved capability of the human brain to process information, and so it may well be that our own species is still improving. Will another species evolve from humans? Not likely, because to form a new species a level of isolation must be present. In at least some physical or temporal domain, there must be a subpopulation with limited or no contact with the general population. Then, with genetic variation and constant environmental pressure (presumably different from that of the general population), competitive selection would eventually lead to a population whose members could no longer breed with members of the parent population—a new species. Humans are too mobile for this process to lead to a new species (at least on Earth).

It is more likely that human improvement will come from cultural information passed from one generation to the next (so called memes). If we look at the genome as an information repository, then books, videos, sound recordings, traditions, and common beliefs are other parallel repositories that can also contain information passed from one generation to the next. This information has as much chance of making permanent physical and behavioral changes in humankind as does information coded by the genes. In the future we are likely to see more effective information stored and used through memes than through genes.

It has long been recognized that biological systems are chaotic, in the mathematical sense. That is, the present state of an organism depends on its starting point and its history. Choices along the way result in magnified consequences. Some choices might not even be available if other prior choices were not made one way or another. The whole scheme appears to be random, but isn't. As long as the history of choices and influences could be reproduced, the end result is deterministic.

So, if biological systems are chaotic, and the outcomes are varied and almost unpredictable, how are we assured that individuals within a population don't continue to diverge from one another. Nam Suh, from MIT, has offered that birth of a new generation is equivalent to a resetting process. Each new generation (within limits) begins with the same genetic starting point as the previous generation. Each new generation is taught many of the same traditions, cultural beliefs, and educational skills as previous generations. So, although each life moves through a path completely different from all other life paths, we all start out from the same beginning.

There’s a lot for an engineer to understand here.

Troubles in the Biology Classroom

Arthur T. Johnson

Appeared in volume 31, number 3 issue of the BMES Bulletin.

For many centuries, the studies of science and philosophy (religion) were unified, with little distinction between explanations of events of natural life drawn from each of these sources. That changed after the age of enlightenment in the centuries following the middle ages. At that point, a divergence began when scientific advances produced explanations for physical events that did not require supernatural interventions. Engineering and technology pushed this trend even further when people developed the capability to design and build improved solutions to human needs using only information based on empirical knowledge.

The trend toward separation of science and religion has continued almost to this day, but scientists are now treating metaphysical subjects as objects for scientific study. Bering (2006) has reported on results of developmental psychology experiments in which he concludes, among other things that:

1. belief in the afterlife is innate and is not the result of cultural indoctrination.
2. those who believe that a supernatural being is constantly watching them are less likely to cheat than are those who have no such beliefs.
3. even those who claim not to believe in the afterlife (the existence of consciousness even after death) are fundamentally ambivalent about their beliefs.
4. interpretations of natural events can be seen as symbolic of signs from unseen agents.
5. the default state of the human mind is to believe in the supernatural, and that this trait is the result of evolutionary selection.

This was followed a year later by a special issue of *Time* magazine devoted to new findings in brain research. Using such tools as fMRI, neuroscientists are discovering areas of the brain involved in different mental processes, and linking different areas to different senses, processes, and attitudes. They are even searching for the source of consciousness within the brain (Pinker, 2007).

There is no more essential characteristic of human existence than the state of being aware of one's self. This state has been referred to as the "mind," and the mind has been somehow linked with the brain but also divorced from it. If the state of consciousness is found to be tied directly to brain neural activity, it will have severe metaphysical implications. A quote from the article says it all:

> "*. . . . few scientists doubt that they will locate consciousness in the activity of the brain. For many nonscientists, this is a terrifying prospect. Not only does it strangle the hope that we might survive the death of our bodies, but it also seems to undermine the notion that we are free agents responsible for our choices. . .*"

In a third article, it was reported that actions and reactions are actually planned in our brains before we are conscious of them (Obhi and Haggard, 2004). The conscious choice we have, then, is whether or not to follow through with the preplanned actions. Free will, it was maintained, is actually "free won't."

These new discoveries call into question the concepts of God, soul, and free-will choices. These will be replaced by evolution, genetic programming, and environmental influences.

As a teacher of biology for engineers, this poses a real problem for me. It is my intention to teach modern science, and this includes evolution in all guises. But it is not my intention to undermine anyone's religious faith. Yet, if I'm not careful, that's exactly what could happen. The newest scientific knowledge is supporting and being supported by evolutionary explanations. Whereas science can never really answer why all this happens, it can provide answers that at least mask the most fundamental questions concerning human existence. Why are we here? Why do we love, hate, exhibit jealousy? Why are we kind to one another? Why do we feel good when we help others? Is there really a God? Evolutionary scientists, especially the evolution activists, are providing stronger and stronger answers for these questions all the time. If I do not wish to be an evolution activist in the same mold as the others, am I not abetting their cause by presenting their evidence?

Yet, I cannot, in good conscience (whatever that is), leave out essential scientific details. That would be dishonest and unscientific. So, I feel that I must present all the evidence, but hope that it won't leave students repudiating their upbringing. I have yet to be confronted by an individual who rejects evolution in favor of an unscientific explanation of creation, so my reaction to such an individual is untested. But, at the same time, I don't want to be the individual who positions evolution so that there is not room for faith in the minds of my students. I think there is room for coexistence, if the individual so desires.

The idea that humans descended from monkeys, although not exactly the way that evolution would explain it, upset many and caused them to repudiate evolutionary theory. If that idea elicited such a strong reaction, the newest neurophysiological discoveries will go much farther. Studies of the workings of human and animal brains could leave us wondering about our place in the world, and, not just where we came from, but where we are going. This prospect is daunting.

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Evolution and Biology for Engineers

Arthur T. Johnson

Appeared in the vol 22, no. 3 March 2009 issue of The University of Maryland Faculty Voice

Dear Editor,

Stephen Brush reiterated the need for evolution to be taught in high-school as well as in college-level courses. Evolution permeates my Biology for Engineers course taught at College Park. Not only do evolutionary principles explain many biological and psychosocial phenomena, but they also are predictive of future trends. Engineers who deal with living things need to be able to anticipate biological responses in order for their designs to be successful and to avoid unintended consequences of their actions. That living things react and adapt to new situations makes engineering using biological systems very challenging, but also very interesting.

Evolutionary principles can explain more than just responses of individual organisms. These principles make sense of actions of both competitors and cooperators, predators and prey, groups of individuals as well as single beings. New research into biofilms and quorum sensing confirms the portents offered by evolution. Also, evolutionary principles have begun to be used by engineers, designers, and inventors as a tool toward product improvement. This technique is called directed evolution and involves random changes in the product followed by the selection according to some pre-agreed judgment criteria. The best variant is then caused to mutate, followed by another selection. After several of these cycles, an improved product results. Directed evolution has been used to improve microwave antennas, skyscraper buildings, and artificial enzymes.

The mistake made by Dr. Brush in his writing was to assert that evolution depends upon random genetic mutations. This same assertion is made by nearly all evolutionists and has no real proof to substantiate it. There is even evidence to the contrary.

First of all, evolution does not depend on a genetic legacy. Information may be passed from one generation to the next in the biochemical nucleic acid form we know as genes. That is the classical means. For higher level animals, however, intergenerational information can also be taught and learned. This cultural information legacy is termed memes. It is known that adult birds and mammals communicate with the young to teach survival and reproductive skills. If that information is faulty, it does not get passed on because the recipients either die or don't reproduce. Evolution is just as much at work here as it is for genetic selection. Humans, in particular, use this method to improve survival of their young; that is why many of us are faculty at the university. Perhaps memes don't apply to microbes, but I wouldn't bet on it in view of the chemical communication means we are learning about microbes.

Second, there are regions of the genome that are more often mutated than others. These often occur during DNA replication and can involve looping and repetition. Some mutations occur orders of magnitude more often than others, and can even be predicted.

Blood pathogens, for instance, can hide from their host's immune system by changing their outside coats. These changes are determined by the genes that control coat protein formation. Natural selection has favored biochemical mechanisms that alter just these genes and no others. These genes are located in areas bracketed by conserved sequences of bases; these do not change, but the regions between them do. Other examples come from venom production and antibody formation. Indeed, it appears that there is at least a second-order selection process in place that not only selects for genetic mutations leading to the best survival and reproductive advantage but also to places in the genome that, if mutations were to occur, would then lead to survival and reproductive advantages. There seems to be a selection for those individuals that can mutate their genes in regions likely to improve survival.

Lastly, we come to the question of "why?" This cannot really be answered by science or engineering, but is an interesting contemplation nonetheless. Why did there appear at some ancient time chemicals that competed with other chemicals for resources in order to reproduce themselves? Once these chemicals appeared, a never-ending process was in place for evolution to proceed to and through the present. I have been amazed that these chemicals appeared in the first place. I'm no chemist, but I don't see other chemicals "behaving" in the same way. If the hand of God is present, it had to be when these protogenes first appeared.

Biology Should Not be Divided

Arthur T. Johnson

Appeared in the volume 9.1 (spring 2005) issue of the IBE Newsletter.

We recently had a faculty meeting where some of the specialists in ecological engineering were expressing discomfort about answering questions from advisees interested mainly in biomedical engineering. From their comments, it was clear that they would prefer to narrow the focus of their own academic lives to wetlands, restoration ecology, and emergy. I have heard the obverse from faculty particularly keen on biomedical engineering.

Whereas it is clear that in our own research we must focus on specific topics that usually, although not always, deal with narrow segments of the biological realm, we often forget that the burden of the Biological Engineer is to have some level of understanding of all of biology, just as we must be familiar with general engineering approaches to problem-solving. This generalized approach to understanding of biology sets Biological Engineers apart from others such as biomedical engineers and biochemical engineers.

Too many of us are more comfortable with talking about Biological Engineering than with biology, and that causes some of our hesitance to speak confidently about biological topics outside our areas of specialty. Yet, there are certain principles in biology that are not observed just at one level or another, but instead permeate all of biology.

It is at this general principle level that biology can be understood most easily. Once the general principles are known, it becomes more realistic to expect to be able to transfer knowledge of a familiar biological subject to one which is unfamiliar.

So what are these principles? Unfortunately, they have not yet been written down. They are waiting for Biological Engineers, such as you and me, to articulate them. I have tried to start this process in my Biology for Engineers book (www.bre.umd.edu/johnson.htm), but it will take many of us to get it right. One principle, however, is clear: the genetic foundation of a population does not change unless there is a reproductive advantage to doing so. "Desirable" genes are not selected for, and "undesirable" genes are not selected against unless there is a selective process going on to begin with. You can bet on it.

Brian Hayes, writing in the July-August 2004 issue of American Scientist, describes a time when all knowledge was classified together as *natural science*. Every kind of knowledge and understanding, from chemistry and physics, mathematics, and biology to philosophy, metaphysics, and religion were taught as one. As time went on, these fields gradually split, each developing appropriate methods and terminology, and this reductionistic trend continues today. In the subdiscipline of biomaterials, for instance, we have specialists in polymers, in ceramics, and in metals. Some day, it seems, we may even see one specialty per specialist, and no one will understand anything anyone else has to say.

Stepping back a bit, we explore our own selves and find that we have some understanding of science, engineering, philosophy, music, art, social graces, religion, and countless other things. In other words, as biological beings, we integrate knowledge about many specialties all the time.

A Biological Engineering design to produce a product or process intended for you and me can only be successful if all these areas of knowledge are considered. A design that fails in one critical area will be unsuccessful even if all else is perfect. The same would be true no matter what biological system is involved.

I conclude from all this that a basic understanding of the entire field of biology is necessary for the Biological Engineer. We can not chop off pieces of biology and ignore the rest; we cannot fail to recognize biology as entirely integrative and unified.

So, while my fellow faculty members may not be able to give specific answers to job possibilities outside their own fields of specialization, they ought to at least have some understanding of the broad opportunities that exist. And, when it comes to answering questions about biology or engineering, they should be confident in the answers they dispense. After all, biology is biology is biology. Right?

What Is Life, Really?

Arthur T. Johnson

Published in the IBE E-Life News, December 2011

An interesting convergence is taking shape these days. On one side, we have the successful biotechnological efforts to insert a completely synthetic genome into a living cell to produce a living, respiring, and reproducing new life form, an organism that has never existed before and did not evolve in the natural way. By anyone's definition of life, these scientists have created new life. The reason, the scientists give, is to transform common bacterial cells, such as *E. coli*, into efficient biofuel factories capable of producing in a bioreactor all the fuel we could want or use.

On another side are the creations of engineers building robots with ever-increasing useful capabilities. There is agreement that robots will find very useful service in the field of health care. Robots can already sense their environments, make simple decisions, and follow commands, but can they actually think and make sound judgments? They must become more autonomous if they are to truly serve to improve health care. Their programming is moving in the direction of incorporating ethical principles into their decision-making. That way, a robot ought to be able to think its way out of a command conflict in the same way that a human would.

Coming at the same issue from another direction, we are on the threshold of a prosthetic device revolution, where implanted parts become indistinguishable from the host person into which they are implanted; the person will be unable to function properly without these parts, and they will become essential components of the human beings who harbor them. Artificial organs, circuits to replace lost brain functions, prosthetic limbs, bioelectric sensors, and enhancer medicines will become at one with the human persona, influencing not only physical capability, but also building confidence, and changing personality.

It is not hard to see the future for synthetic biology. Whether programming cells to perform the way we want them to, or programming robots to perform the way we want them to, the only real difference between them is their starting points – one starts with something clearly living and the other starts with silicon and steel – but they both could end up in the same place, where life is indistinguishable from nonlife. Perhaps the two sides may hybridize, with the robot providing a matrix for the growth of synthetic neurons to form a brain of sorts for the humanoid robot.

There has never been a good definition of life. There are attributes, but no definitive demarcation between the living and the nonliving. Even harder is to try to define a sentient being from one that isn't. We are about to enter an era where no demarcation will be possible. When these trends finally do converge, there will be acting, moving, thinking beings with some living parts and some nonliving parts, neither clearly distinguishable from the other.

This brings me to one of my most memorable episodes of Star Trek: The Next Generation. It is entitled "The Measure of a Man". In this episode, Lieutenant

Commander Data, a remarkable android, is very human-like and an indispensible member of the command structure of the starship Enterprise. Data was created by a brilliant human who made only one model like him. That human had since died, taking the knowledge of Data's creation with him. There were those in Star Fleet who would like to clone Data, but, in order to do that, they had to completely disassemble Data, and there would be no guarantee that they could reassemble him (it?) exactly as he was before.

Right now, Data is self-aware, and disassembling him would be humanly equivalent to death. He has been ordered by Star Fleet to submit to the disassembly process, but he is conflicted between following orders given by his human superiors and his own self-preservation.

The case goes to trial, with Commander Riker (the second in command) forced to prosecute and Captain Pickard defending Data's right to refuse the order. The dramatic courtroom defense delivered by Pickard has meaning for our own future:

PICARD: *Commander Riker has dramatically demonstrated to this court that Lieutenant Commander Data is a machine. Do we deny that? No. Because it is not relevant. We too are machines, just machines of a different type. Commander Riker has also reminded us that Lieutenant Commander Data was created by a human. Do we deny that? No. Again it is not relevant. Children are created from the building blocks of their parents' DNA. Are they property? I call Lieutenant Commander Data to the stand.*
(Picard has Data's case with him. He opens it)
PICARD: *What are these?*
DATA: *My medals.*
PICARD: *Why do you pack them? What logical purpose do they serve?*
DATA: *I do not know, sir. I suppose none. I just wanted them. Is that vanity?*
PICARD*: And this?*
(The book)
DATA: *A gift from you, sir.*
PICARD: *You value it?*
DATA: *Yes, sir.*
PICARD: *Why?*
DATA*: It is a reminder of friendship and service.*
(Picard activates the hologram of Tasha)
PICARD: *And this? You have no other portraits of your fellow crew members. Why this person?*
DATA*: I would prefer not to answer that question, sir. I gave my word.*
PICARD: *Under the circumstances, I don't think Tasha would mind.*
DATA: *She was special to me, sir. We were intimate.*
(Phillipa sits up)
PICARD: *Thank you, Commander. I have no further questions for this witness.*
PHILLIPA [the judge]: *Commander Riker, do you want to cross?*
RIKER: *I have no questions, Your Honour.*
PHILLIPA: *Thank you. You may step down.*
PICARD: *I call to the stand Commander Bruce Maddox as a hostile witness.*
COMPUTER: *Verify, Maddox, Bruce, Commander. Current assignment, Associate Chair*

of Robotics, Daystrom Technological Institute. Major papers
PICARD: *Yes, yes, yes. Suffice it to say, he's an expert. Commander, is your contention that Lieutenant Commander Data is not a sentient being and therefore not entitled to all the rights reserved for all life forms within this Federation?*
MADDOX: *Data is not sentient, no.*
PICARD: *Commander, would you enlighten us? What is required for sentience?*
MADDOX: *Intelligence, self awareness, consciousness.*
PICARD: *Prove to the court that I am sentient.*
MADDOX: *This is absurd! We all know you're sentient.*
PICARD: *So I am sentient, but Data is not?*
MADDOX: *That's right.*
PICARD: *Why? Why am I sentient?*
MADDOX: *Well, you are self aware.*
PICARD: *Ah, that's the second of your criteria. Let's deal with the first, intelligence. Is Commander Data intelligent?*
MADDOX: *Yes. It has the ability to learn and understand, and to cope with new situations.*
PICARD: *Like this hearing.*
MADDOX: *Yes.*
PICARD: *What about self awareness. What does that mean? Why am I self aware?*
MADDOX: Because you are conscious of your existence and actions. You are aware of yourself and your own ego.
PICARD: *Commander Data, what are you doing now?*
DATA: *I am taking part in a legal hearing to determine my rights and status. Am I a person or property?*
PICARD: *And what's at stake?*
DATA: *My right to choose. Perhaps my very life.*
PICARD: *My rights. My status. My right to choose. My life. It seems reasonably self aware to me. Commander? I'm waiting.*
MADDOX: *This is exceedingly difficult.*
PICARD: *Do you like Commander Data?*
MADDOX: *I don't know it well enough to like or dislike it.*
PICARD: *But you admire him?*
MADDOX: *Oh yes, it's an extraordinary piece of*
PICARD: *Engineering and programming. Yes, you have said that. Commander, you have devoted your life to the study of cybernetics in general?*
MADDOX: *Yes.*
PICARD: *And Commander Data in particular?*
MADDOX: *Yes.*
PICARD: *And now you propose to dismantle him.*
MADDOX: *So that I can learn from it and construct more.*
PICARD: *How many more?*
MADDOX: *As many as are needed. Hundreds, thousands if necessary. There is no limit.*
PICARD: *A single Data, and forgive me, Commander, is a curiosity. A wonder, even. But thousands of Datas. Isn't that becoming a race? And won't we be judged by how we treat that race? Now, tell me, Commander, what is Data?*

MADDOX: *I don't understand.*
PICARD: *What is he?*
MADDOX: *A machine!*
PICARD: *Is he? Are you sure?*
MADDOX: *Yes!*
PICARD: *You see, he's met two of your three criteria for sentience, so what if he meets the third. Consciousness in even the smallest degree. What is he then? I don't know. Do you? (to Riker) Do you? (to Phillipa) Do you? Well, that's the question you have to answer. Your Honour, the courtroom is a crucible. In it we burn away irrelevancies until we are left with a pure product, the truth for all time. Now, sooner or later, this man or others like him will succeed in replicating Commander Data. And the decision you reach here today will determine how we will regard this creation of our genius. It will reveal the kind of a people we are, what he is destined to be. It will reach far beyond this courtroom and this one android. It could significantly redefine the boundaries of personal liberty and freedom, expanding them for some, savagely curtailing them for others. Are you prepared to condemn him and all who come after him to servitude and slavery? Your Honour, Starfleet was founded to seek out new life. Well, there it sits. Waiting. You wanted a chance to make law. Well, here it is. Make a good one.*

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Refuge Plots

Arthur T. Johnson

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One mistake that is easy for a Biological Engineer to make is to aim for perfection in his or her designs. This includes perfect elimination of unwanted organisms. However, management and control, not total elimination, is the key to a successful biological strategy. Biocontrol can be achieved through the application of one or more living natural enemies, parasites or predators, or through the recruitment of natural tendencies, none of which are absolutely effective. Working in harmony with nature beats working against nature in the long run.

Biological scientists have made many impressive discoveries, and these can often be used as mechanisms to solve some puzzle needing fixing. Advances made in knowledge about genetics, behaviors, or toxins have been foundational for new methods and strategies to control pests, reduce disease, or increase yields. However, these seminal advancements have usually come one at a time, after much toil and travail, and unfortunately, they are then used one at a time to solve some problem of importance.

Redundancy is the hallmark of biological response. Whether the problem is pestilence, disease, predators, or environmental challenges, living things react to these affronts with multiple responses. The immune system is a great example of this, depending on not just one, but a whole host of means to thwart challengers to health and survival. It needs to be thus, because the biological threats themselves are constantly changing and attempting to nullify or avoid immune responses. The result is a dynamic, a biological parry and thrust, that rewards the strong and sacrifices the weak. Control of the target over the challenger is never totally achieved, but the target survives as long as it can, and that, in itself, is biological victory.

We as biological engineers have all too often depended upon unidimensional magic bullets to solve our problems. These remedies have included incorporation of individual genes, dependence on pesticides with one action mechanism, and saturation with toxins differentially poisonous to pathogens over hosts. The results are genetically modified crops, antibiotics *du jour*, anticancer drugs, and overuse of antiseptics. It's not that these solutions are bad, because they aren't, but they do not take into account that single mechanisms have not proven to be long-term solutions to problems. Pests can overcome single gene protections, microbes develop means to overcome antibiotics, cancers can survive drugs, and no antiseptic is guaranteed to kill all unwanted organisms. What one gets when one depends on a single magic bullet is a temporary victory at best.

Rather than try for a complete and total knockout of the enemy, a better solution may be, and usually is, one that establishes a dominance of the favored over the unfavored individuals. Thus, the ideal pesticide is not one that eliminates all individuals of a problem pest, it's the one that shifts the balance back in favor of natural enemies. The ideal antibiotic is not the one that cures the disease 100% of the time; it's the one that weakens disease organisms but does not select for antibiotic immunity. The ideal chemotoxic anti-cancer drug is not the one that kills all rapidly-growing cells; it's the one that favors effective immune system response.

There have been many modern incidences of invasive pests, and one strategy for dealing with them is to discover natural enemies that can bring invasive pests back into natural balance. We know that in order for these natural enemies to continue to be effective a small population of pests must be maintained. The result is not elimination of the pests, but a balance that can be tolerated.

Bt (*Bacillus thurengiensis*) corn is a genetically-modified grain that is poisonous to *Lepidoptera* larvae, such as corn earworm. This pest used to be very destructive to corn yields, but, since Bt corn has been grown, corn yields have increased greatly, with the additional benefit that chemical pesticides are no longer needed to control corn earworm. Bt corn is so good that farmers want to plant nothing else. Yet, 100% of a corn crop that is Bt corn would ultimately lead to corn earworm insects resistant to the protection of the Bt gene; Bt corn would no longer be effective.

Farmers are required to plant 5-15% of their corn crops to non-Bt corn. These are called *refuge plots*. Refuge plots reduce the reproductive pressure for all corn earworm insects to develop Bt resistance. With refuge plots, any Bt resistant insects have ample opportunity to mate with nonresistant insects, thus diluting resistance genomes and reducing the possibility that resistance will be passed on to the next insect generation.

The concept of refuge plots should be known by all Biological Engineers and be a candidate for application to many other situations. Not all household locations need to be spotlessly clean and not all hands need to be disinfected. Not all defective genes need to be eliminated, and not all microbial infections need to be treated with the most powerful antibiotics. Imagine, if you will, that MRSA (*methicillin-resistant Staphalococcus aureus*) would not have existed if antibiotics had not been so generally used. Some Staph patients could have fought the infection without the use of powerful antibiotics, perhaps with the help of some probiotics, and acted as refuge plots for nonresistant staph bacteria. *Staphalococcus aureus* bacteria are omnipresent on human skin, but kept from becoming a problem because of resource competition from other bacteria also on the skin. These other bacteria are the natural enemies of Staph that we could have exploited as part of our refuge plot strategy.

Agricultural fungicides are very important to protect fruit, grain, and vegetable crops from infections that could destroy them. The most effective fungicides are those with single modes of action. These are also the fungicides that promote disease resistance. Fungicide manufacturers are beginning to package these very effective single-mode pesticides with broad spectrum pesticides. Any disease that could develop resistance to the single-mode fungicide is killed by the broad spectrum fungicide. The second fungicide acts as the refuge plot for the first fungicide.

Biological Engineers should appreciate the value of natural mechanisms and work with them rather than trying to conquer nature. Total control of the entire biological system is not, nor ever will be, a possibility for a biological engineering solution. Balance, not perfection, is the key to successful designs.

Refuge Plots II

Arthur T. Johnson

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When we finally wrest the ultimate secrets of biological control, will we know how to use them wisely? There is evidence given in *Lancaster Farming* that we will not. In the November 10, 2012 issue, an article appeared that reported that the agricultural uses of herbicides and insecticides were on the increase after a short period of decline. What this means is that the advantages given to growers of genetically-modified (GMO) crops will be short-lived at best.

Remember that Roundup-Ready corn, soybeans, cotton, alfalfa, and other crops contained a gene that made these crops resistant to the popular and relatively less dangerous herbicide Glyphosate (commercially sold as Roundup). Spraying Roundup-Ready crops with Glyphosate would kill the unprotected weeds but leave the crop unharmed. Competition from weeds for water, nutrients, and light was eliminated, and crop yields increased greatly, with little increase in cost.

Bt (*Bacillus thuringiensis*) corn contains an inserted gene that kills the larvae of corn earworm, the most destructive pest of corn. Planting Bt corn eliminates the need for most insecticidal sprays, increasing yields while decreasing costs.

Scientists at Monsanto, the developer of Roundup-Ready crops knew that there was the possibility that something could go awry. Nature, after all, is nothing if not resilient. So, they recommended that 10% of crop area be planted with non-GMO varieties. This was later amended to be 15%. These areas were known as Refuge Plots.

The idea behind Refuge Plots was a good one. They were meant to allow the breeding and survival of weeds or insects not harmed by the genes inserted into the GMO crops. These pests would have no evolutionary pressure to become resistant to the inserted genes. Those weeds and insects that inevitably developed resistance to Glyphosate or Bt toxin would cross-breed with the nonresistant pests, and thus delay, or even eliminate resistances from passing to the next generation.

But guess what? Glyphosate-resistant weeds have become a real problem in Midwestern corn and soybean fields. So, now growers must not only spray Glyphosate, but they also must spray with more dangerous herbicides, such as 2,4D. As a result, the agricultural use of herbicides has gone up rather than down.

Left in the hands of scientists, these problems may have been avoided, but when practiced by a large segment of the populace, they have developed robustly.

This is a classic example of the cheater's dilemma. If there is an advantage to be gained by cheating, then the cheater wins the game. But, if everybody cheats, then everybody loses. There was an economic advantage to ignore the refuge plot and plant only the GMO crop. So, apparently, growers asked themselves why they had to relinquish the advantages of the GMO crops on 15% of their land and be satisfied with 85% of the profit they could have. Seeing no particular advantage for themselves to follow the recommendations, enough of them cheated. Now everyone pays the price.

If we think that it is only ignorant farmers who cause these problems, then we need only look to medical professionals to see that even among the learned the same tendencies prevail. Medicine has overused one powerful antibiotic after another, or, also, one powerful antimalarial drug after another. The refuge plots for these medicines were the instances that they were not required, allowing some medical conditions to heal without them. Instead, the wonder medicines were used nearly every time, and resistant organisms developed. The result of this is that pharmaceutical companies are scrambling to find new means to control or cure diseases.

This brings me to synthetic biology, using what we known about functional genomics to produce new living organisms to serve our needs. Scientists at NIH have for a while now issued a set of guidelines for the careful introduction of transgenic organisms into the environment. In general, these guidelines have worked well; environmental disasters of this kind have not happened.

But what happens when the development of new synthetic organisms becomes commonplace? They will probably have advantages, mostly economic, for their uses. Who will be able to keep the cheaters in check? How can we avoid the seemingly inevitable environmental disaster that could ensue when these new organisms escape confinement? History shows that we won’t be able to avoid the consequences.

We are rapidly approaching the time when we will know enough about genomes, epigenetics, gene regulatory mechanisms, cellular inclusions, and proteomes that we will be able to manipulate living organisms to do almost anything we dream possible. Synthetic organisms could be everywhere and do many wondrous things. Perhaps I am overly pessimistic abut these things, but I can see that it will take a whole lot of reasoning and wise agreement in order to avoid environmental disaster. After all, humanity has so far avoided blowing up the world with atomic bombs, but, in that case, everybody didn’t have one.

Refuge Plots III: Calibrated Personalized Medicine

Arthur T. Johnson

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Beekeepers know that *Varroa Destructor* mites are a constant threat to their honey bees, but they have learned that it is nearly impossible to eliminate all the mites from their hives. Instead, they monitor mite levels in their hives, and, when an economic threshold mite population has been reached, they treat with a miticide.

Orchardists know that insect pests are always lurking, but they cannot completely eliminate them. Instead, using integrated pest management (IPM), they monitor pest populations by trapping, and, when the pest numbers become high enough to cause potentially serious damage to the fruit, they spray insecticides to kill or disrupt the pests.

Farmers wishing to plant corn genetically-modified (GM) to kill insect pests are required to plant 5-15% of their corn crops to non-genetically-modified corn. These are called *refuge plots*. Refuge plots reduce the reproductive pressure for corn insect pests to develop resistance to the transfected genes. With refuge plots, any resistant insects have ample opportunity to mate with nonresistant insects, thus diluting resistance tendencies and reducing the possibility that resistance will be passed on to the next insect generation.

Why is it, then, that modern medicine tries to eliminate all traces of a disease-causing microbial assailant with chemical drugs given to the infected patient? There is a certain evolutionary advantage to allow a small portion of the infecting agents to survive the drug. That is because a less effective drug is less likely than a more effective drug to result in the development of microbial resistance to that medicine. Just as agricultural crop refuge plots allow non-resistant pests to persist and dilute the genetic pool of resistant pests, delaying resistance development in entire pest populations, antibiotics that kill 80-90% of microbes are much less likely to result in resistant microbes than are antibiotics that kill 99.9% of their targets.

When it comes to human medicine, we are no longer concerned only with whole populations of infected individuals; every victim has his or her own importance. Thus, the population probability density function shrinks to a sample size of one. Desperate to assure the recoveries of each and every ill patient, drugs are given at dosages designed to cure the vast majority of those infected with the disease. This guarantees that most patients are given higher doses of medicine for longer times than is needed. The result is that the drug effectively kills almost all of the infecting microbes and the only survivors are those resistant to the drug. These resistant microbes eventually form a new genetic population that is not diluted by non-resistant types.

Each patient has an immune system that is a marvel when dealing with foreign threats. These immune systems have evolved with complex multimodal mechanisms not likely to be overcome or to lead to developing resistant microbes. Some patients have more robust immune responses than others, but, usually when antibiotics are prescribed, this is an indication that immune responses have been inadequate to deal with an infection. Nevertheless, individual patient immune responses are still present when a drug is given; it’s just that they are all but forgotten in favor of the administered drug.

In addition to the immune system, there are genetic and protein correcting mechanisms at the molecular level to assure that errors in cellular genetic codes or misfolded proteins are either corrected or destroyed. These mechanisms, for instance, guard against the development and proliferation of cancer cells.

The collection of microbes on and in the physical bodies of humans, animals, and plants, called the microbiome, is becoming appreciated for its role in health maintenance. Knowledge is accumulating that the microbiome composition, although unique to each individual, can be classified into different groups either susceptible or resistant to different diseases. Microbes in the human gut, for instance, signal the host immune system as friends or foes, and that helps the body to distinguish between pathogenic and benign or beneficial organisms. Parasitic helminthes, although not usually considered part of the microbiome, can suppress overly sensitive immune responses that lead to autoimmune conditions. Medicines, especially antibiotics taken orally or disinfectants applied externally, can severely disrupt the complex interplay between guest and host, and lead to unwanted side effects. The result of all this is that each of us deals with health challenges in a unique way assisted by other organisms living in and on our bodies. Medical treatments can sometimes interfere with our inherent abilities to fend off disease.

There are other homeostatic guardians of the body, as well. For instance, small blood clots constantly form in the blood stream, but anticlotting mechanisms normally break these apart before they grow and disrupt blood flow in critical areas. Indeed, one of the hallmarks of human and biological health s a result of antagonistic action whereby one process performs one action and another process performs an action directly opposite to the first. Each of these processes may themselves be a complex combination of many supporting subprocesses. It is the difference between the results of these two processes that determines the ultimate course of action.

It is only when these mechanisms have been weakened or otherwise overwhelmed that remedial action must be taken to restore health. Despite the fact that some modern drug development is directed to boosting one natural function or another, many individual drugs still override the inherent correcting capabilities of the natural system still in place.

Personalized medicine is the catchword term used to describe the prediction of drug efficacy based on a genetic profile of the patient. Some drugs are much more effective when given to patients possessing certain genes than are other possible drugs. Personalized medicine has been used, especially, with the delivery of certain anticancer drugs.

Personalized medicine is really a misnomer. It is really just another means to categorize patients into smaller groups than before. The classification biomarker scheme is the presence or absence of certain genes. Once this information is determined through genetic testing, then personalized medicine devolves again into responses expected from populations of individuals with identical genetic makeup. This may or may not be sufficient to predict what effect the treatment may have on the individual patient. This brings us back to the problem of a sample size of one.

Although the personalized medicine approach does narrow the choices for drugs likely to be effective in the treatment of the disorder, it is only the first step; it only indicates the tool to be used, but it hasn't as yet included quantitative information relevant to the patient, and, especially, the ability of the patient's inherent abilities to help combat the disease. Every engineer knows that the first step to the solution of a problem is to choose the method, but the second step is to determine by measurement and analysis quantitative details of the solution. How big does the column have to be to support the expected load or how much heat is required to fractionate petroleum? Personalized medicine has not yet included quantitative measurement.

A mechanic needing to tighten a nut can choose a torque wrench to do the job, but he also needs to know how many foot-pounds of torque to apply. A surgeon can choose a scalpel to cut through the skin, but he needs to know how deep to cut. A respiratory therapist can choose a bronchodilating medicine to administer to a patient, but he must also know how much to give.

Personalized medicine needs to calibrate each patient to determine the ability of each to fend off disease. To do so will require more biomarkers than just gene type. There will have to be measurements made of the inherent capabilities of the patient's immune responses, or genetic correction mechanisms, or protein guardian processes, or other relevant determinations. Accounting for inherent patient capacity to deal with health challenges, treatments and dosages can be tailored to the needs of the individual, with the goal to give only enough drug to fill the gap between an individual's ability to deal with the health threat and the actual level of the health challenge. In that way, it is likely that most patients will not be prescribed enough of the drug to be 99% effective, but rather to be 80-90% effective. The other 10-20% (or more) required to overcome the health threat would come from the patient him- or herself. The result would be a more sustainable medical system.

One disease treatment that comes close to this type of calibrated personalized medicine is that for diabetes (both Type I and Type II). Blood glucose level is monitored at frequent intervals, and insulin (if needed) is administered at a level based on need. Some systems even have indwelling glucose monitors and insulin pumps to give just the right amount of drug to control blood glucose within tight limits. If there is still some, but not enough, insulin production in the pancreas of a Type I diabetic, than less insulin is externally administered than would otherwise be the case.

The hygiene hypothesis submits that challenges to the immune systems of children helps them to distinguish between those threats that must be fought and those that don't. Our obsession with cleanliness sometimes prevents our immune systems from maturing in the most effective ways. The results range from extreme disease susceptibility to overactive autoimmunity. When drugs are given to children to cure normal childhood diseases, we may be inhibiting their immune systems to deal with future infections. So, calibrated personalized medicine may be especially important for the young. It is also possible that some hygiene effects may be seen in older adults as well.

Although the emphasis of this essay has been human medicine, there is a tie to other biological systems. As shown in the introductory paragraphs, some biological applications already incorporate some of these principles. However, the worth of the individual human is unique in the biological world. One cannot imagine a poultry framer testing each of his birds to administer just the right amount of antibiotic to maintain the health of each chicken. Likewise, one cannot imagine a botanist testing each ash tree to individually administer anti-borer medicine (although one might admit that certain pets could be individually treated). In these cases, the response expectations of the population of individuals would have to do, at least for now. But, in the long run, it is better to work with what the biological system gives than to ignore inherent capabilities, or, even worse, to work against them.

A Rose by Any Other Name is a Different Rose

Arthur T. Johnson

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The voting is over and the election is done. The people have spoken. There were winners and losers, sometimes the right ones and sometimes the wrong ones, but it is over.

I have learned a lot about biology, and one of the most stunning things I have learned is that voting preferences are 60% genetically determined. This was reported by Hatemi et al, (*Behavior Genetics*, 37(3): 435-448, 2007) from results of twin studies in Australia. This voting preference fact was brought to mind again by a recent study that identified a certain gene in people that made them more likely than others to have liberal tendencies. This so-called "liberal gene" apparently relates to dopamine receptors in the brain that makes those who possess them much more likely to have personalities open to new ideas (Settle et al, *Journal of Politics*, 72(4): 1189-1198, 2010).

It seems that, despite how much we protest, much of what we say or do is determined by some basic and primal characteristics over which we have little or no control. Our genes are powerful indeed, and have a lot to say about who we are and how we act.

There are those who would point to the 60% voting preference figure and forget the other 40% . These are the people who believe that if we could figure out what genes are present, and the functions of each of these genes, we could determine exactly what each microbe, plant, animal, and person is likely to do. The genome *uber alles*!

We are still on the cusp of the genetic revolution, and, as with all new technologies, the gene has been oversold. There is still that other 40%, and that's where my interest lies. What are the environmental factors that modify behaviors that would otherwise be predictable from the genes that are present?

Biology displays a complexity based upon many interactions, feedback loops, and redundancy. The genome is one example. We know that Mendelian genetics is only the simplest of cases; there are interactions, modifiers, competition, and overlappings among genes; there are epigenetics and transposons. A gene may be an active gene in one set of circumstances and may not act at all as a gene under other circumstances.

The genome serves as an information legacy to pass successful biological characteristics from one generation to the next. However, it is not the only such legacy. There is cultural information taught by members of older generations to those younger than themselves (so called memes). This mode of information transfer has been particularly successful for humans, but has also been advantageous for survival and reproduction of mammals and birds (and perhaps other animals). Another information legacy is in the microbes we carry in numbers ten times as many as our own human somatic cells. These microbes are very important to our health and survival, and, because of this, are passed down from generation to generation. They are so important, that probiotics, microbes normally passed from mother to infant during nursing, have been added to commercially-available infant formula. Microbes are passed from older cudchewing animals to their youngsters through fecal exposure. Nitrogen-fixing bacteria are passed from growing legumes to seedlings. This is truly an important information legacy.

A fourth information legacy appears in the form of prions, those misfolded proteins that are the cause of many degenerative diseases, such as Alzheimers and transmissible spongiform encephalopathy (TSE). Prions also may have positive effects in that they assist in the formation of new neural memory connections in the brain. Importantly, prions can self-replicate; they don't need the DNA-RNA-ribosomal-protein process that other proteins require. These prions may be passed from one individual to another as a source of information.

So, there you have it. Four types of information storage and transfer, only one of which, the genome, has generally been credited with wondrous properties. How much of the other 40% is determined by the alternative three legacies is not yet known, but there are challenges for bio-based engineers and scientists to find out. Once we know, and our comprehensive models can truly and accurately predict outcomes, we won't need to endure endless Robocalls, TV ads, and the surprises that result from real live voting.

The Fallacy of Genetic Selection

Arthur T. Johnson

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"Genetic elements … contribute to survival and reproduction of the organism. Those that do not are quickly weeded out by selection." – Rob Dorit, in American Scientist, vol. 101(5): p 345.

This common statement, and ones like it, are grossly misleading. The assumption behind the assertion that genes are either useful and present or harmful and extirpated is that this is a binary situation where genes are either one way or the other. The reality is that there are more than two choices, and, more likely, a gradation from highly undesirable to the organism to highly desirable, with the intensity of natural selection graded as well.

Examining the simplest case first, there are genes that are neither helpful nor harmful. These may have been vestiges of genetic history, passed down through the ancestral lineage that led to a particular generation, and that once may have been very useful to some preceding organism. As long as there is no penalty for these genes to remain in the genome, there is no selection pressure to remove them. Likewise, unexpressed genes, those that are hidden deep within the balled-up histone, or those made ineffective through epigenetic processes, cannot have any effect on the organism one way or another, and thus would have no selection bias.

Natural selection and genetics are more complex than often realized. There is *antagonistic pleiotropy*, for instance, which is the term given to a gene that has a strong positive reproductive effect on the young and an adverse impact on the old. Such a gene will be retained in individuals of the species because of its dominant effect during the reproductive years, despite the fact that it may disadvantage those same individuals later in life. It has been thought that male humans have genetically shorter life spans than female humans because they possess more of these antagonistic pleiotropic genes than do female humans.

There is also a multi-level genetic selection, where the survival of certain genes operates for ecosystems as a whole, populations within ecosystems, species within populations, individuals within species, and specific competitive genes within an individual genome. All genetics are contained in the cells of an individual, to be sure, but individual genomes can support these other levels to the benefit of genetic survival and reproduction. Multi-level genetic selection can provide opportunity for the retention of genes that have no particular benefit for the individual, but can support an ecosystem, for instance. This opens the possibility that cooperation among species, rather than competition, can be a driver of natural selection. Examples of this might be nitrogen-fixing bacteria living within the roots of leguminous plants, the giant green anemone as a fusion (chimera) of green algal cells with the animal tissues of the anemone, the amalgamation of sundry organs to form a complex multicellular organism, and the digestive microbiomes in humans and animals. Genes that allow such cooperation could be retained in an individual genome because the overall benefit of retention exceeds the cost to an individual of maintaining the genes.

There has long been a genetic mystery about retention of genes that are clearly somewhat disadvantageous to the reproduction of individuals of a species, but, which, nonetheless, are retained in the genome throughout many generations. The principle of survival of the fittest (natural selection) would seem to dictate that only the genes most beneficial for survival and reproduction of individuals would remain in the genome; all others would be lost over time. However, that is not always the case. There is genetic material clearly not optimum in the genomes of some individuals of a given species.

This mystery may be explained by considering natural selection in a multi-level context. Yes, natural selection would seem to indicate that for any given organism it would be best to carry the genes that maximize survival and reproduction, but, from a species standpoint, looking at it from a vantage point above each single organism, the species can survive best if it maintains some genetic diversity that allows it to meet unforeseen environmental challenges. No realistic environment is so invariant that one set of genes is the only one to meet the test of natural selection.

Engineers can look at this as an optimization process. Biological optima are rarely narrow; they are more likely to be broad as long as deviations from the exact optimum do not carry penalties too large. Retaining genes that are beneficial to survival and reproduction, just not as beneficial as some other genes, is a strategy that carries some small penalty for certain individuals, but allows them to survive better than their relatives if the reproductive environment undergoes changes. Thus, the whole species is not disadvantaged.

Thorough understanding of genetic dynamics is useful to all engineers dealing with biological systems. That is why we must question oversimplifications similar to the above quote. Natural selection, as powerful as it is, is not always as simple as it seems.

Hands

Arthur T. Johnson

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Hands are awesome. Hands are marvelous in every sense of the word, and are as important to us collectively and individually as are our intellects. Hands are the difference between thinking and doing. There may be other creatures in this world that have intelligence, but if they don't have hands, they cannot act on that intelligence. They cannot make things and place things. Without hands, they are trapped in a world that they cannot control. We should appreciate our hands; they have let us change our environments for good and bad, but always to our will.

Hands can do so many things: a soft touch, a strong handshake, a means to write and to type. Hands relieve an itch, point in a direction, pick a four-leaf clover, slice a tomato, hold an apple, twirl a baton, swat a mosquito, turn a door knob, propel and launch a paper airplane, hold a railing, unwrap a gift, form and throw a snowball, paint a picture, snap a photograph, form a ceramic piece, tie shoes, operate a computer or a diesel truck, climb a ladder, weld a brace, apply tape, hammer a nail, hang a picture, tighten a nut, adjust a volume control, and connect us to our loved ones, so many things we don't even think about.

They can hold on to things both large and small; they are capable of strength at times or yet precise gentleness at others. They feel. They caress. Their gentle touch can reassure; their strong grip can convey strength. They are expressive. Open hands convey receptivity; closed hands signal belligerence. For people unable to hear, hands are the means to communicate; when hearing is not impaired, hands reinforce what is being said. When they work correctly, as with all other parts of the human body, hands are miraculous. When they do not work well, as when arthritis strikes, hands can cause anguish.

A little story illustrates then importance of hands. It seems that a man died and was given the choice about whether to spend the rest of eternity in heaven or hell. He asked to see them both before he made his decision. In hell, he saw that the people had the most luscious food to eat piled high on tables in front of them, but that their arms were strapped so that they couldn't bend at the elbows. They could pick up the delicious morsels, but their hands couldn't deliver the food to their mouths. They anguished over the frustration of not being able to satisfy their hunger. In heaven he saw the same thing: great food and arms strapped stiff so that they couldn't bring the food to their mouths. But the residents were not hungry and frustrated as they were in hell. The difference was that in heaven the people were feeding each other.

When I look at other animals trying to eat foods such as apples, so easy for us to hold as we bite into them, I realize how lucky I am to have hands that operate as they do. Especially if the fruit is bigger than the size that fits readily into their mouths, they really have difficulty taking bites. If such a food is bigger than we can easily fit into our mouths, we can always use our hands to cut the food into smaller pieces.

As I look at my hands now, I realize that they have become my father's hands. My hands used to be youthful with taut, smooth, unblemished skin; now they have dark spots, wrinkles, and protruding veins. This is how I remember my father's hands in the years before he died. His were strong hands, hands that had performed many years of manual labor, hands that fixed cars when we could not afford to hire a mechanic, hands that held my children when they were small, hands that did not quiver as some do when they age. But, they showed his age, and that's what mine have become, too.

I never thought it would come to this. My hands were once young and strong. They could be gentle when needed; they could place a small electrical resistor in a circuit board or hold delicate thermocouple wires as I soldered them together. They could also be strong when used to open a tightly-closed pickle jar lid or hold a rope with a steer on the other end. These hands of mine, they always did what they were told, and they hardly ever complained.

When I was in high school, we frequently played softball in the springtime. I loved to play center field; from that position, I could see everything happening in front of me, I could run around to back up the other fielders, and I could make spectacular catches of fly balls hit my way. When I didn't remember to bring my glove, I played anyway, and my hands, always on the larger side, could catch those fly balls with nary a problem. I became known for my bare-handed catches.

During and after college, I used my hands in artistic ways. I took up the guitar, and used my hands to entertain me and others around me. I had to play a 12-string guitar because the size of the neck on a 6-string guitar was a little too small to fit my large fingers comfortably. The sound of a 12-string guitar was pleasant to my ear, so I enjoyed playing. I also painted on canvas and tried a little sculpting. Although not museum-quality masterpieces, these works helped me to express my creativity in ways that nothing else could satisfy. These hands of mine have done a lot of things that have made my existence richer and more fulfilling than would have been the case without them.

I have always thought of the healthy human body as a technological marvel. The way that everything works together, much of it automatically, and most submissive to our will, can be beyond belief. If we, as engineers, had to design a human body from scratch, we could do not an iota as well as the body each of us has without thinking of it. And a large part of that is due to the hands we have that make life better through manipulation. Even my hands, which have now become as my father's, are still a source of comfort, satisfaction, and awe.

We appreciate comfy warm gloves in winter's bitter cold; how much more thankful we should be for the hands that fill the gloves.

Genetic Discrimination and Racism

Arthur T. Johnson

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Discrimination seems to be an intrinsic trait inherent in our very being. We, as people, seem to be disposed to discriminate either for or against those who, for one reason or another, are unlike us. This dissimilarity may be recognized in speech, dress, comportment, age, or a host of other differences. Thus, there is discrimination against people speaking different languages (as between French and English speakers in Canada), wear different clothes (e.g., different clothing items dictated by religious customs), physical capabilities (e.g., obvious physical, mental, or vocal disabilities), or ageism (e.g., the elderly complaining about today's youth or the young treating the old with disdain). Skin color, even among different shades, is a divisive attribute, as is social rank. Each of these is a recognition of unrelatedness and a cause for discrimination. It is likely that there is a biological explanation for at least a part of this bias, and it goes back to the very basics: genes, competition, and evolution.

Biology is often looked at as a confusing collection of many unrelated facts, when, instead, many of these facts fall into line to form principles that are easily understood and very powerful in their abilities to explain present actions and predict future outcomes. Such is the case with genes and discrimination.

Let's look at the facts: we know that genes are chemicals that are uniquely driven to reproduce exactly and indiscriminately. Genes at the most fundamental level compete with each other for dominance, by which we mean the ability to use all the resources available and to reproduce as much as possible. This competition exists even within the individual genome (Dawkins, 1989; Ganetsky, 2000). There are cheating genes, jumping genes and assassination genes, which place themselves in more favorable positions to reproduce compared to their neighbor genes (Johnson, 2011). They seem to tolerate the presence of other genes as long as those other genes are necessary for their survival and reproduction. In fact, the genomes of living individuals are collections of mutually supportive genes that do their best to survive together as a group. Each additional gene had better improve the likelihood of group survivability or there would be no justification to expend the resources necessary to maintain that additional gene. A gene that does not improve chances of survival and reproduction would be expected to be lost over time (see also, Johnson, 2014).

Individuals carrying these genomes act in ways expected to give their genes the best chances for survival and reproduction. Living things almost always go to great lengths to avoid death (e.g., the stories about trapped animals chewing off their limbs to escape and live, albeit with a handicap, are true).The drive to reproduce is at least as strong as the will to survive because failure to reproduce greatly increases the chance of the gene eventually dying out.

We also know that favoritism among individuals is strongest for those that are most closely related and most likely to share the same genes. Parents and children, for instance, share one-half of their genes. Siblings also have one-half of their genes in common. Grandparents share one-quarter of their genes with their grandchildren. More distant relatives share smaller and smaller proportions of the same genes. The willingness of an individual to share limited resources with other individuals appears generally in accordance with the likely proportion of shared genes. This is called Hamilton's Rule (Hamilton, 1964 A&B).

People, it seems, generally act in the same way. For example, when it comes to choosing their mates, they seem to maximize the likelihood that they will share as much genetic material as possible with their prospective partners. Many men and women choose partners who have similar facial features (Johnson, 2011), as if these features reveal similar genomes (perhaps this is because similar features remind them of their parents and the high proportion of genes they share). Indeed, to find a match, the dating service Three Day Rule examines facial shape, jaw structure, and eye and nose coordinates, among other candidate attributes. A recent study of married couples in the U.S. show that paired couples share a higher share of genetic material than would randomized pairings (Domingue et al., 2014). Vertebrate and invertebrate matings of adults of both sexes also prefer certain mating partners over other candidates (Ackerman, 2006; Purdy, 2005). When these adults were allowed to mate with their preferred partners, the survivability of the offspring exceeded those from partners chosen at random. This can be taken as evidence that genetic favoritism operates over a broad range of hierarchical levels.

The ability to recognize similar or dissimilar genes in other people is deeply ingrained in our fundamental selves. The closer our relationships, the more we favor those individuals; the farther apart we are, the more we recognize the differences. We treat diversities as excuses to direct our positive attitudes elsewhere, especially if we consider dissimilar individuals as competing for limited financial, physical, or emotional resources.

One troubling form of discrimination is racism. Racism exists in many forms and many places; it is especially noted whenever different races come in close contact with each other. Fortunately, I have observed over the course of my lifetime that racism in the U.S. has diminished somewhat, although no one dare says that racism is even close to being eradicated in our country. Having lived through the time of the civil rights marches fifty years ago, listened to and taken to heart the words of Martin Luther King Jr., and admired the courage and resolution of Rosa Parks, I am very happy with this trend. And, it seems that the acceptance of other races is being led by the young, who seem to be much more tolerant than their parents.

Discrimination may be a natural consequence of our genomes, but discrimination does not have to turn into racism. In order to keep that from happening, we should become more familiar with the other people so that the differences become less important compared to the similarities we discover. If we no longer consider relationships as competitive, then we can act in a more generous and tolerant way. Engineering success, which should be based on merit and cooperation, can become a model of the way that we wish society in general should behave. In this case, we can exercise another deeply-ingrained biological attribute, that of fairness and altruism, also embedded in our genomes (Brosnan and DeWaal, 2003; Range et al., 2009). That should make it easier to move beyond the extremes of discrimination originating with our genes.

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Part 7

Medicine

A Fight Worth Fighting

Arthur T. Johnson

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"*Anything that doesn't fit into the political appointees' ideological, theological, or political agenda is ignored, marginalized, or simply buried*," said former Surgeon General, Dr. Richard Carmona, as quoted in the Baltimore Sun. Three past surgeons general, including Carmona, C. Everett Koop, and David Satcher testified before Congress that they had each encountered political interference against medical positions on morally-sensitive issues. Reports of similar complaints by other scientists are numerous.

Granted that some of these issues, such as sexuality, drug use, and global warming can evoke heated responses and varied positions, but unless government officials are willing to assert that their experiences and qualifications are more than equal to those whom they select for high office based upon their lifetime careers in medical, scientific, or engineering careers, then government officials should defer to the opinions and judgments of those appointees. A surgeon general, for instance, is the nation's physician, and, as such, is concerned with the physical health and well-being of the populace. Moral judgments are not part of this field. Often, as a matter of fact, physicians must appear to be amoral in order to be effective with their primary responsibility.

The Union of Concerned Scientists (UCS) recently surveyed 1,586 Environmental Protection Agency (EPA) scientists. Of the anonymous survey respondents, 889 reported that they had been subjected to political interference in at least one instance. EPA regional administrator Mary Gade was fired because she requested a chemical industry cleanup of a dioxin-contaminated site in Michigan (IST, 2008).

There was a time when science and science advisors were respected by government officials and whose counsel was highly regarded. Vannevar Bush during World War II was one of President Franklin Roosevelt's closest advisors. When the Soviet Union launched Sputnik in 1957, President Dwight Eisenhower quickly established the President's Science Advisory Committee (PSAC) with James Killian at its head (Mahoney, 2008). The relationship between the President and his science advisors was very close, and this relationship continued under President John Kennedy.

President Lyndon Johnson came into conflict with PSAC advice over antiballistic missiles, supersonic transports, and the conduct of the Vietnam War. Donald Hornig, science advisor to Lyndon Johnson, wrote "*There is nothing sadder than an advisor whose advice isn't wanted*". President Richard Nixon abolished the PSAC, but it was restored later in modified form by President Gerald Ford. Since then, presidential science advisors have advised, but have been largely relegated to the sidelines of policy formulation.

Because of the authority they represent, governmental positions are often readily accepted as truth. Because of the access that government has to its citizens, it has the advantage of information dissemination. Dissenting scientists and engineers are severely disadvantaged, even if they have the weight of proven, sound scientific evidence on their side. They may never be heard by a great portion of the citizenry.

As much as scientists have been ignored by political leaders, we have not before seen actual large-scale interference with conclusions based upon scientific facts. The situation existing at present is reprehensible and deeply disturbing.

In his new book, *True Enough: Learning to Live in a Post-Fact Society*, Farhad Manjoo has shone a spotlight on spin. Different news organizations present the same news in different ways, and the result is that the public has formed vastly different impressions of factuality. Our public these days believes what it wants to believe, and the facts be damned! So, there is no scientific evidence that cannot be refuted by a pseudo-scientist, and there is no scientific evidence that cannot be overcome by personal belief. Sad, isn't it?

When asked about the governmental policies that most need attention, many of us would answer with some issue related to funding of science and engineering research. Although funding is very important, I think political interference is much more important. Many of us have been so accustomed to academic freedom that we have perhaps forgotten just how precious it is. Taking for granted the ability to present facts, accept evidence, and conclude based upon the evidence, and the failure to defend against assaults to this freedom, may ultimately result in its loss. Freedom should trump funding.

BMES members, and the BMES organization as a whole, should be deeply disturbed about governmental interference in issues related to medical, scientific, or engineering information and its dissemination. We simply cannot accept scientific truth based on investigational evidence and at the same time tolerate positions either not based on evidence, or, in some cases, completely ignoring evidence.

With the new governmental administration in place, we can hope that political interference in policies related to scientific evidence will no longer continue. Given recent past history, however, it would be wise for all of us to keep watch, that such interference does not happen again. We need to monitor the government, and we need to take every opportunity to educate the public about sound science, and what sound science means. It is the public, after all, that allowed this interference to continue.

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Caution: Medical Technology Can Be Dangerous to Your Health

Arthur T. Johnson

Published in the BMES Bulletin vol. 34(1), February 2010.

News item: It was reported in the *Archives of Internal Medicine* (Redberg, 2009) that Americans are overexposed to radiation from diagnostic tests. Radiation from CT scans done in 2007 will cause 29,000 cancers and kill nearly 15,000 Americans.

We may be tempted to defend CT scans and the benefits derived from their continued use. We may feel that medical technology is always beneficial, and that attacks on medical technology hits us in our technological solar plexuses. Biomedical engineers, after all, spend large amounts of time, effort, and resources to develop these technologies—make them work, make them reliable, and make them affordable. These things are undeniable, and have made modern medical health care the best that it has ever been. Patients suffering from trauma or disease are now surviving, whereas a century ago they would have died or been severely incapacitated.

But before we completely dismiss negative comments about the medical technologies we have spent so much of our very beings developing, we must admit that even the safest technologies have limits. We have not, and cannot, assure that medical technologies will always be used correctly, or that medical equipment will always function as intended.

Related to the above news item is another that was recently in the news. Direct consumer advertising about the benefits of robotic prostate surgery has prompted a number of patients to elect robotic surgery over traditional surgical methods or other types of procedures dealing with prostate cancer. The only problem with their choice is that it has been shown that, at least at this stage in the technology cycle, complications of robotic surgery are worse than for other surgical methods (Hu et al., 2009).

Drugs are part of modern medical technology, and direct advertising of pharmaceuticals to consumers is clearly with us, and apparently paying off for pharmaceutical manufacturers. Patients see the ads and claimed benefits, but apparently do not pay attention to side effect risks of using the drugs. Patients with varying degrees of desperation try to insist on choosing their own methods of treatment without knowing the risks. The results can sometimes be disastrous for the patients. Just recently we have learned that the pain killer Vioxx poses serious risks of heart attacks and stroke. The drug Baycol lowers cholesterol, but also causes kidney failure.

In order for medicines to be effective for a vast majority of those taking the drugs, more sensitive patients must receive an overdose. That means that the standard dosage for at least half of the patients is too large, and the risks-to-benefit ratios of these medicines rises accordingly. Until personalized medicine becomes a reality, this situation will continue to prevail.

Defensive medicine is too easily practiced with modern medical technologies. If one CT scan is good, are not two better? Certainly, two have a better chance than one of keeping the lawyers at bay, but do they result in better care? That is arguable, but the long-term risks of radiation exposure are cumulative. Two CT scans have twice the DNA-damaging risk without twice the benefit. That should give pause to those who would over-prescribe X-ray exposures.

As a personal case in point, my wife Cathy had a serious fall on 1 September 2009. She suffered a fractured skull and cranial bleeding in the occipital lobe of her brain. She was brought to a local hospital and then to the Shock Trauma facility in Baltimore. Her condition was very serious. This is a list of the X-ray procedures she was given:

1 Sept	Chest X-ray
1 Sept	CT scan of head/brain
1 Sept	CT scan of maxillofacial area
1 Sept	CT scan of neck/spine
2 Sept	CT scan of head/brain
2 Sept	CT scan of thorax
2 Sept	CT scan of head/brain
2 Sept	CT scan of head/brain
2 Sept	Chest X-ray
2 Sept	CT scan of abdomen
2 Sept	CT scan of neck
2 Sept	CT scan of pelvis
2 Sept	X-ray exam of pelvis
2 Sept	CT scan of pelvis
2 Sept	CT scan of thorax
2 Sept	CT scan of head/brain
3 Sept	CT scan of head/brain
3 Sept	Chest X-ray
4 Sept	Chest X-ray
4 Sept	X-ray exam of abdomen
4 Sept	Chest X-ray

She has fortunately recovered nearly completely, but were all these necessary? Will there be any long-term effects? We'll have to see. But, in the meantime, she will insist that her dentist forego the use of X-rays in his exams over the next few years. What else can she do?

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Is It Really Personalized Medicine?

Arthur T. Johnson

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They call it personalized medicine, genetic testing of the patient to determine the predicted efficacies of an array of alternative pharmaceuticals. Some of these may be more effective and some of these may be metabolized differently. The choice of medicine to administer for everything from cancer to depression is improved if we know beforehand the presence of indicative genetic markers.

Knowing that each person's health history depends only partially on the genetic blueprint carried by that person, I wonder where all this is going. Certainly, improvements in medical treatments should be able to be made as more information about the patient becomes known. But, the presence of certain genes tells only part of the story. Whether those genes are expressed or not is important, and so are the many environmental factors that make life so unpredictable. If Uncle John stepped into a vat of acetone, I think he would probably be treated to counteract its toxic effects no matter what his genome said.

Years ago, there was a group of researchers who placed a lot of faith in the "physiome" project. The hope of this work was that knowing the full genetic complement of a person would completely determine her or his characteristics. But there is a difference, sometimes very large, between the genotype and the phenotype of a person. Each living organism is a product, not only of its genetics, but also its physical, chemical, and biological environments. The present outcome for all living things is a chaotic (in the mathematical sense) result of the entire sum of all past experiences (recently called the "exposome"), and, given what we know about epigenetics, some past experiences of those who predate us.

Personalized medicine certainly is a great catch phrase that captures a lot of attention. But, it seems that patients are only being distributed among smaller queues. Instead of blindly prescribing a few standard drugs to everyone and monitoring the results to see if they have the desired effect, prior genetic testing can now be used to make this less of a trial-and-error medical adventure. This, in itself, is good. But is it really "personalized medicine"? I think not.

My experiences in hospitals, both as a biomedical engineer working there and as the husband of a trauma patient, is that there is little personalized anything in a hospital setting. A hospital is largely a get 'em well factory with sick patients in and (we hope) cured patients out.

Truly personalized medicine will come about when primary care physicians become the central core of medical care. Especially if a long-term relationship has been developed between the physician and the patient, the primary care physician knows much more about the patient, including life style, occupation, health history, and medical preferences than is likely to be known by doctors and nurses in the get ‘em well factory. This intimate knowledge needs to be incorporated into the factory routine.

More detail about a patient’s genome is useful, but does not, by itself, lead to personalized treatment. Only recognition of the patient as a human being worthy of respect will do this. I have suggested that this respect can come from enhanced involvement by primary care physicians, and this may be a heavy burden for them to bear. What personalized medicine really needs is more primary care physicians and fewer specialists.

Part 8

Health

To Keep the Well, Well

Arthur T. Johnson

Published in the BMES Bulletin vol. 32(3) 2008.

It was my opportunity and privilege to spend the year on sabbatical leave at the Shock-Trauma Center in Baltimore. I was able to witness first-hand the cases of severe injury that came in each day, the intensity of activity, and the tragedy of lives forever changed by events that may have taken milliseconds to unfold.

I attended morning rounds and listened as arguments ensued about the best ways to treat each patient. The surgeon would say that he thought a certain activity was best for the patient; the radiologist would point to his x-ray photos and point out why something different needed to be done; the chief nurse would offer something completely different from what the other two had said. Indeed, there may have been twenty people in that room, and at least half of them had their own opinion for treatments that they advocated.

In those days, trauma medicine was still young, and many of the injuries that came to the center had not been seen before. So, it was natural that there should have been so many different ideas for treatment. Yet, what I found most interesting was the egalitarian nature of the discussions. There seemed to be no rank in the room, no social hierarchy. All who had opinions could express them freely, and the final course of treatment was worked out among those with interest in the case. I was never fully aware of the social mechanics of the way treatment decisions came about, but there was closure every day, and each case would be discussed anew on the next day, then with newer information available.

I learned a few good lessons during that year. Above all, I learned that my interest was not to spend my effort among the infirm. I knew then that I did not want to patch up the injured or restore the sick. Instead, I wanted to concentrate on maintaining the health of the healthy, to keep people safe and out of hospitals. I had much more interest in the marvelous physiology of the healthy human body than in the workings of the injured, the sick, or the impaired. And, so, I rededicated myself to my work with protective clothing (and respiratory protective masks in particular) and to the development of the Airflow Perturbation Device to measure respiratory resistance noninvasively. Both have gone well since, and I am proud of any small contribution I have made to keeping people safe and healthy in their daily lives.

Since then I have talked to a number of other people who have the same feeling. Yes, many budding biomedical engineers want to work with the ill, either directly or indirectly, but there are those who would rather prevent injury and forestall illness. I applaud these men and women, because they seem to realize that protecting the many, normal people out there is just as important, nay more important, than healing the sick. The glory may accrue to the one who develops the perfect prosthesis, or who can tissue-engineer a new heart, or who can find a cure for AIDS, but the really noble activity is associated with those who can keep those conditions from happening in the first place. A respirator mask may seem mundane, and may not be very glamorous, but it has prevented debilitating disease that accumulates with time working in dangerous conditions. My hat is off to all who have made life safer for the vast majority of us, most who will never have to find themselves as patients in a shock-trauma center like the one in Baltimore, most who can look forward to safe, productive, and fulfilling lives.

PPE and Productivity

Arthur T. Johnson

Appeared in the AIHA Synergist, November 2005.

I recently read the February 2005 *Synergist* article (pp. 32-33) on PPE (personal protective equipment) costs by Ryan Stewart. In this article, Stewart considers many costs that determine choices of PPE equipment, and he makes good points about selections to be made. But there is one cost item that was not included that can have a large effect, and that is worker performance degradation due to the use of PPE.

There are many competing choices for various PPE items. Selections can be made in the manner that Stewart suggests, or solely on initial cost, or using other rational or irrational reasons. In almost no instance that I know of, the choice can be made on worker productivity while using that PPE item. Considering the amount of time that a worker is encumbered with PPE, performance degradation can result in an overall cost much larger than any other factor.

For example, scratched lenses on a respirator that degrade visual acuity form 20/20 to 20/30 result in a 20 percent reduction in correct responses on a console-monitoring task. This reduction in performance could be very costly from an economic or safety standpoint.

In our continuing work with respirators, we have focused on task performance as the bottom line, integrative figure of merit by which respirators should be evaluated. From the wearer viewpoint, such a focus makes sense because a worker who feels better about his PPE will work better and more productively. The PPE will be better tolerated, and more likely to be worn. From the corporate side, higher productivity means greater output or less cost. PPE that interferes greatly with task performance can cause workers to need either more time or more help to complete a task. As with many economic choices, initial costs for PPE are often comparatively very much smaller than continuing operating costs.

Recommendations for specific PPE items would often be better tolerated if worker performance while wearing those items were taken into account. Industrial hygienists who consider productivity while still maintaining adequate protection for wearers would also demonstrate that they are trying to help both employer and employees.

Unfortunately, at this point there is little productivity data available by which PPE choices may be compared. There is a lot of work to be done, and a good deal of it could be done locally by individual industrial hygienists. An accumulation of such productivity data would be of help to project managers seeking to estimate costs of new projects, supervisors who need to know how much time and effort to expend to complete a job, workers who would have a better basis for their uses of PPE, and PPE manufacturers who would know which of their innovations actually have merit.

Another benefit of such productivity data would be that, when all costs are taken into account, the cost of engineering controls may not appear so prohibitive. The workplace may become much safer.

The cheapest PPE for the employer is PPE not purchased. The most expensive PPE for the worker is PPE not used. What we want is to see PPE purchased and used, both for the same reason: it is the best available.

Part 9

Other

The High Cost of Belonging

Arthur T. Johnson

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Knowing about and thoroughly understanding biology can help one to understand all kinds of human affairs. Take the costly signaling theory of ritual, for instance (Sosis, 2004). When belonging to a group that conveys significant advantages (usually survival or reproductive advantages) to its members, there must be some substantial cost to join the group, some personal sacrifice that must be made, or the group membership advantages are likely to be diluted by members who use the benefits but who do not contribute to the group's well-being. These members are naturally called "cheaters".

The biological realm is replete with both intraspecific and interspecific cooperative groups for defense, hunting, or resource allocations. Social insects such as ants, bees, and termites do it; lichens, legumes and nitrogen-fixing bacteria, and grasses and endophytes do it; herds of bisons, lions, and chimpanzees do it; even religious and social human beings do it. In each of these cases, there has had to be some major cost to the individual organism for the group as a whole to thrive.

Without significant personal sacrifice, a large number of unsupportive cheaters can ruin the group. The group fails and disappears. Natural selection operates at the group level as much as it does at the organismal level (Johnson, 2011).

I was reading in *Time* magazine about the ongoing economic troubles in Europe (Foroohar, 2011). Stability of the Euro is being threatened by unsound economic policies by a handful of countries in the euro zone. These policies have led to the need to borrow huge amounts of money to stabilize their economies, but the risks to lenders are so high that the costs of borrowing have skyrocketed. Normally, countries with independent currencies can devalue their currencies, if need be, making things they sell cheaper and increasing their international economic competitiveness. That cannot be done within the euro zone with its common currency and monetary system.

What does all this have to do with biological groups and personal sacrifice for membership? It seems to me that there is a close parallel here. There was no costly sacrifice required to join the European Economic Community. Countries accepted for membership were not required to relinquish portions of their national sovereignty for the common good. Countries using the Euro could pursue national policies that eventually cost more than could be sustained.

There are few choices left. If it is not too late for the community to survive, then high costs of membership will soon have to be extracted. If not, then the Euro as it now exists is history. That's biology, but it's also economics.

A thorough understanding of the workings of biology imparts perspective relating to many diverse human affairs. It seems that few national leaders have this biological understanding. Perhaps it would be to everyone's benefit to elect as national leaders a few good bioengineers.

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It's All Positive

Arthur T. Johnson

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Taken as a whole, the research literature is dishonest. At the very least, it can be considered somewhat misleading. That is because negative results are usually not publishable. Those of us who conduct research and publish the results know that our experiments hardly ever work the first time. There are protocol adjustments to make, temperatures to control, additional measurements to make, timing issues, calibration problems, and a host of other reasons why failures occur. Biological experiments are often much more sensitive to specific conditions than are other kinds. Enzymes require optimal conditions to be effective, biochemicals degrade with time, target cells adapt to new environments, and temperature fluctuations may have profound effects. There are so many reasons why an experiment may not have the expected results that extreme care is usually required to b successful. Sometimes they also take trial-and-error, or even luck, to succeed.

Those who read the literature can easily be misled. After all, the papers they read overwhelmingly describe successful outcomes. Very often, the unsuccessful trials that led to successful outcomes are not mentioned. Sensitive conditions for success are not usually emphasized, even if mentioned at all. If one were to try to replicate an experiment, the best thing to do is to contact the experimenter to find out details of what actually was done. Otherwise, the path to a successful outcome could become very tortuous. All this is almost never written in a published paper.

A case in point is a paper that I just published giving the results of visualization of flow pathways of leakages into respiratory protective masks. I had included in the paper the means we had used to generate visible particulate smoke to see the paths taken by the smoke between the leakage sites and the mouth during inhalation. The more twisted the pathway, the longer it would take for the wearer to inhale potentially contaminated air, and the more protection would be afforded by the mask.

This was not the first method to generate smoke that we tried. We had actually tried three or four other methods first. In order to let others know of our prior unsuccessful methods, I had included a short paragraph describing those other methods. One of the reviewers thought that it was useless to include this extra information, and that the paragraph should be eliminated. Without that paragraph, others who tried to conduct similar experiments might use our successful method first, but might not, because the successful method was more expensive than some of the unsuccessful alternatives. Retaining that paragraph might have helped others to avoid the same mistakes we had made. I insisted, and the paragraph was retained, but it could just as easily been eliminated.

It is easy to publish positive results, but difficult to publish negative results. Not all failures can be useful, but sometimes negative information can be positive.

Where Do You Get Your Technical Information?

Arthur T. Johnson

Appeared in the Fall 2007 issue of the IBE newsletter.

Biological engineering has often been described as multidisciplinary. I really would rather see it described as a single, distinct discipline of its own, but so broad that it needs to connect with many other scientific, engineering, and even some non-technical fields. No matter what you call it, biological engineering is broad, and its practitioners do need to keep up with advances in many directions that are coming at a very rapid pace. I can think of no more interesting and exciting work these days than the new discoveries about the workings of the brain.

The challenge for us teachers of biological engineering subjects is to keep current with all this new information in many fields often peripheral to our own research. I have found that what works best for me is to read (continually!) articles that summarize, explain, and connect sundry scientific advances, each of which has been the subject of its own published paper. Thus, journals such as *Science* and *Nature*, I have found, do not well serve my needs.

Instead, there are some publications that, more times than not, give me the information in the form that I need. First among these is *American Scientist* . There is no better source of information in the context of perspective than in this journal. The articles seem to be written at just the right level: to those of us who are scientifically literate, but unfamiliar with the details of specific areas of research. *American Scientist* articles are well-explained and interpreted, so that I can use that information almost immediately in my classes. *Scientific American* is similar, but does not fit my needs as well.

For general advances in technology, the *MIT Technology Review* is good, although it doesn't give me the interpretations and perspectives that I need. Its articles do not give enough depth of information nor explain how the information that is presented fits with other knowledge.

For information about basic biology, and especially cells and genetics, *HHMI*, a publication of the Howard Hughes Medical Institute, does a fine job. Its articles focus on individual Howard Hughes Medical Investigators and the work that they do. Interviews with the researchers result in both explanations of their progress plus perspective about why it is important.

The popular press can be helpful. The *Baltimore Sun* frequently has short articles extracted from scientific papers published elsewhere. Reading these can alert me to advances that I perhaps had not been aware of and need to be. I then go to the original cited source for the details. Interestingly, however, the *Sun* article is often more useful for judging the importance of the research findings. *Time* magazine has had a set of very informative special issues about specific scientific advances. There was one recently about the workings of the brain, of the mind, and what constitutes consciousness. Other issues have dealt with evolution, astrophysics, and biomimetics. These articles are very well written and amazingly scientific in their tone. Written for an audience of broad background, they are instructive in style yet not devoid of hard scientific findings.

I have also found *Popular Science* to be useful. It was in this publication that I first read about synthetic biology and about the use of random processes as a design tool. There is a lot of filler in *Popular Science*, so its use for me is not as great as some of the other publications I read, but when I find something useful, it is a gem that usually is not found anywhere else that I look.

For information about agriculture, food, and environment, *California Agriculture*, published by the University of California system, and *Agricultural Research*, published by the USDA Agricultural Research Service are very good sources. Articles in these two are light reading, but written for a broad audience, and so can alert me to scientific advances with a practical flavor.

Because I keep sheep, I also read *The Shepherd*, a sheep industry journal. Included frequently are articles on nutrition basics, workings of the immune system, and other practical, but fundamental, issues. The *American Bee Journal* has also helped fill voids in my scientific knowledge base, as does *Good Fruit Grower*.

There are publications from universities that I sometimes find useful. The University of Illinois School of Engineering used to have one of these (I cannot remember its name) and the University of Georgia has the *UGA Research Digest*. Articles in these issues usually take the form of interviews with local faculty members, and I often get useful information from them.

American Heritage of *Invention and Technology* is a good source of information, not for the newest advances, but for the history of technology. I have found the articles normally very interesting and fun to read. Topics range from the building of the interstate highway system, to bringing water to Los Angeles, to development of artificial organs, to steamships, to development of the sewing machine. Virtually no type of technology is left out, and there seem to have been more articles recently concerning biomedical technologies.

I do read my share of scientific and engineering journals, but these are not enough to inform me of what is going on in the wide-ranging scientific specialties that I feel I need to know about. The same can be said for the internet. Yes, there is a lot of information on the internet, but if you don't know the topics to search for, then this information is largely useless. I let these other publications alert me to the need to investigate a topic further.

So, you can appreciate the amount of reading I do, and it is reading directed to the goal of keeping me abreast of everything. That's not an easy task, and I sometimes am asked a question in class, or some student brings to my attention some new fact of which I had not been made aware. But, given my diligence, the situation is almost always the other way around. I take it as a personal challenge to be as knowledgeable to things relevant to biological engineering as possible, and this is how I do it.

So, do you have a different approach or different publications that you have found useful? If so, I'd like to hear from you. Where do you get your information?

Oh Mama, Where's My Comma?

Arthur T. Johnson

Published in the IEEE-EMBS Pulse, Nov-Dec 2011, p.80.

I was taught in no uncertain terms that a list of words was separated by commas. If a comma did not appear between two words, then they were to be read as collective equals, both together and inseparable. So we have a list such as: French toast, ham and eggs, and coffee. The "ham and eggs" are to be reasoned as one ensemble, served together such that one without the other would be a huge mistake.

These days, however, for some reason unknown to me and clearly at odds with my memories of long-lost English teachers, the last comma in a list is AWOL. It just isn't there. So now we have lists such as: fear, killing and love. Clearly, "killing" is not supposed to hang out with "love", but that's what this list says to me, being the strict traditionalist that I am.

So, why have the Machiavellian editors plotted to kill the extra comma? Is the print medium in such a tight financial crisis that they can't afford the extra ink or space that this lowly comma deserves? Or, is it just minimalism bursting upon the printed page, inspired by a Phillip Glass musical pseudo-composition?

I need that comma! My eye darts to the end of a list I am reading and seeks to assuage my anxiety: is the comma there, or is it missing? If it is missing, why is it missing? Where did it go? Why are these editors mocking my high-school memories of Mrs. Veterito teaching me how to write, memories that I had not revisited until I first noticed this grammatical ravaging. That ugly scene, that missing comma, is so distracting that all I do these days is mentally edit the piece to make it grammatically correct. The intended message of the prose fades into the background while I fuss over the comma that isn't there. Like the parable of the lost sheep, I cannot rest until I bring that comma safely back into the fold.

Faith in Science

Arthur T. Johnson

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Skeptics deny the validity of religious beliefs, as if science is completely reasonable and only religion depends on faith. They ignore or deny that scientific beliefs also require faith in the sincerity and trustworthiness of the declarer of scientific truth.

Faith is the desire to believe in something as true, or, if not absolutely true, then at least dependable. Faith seems to have been promoted through evolutionary trends, and, as such, it is a concoction of deep brain processes. Related to faith is the concept of truth. Truth is an ephemeral mental construct. We each have some idea of the meaning of truth. Most of the time, our ideas of truth reduce to what we are willing to believe through faith. Truth, in other words, can come from the words of our parents, instructors in our schools, or the teachings of our pastors. Truth can come from books on science or religion. These are different truths, to be sure, but they form the foundations of our essential selves.

We all want to believe in something and that something can vary from individual to individual. I have heard the word “faith” applied almost exclusively to religious beliefs. I don’t disagree.

Nevertheless, it has occurred to me that there is a lot of faith required to believe scientific truths as well as religious truths. After all, in both cases I must rely on someone’s word that what they purport to be true is, actually, true. I have not seen the face of God, but there are those who maintain that they have, so I can either believe them or not, but belief requires faith. Similarly, I have not personally seen a Higgs boson, not do I have the knowledge or skill to recognize a Higgs boson if it hit me in the face, but there are scientists who claim that they have seen one, so I believe them, or at least have faith in their assertions. Nor have I seen an electron, a DNA molecule, or the edge of the universe. I believe that each of these exists because experts have told me that they exist, and I have faith in their claims.

And then there is quantum theory. Particles behave as waves, butterflies fluttering halfway around the world cause tornadoes on the other side of the Earth, information can travel faster than the speed of light, and Schrödinger has a cat both dead and alive at the same time. C’mon, who’re ya tryin’ ta kid?

Quantum Bayesianism, or QBism, is one modern tool used to predict quantum events, but QBism is based upon a purely subjective belief in certain wave functions, which, themselves, are admitted as unreal (*Scientific American*, vol. 308(6), pp 46-51). If ever there was a case for belief in imaginary scientific concepts, this is it. Yet, QBism has been found to be somewhat useful to physicists working in quantum mechanics.

When I was in college, I took a course in the philosophy of science. It was a very interesting course because it showed me how much scientific progress depended on the basic beliefs of the scientists involved. For instance, Einstein’s theory of relativity came about because he believed in the symmetry of the universe. It also led to his assumption of the invariability of certain physical constants.

Science is based on observation. So is religion. Scientific observation these days is based upon techniques so sophisticated that I have no hope of ever seeing these things for myself, so I take the words of others who say that they have seen them. As science proceeds from hypothesis through observation and refinement to almost indisputable fact, the requisite faith necessary to acceptance declines and certainty in the belief expands. Nevertheless, it is questionable whether this is a case of certainty or just familiarity.

Religious beliefs are also based upon observations seen by others who claim miraculous experiences. There seems to be very little difference between the faith necessary to form beliefs in science and religion.

There are charlatans in both science and religion, and one must know when to suspend belief. On the scientific side are the questionable papers authored by David Rockefeller, the false stem cell claims by Hwang Woo-suk, and those responsible for Piltdown man. There is junk science unbelievable to most experts, such as the belief that childhood vaccines cause autism, and there is science-for-hire, such as the Eastman Chemical Company financially supporting so-called "independent" laboratories to prove that its Tritan plastic is safe for human exposure. Some people believe everything they read on the internet, whether it is scientifically reasonable or not. There are even questions being raised about Gregor Mendel's genetic experiments with results seemingly too good to be true.

On the other side of the issue, I recently read letters from readers of a newspaper (*Lancaster Farming*) claiming that Darwinian evolution is not true, and that the Earth, it says in the Bible, is only 6000 years old. I cannot believe the assertions in these letters, but, again, I depend upon my belief in scientists that they know what they are talking about in order to make that judgment.

Science is observational, but it is also correlational, finding connections between different events. Sometimes these become causes and effects; at other times it is not so clear which is which. Science, however, cannot explain why those correlations exist in the first place. To science, the way things are is just the way it is. There is no serious scientific questioning about why a certain set of correlations exist except to try to identify which event causes the other. This gives science the power of prediction as long as the basic set of circumstances does not change. But it is theoretically possible that our scientific truths here and now might be completely useless over there or at a different time.

The strength and appeal of science is that it can explain observations and predict likely future outcomes, but, then, again, so does religion. Unlike religion, science cannot explain the "why" or the "how" about the way things got to where they are in the first place. We live in a universe where time progresses from older to newer. Why did it have to be that way? There is no scientific explanation. We live in a three-dimensional space, although string theory says otherwise. Why? We might alternately have lived in a two-dimensional Flatland. This would give a three-dimensional being unfettered control over our lives. In three dimensions, a four-dimensional creature could have the same power, appearing to be both omnipresent and omnipotent. Could this be the supernatural being who we call God?

With science, replication is key, and if reported results cannot be reproduced, then they are thrown into the trash heap of irreproducible results. The test of religious truth is not quite so easy. Miracles reproduced become commonplace occurrences; only those that are rare can be considered true miracles. In the event that miracles are repeated, we tend to try to find logical, reasonable, and scientific explanations for them. Religious discernments depend a lot on reproducibility and repeatability leading to ageless wisdom, whereas scientific observations lead to universal knowledge.

During the Age of Enlightenment, it became popular that reason, not revelation, should be paramount in human philosophy. As long as science was local, that is, one could see or feel for one's self, science and reason were closely aligned. But, today, much of science is not personal; it is revelatory in that the current objects of much of science are either highly theoretical, or require methods of such sophistication that they are beyond the ability of most to comprehend them. In either case, they far removed from individual observation. To believe in such science requires a belief, not in one's senses, but in the words of others who make claims beyond our own immediate experience.

Reading the earlier scientific literature demonstrates clearly that scientific facts assumed without question today were wrested with great effort from the state of the unknown that existed at the time. Marie Curie's Nobel lecture (1911) on the existence of the electron, Theodor Svedberg's Nobel lecture (1926) on the reality of molecules, and Barry Marshall's (2005) self-inflicted gastric ulcer to prove causation by *Helicobacter pylori* are evidence that some of the scientific facts beyond doubt today were, at one time, very unfamiliar or even discredited. In the not-too-distant past, the existence of microbes, the structure of DNA, and the orbits of the planets around the sun were unknown and their ideas scoffed at. It took hard work, refined methods, risk taking, and open minds to develop those scientific advances that we take as granted today. It took belief and acceptance, first by peers, then by the intelligentsia, then by the general public before these new pieces of knowledge became foundational parts of our core scientific beliefs. If the past is prolog to the future, what we know for sure today will be only a small part of what humans will know centuries from now. Some of what we know most assuredly will be modified or overturned. This process takes time and it doesn't always happen smoothly, but it is essential that the new knowledge is believable.

In his 1934 Nobel Prize lecture on the origin of the Earth, Harold C. Urey postulated: "*None of us was there at the time, and any suggestions that I may make can hardly be considered as certainly true. The most that can be done is to outline a possible course of events which doesn't contradict physical laws and observed facts*." He went on to explain what he thought was the sequence of events leading up to the Earth as we now know as a pretty good place to live. His ideas were speculative, and, with time, modified greatly by other scientists. Yet here was a renowned scientist, a Nobel Prize winner, who had put forth some ideas that eventually were found to be unacceptable. That is the way science progresses, but at what point does everyone start to believe that the stated ideas are, indeed, true?

All this is not to say that science and scientific facts are not to be believed. But I do say that there is an element of remoteness in parts of science that requires believing what others tell us rather than experiencing it ourselves. This, it seems to me, is faith.

Bookcases Empty of Old Friends

Arthur T. Johnson

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I gave away most of my books. It wasn't an easy thing for me to do, because I have never before willingly or knowingly gotten rid of any of my books. I still had many of the books I had acquired as a youngster and all the books from my college education. Many books that I had bought to update my knowledge and support my writing were also there.

This wasn't an easy thing to do. I had always cherished my books, from the paperback novels by Zane Grey that I had bought as a kid to the highly technical biochemistry books only a few years old. They were all treated well. I did not write in my books and I protected them all from the elements. The pages were not dog-eared nor were they visibly worn. Many of my books had plastic covers.

Books are a treasure to me. They have knowledge, ideas, methods, and entertainment. Books can expand one's mind and free one's imagination. Books have been the key to my professional and personal life. But, at least for the books I gave away, their time had come and gone. It had been years since I had opened many of them, and it was now time to pass them on to others who could appreciate them anew.

In *Ecclesiastes,* it says that there is a time for everything: a time to be born, and a time to die; a time to love, and a time to hate. *Ecclesiastes* says nothing about books; however, it does say that there is a time to keep, and a time to cast away. I knew that it was time.

The opportunity came through an email from an organization called *Books 4 Cause.* This organization collects books and sends them to be used in Africa. This was what I had been waiting for; this was the way that I could say goodbye to my old (and not so old) friends and feel good about it. So, it came to pass that my books are now on a long journey halfway around the world.

Of course, I still have some books. Even with most of them gone, the books most useful to me remain. The vacancies on my many bookshelves are slowly being refilled.

Of what use are books these days? There is so much information available online that it is easy to forget the need for books. When I need something fast, I go to the internet, and there it is, right in front of me. And, if I don't understand some of the words that are used, I can explore their meanings with just a few clicks of the mouse. But, as Annie Murphy Paul said in a recent *Time Magazine* article (15 March 2012, p. 65) "*You can't Google context*". When I need more depth, that's when I turn to my books. They tell me everything, although they lack the convenience of *Wikipedia.*

The other day, two of my grad students came to me to ask if they could clean out many of the old journals that I had accumulated for many years. Among them are forty years of *IEEE Transactions on Biomedical Engineering.* "*Why keep them?*" they questioned, "*Everything's on line these days*". And they have a point, but that would mean getting rid of more old friends and removing more of my history. It will take just a little time to get used to the idea, so I said to them, "*Give me a little time, and I will eventually catch up to the 20th century, although it is now the 21st*".

Dollars Are Not an Output

Arthur T. Johnson

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What has happened to academic Bioengineers? Faculty productivity used to be measured as some combination of teaching skills, professional service, and research output, but the system has been perverted by an inordinate emphasis on the number and amounts of outside money brought in. At one time, it wasn't the total direct and indirect costs that were of importance, it was the source of the funds, and whether the grant was from a prestigious or very competitive agency. At one time, we could afford to spend some time developing and improving our classes, because, although we were never given as much credit for teaching as we thought we should get, there was a chance that someone on the tenure committee thought that teaching was important for a neophyte faculty member to do well. And serving as committee members, officers, or program chairs for our professional societies was looked upon very strongly by our peers and superiors at one time.

It now seems that dollars snagged is the figure of merit, not just for individual faculty members, but for whole universities. Our President and Provost, when giving speeches bragging up our University, first declare the amounts of money brought in this year, or this decade, or this other period of time. Many times, they don't even get to a second declaration. There is competition among research universities, and the winner is the one with the most bucks.

Gone, it seems, are the days when Presidents bragged about fundamental research breakthroughs, grand technological advances, books written, students educated, peer-reviewed papers written, new pedagogic paradigms developed, unusual services performed, or mentoring successfully accomplished. It is now clear that the way to the top is through dollars ensnared.

This change in emphasis has given academia a new view of itself. It now justifies its lofty efforts as generators of wealth. It used to be the paragon of knowledge. Our students are now looked upon as future wealthy alumni who can bequeath fortunes to the University. It used to be that we were educating them to serve humanity.

President Dwight D. Eisenhower once warned that scientists could become prisoners of government funding, with contracts becoming a virtual substitute for intellectual curiosity. That day has arrived. The research work that gets done is the work that the government is willing to pay for. Anything without associated governmental dollars is ignored. At least it seems that way.

This has had profound effects on our profession and on those newly entering academia. The effect on the profession is the tendency to drive research towards reductionism, where fundamental research is given priority over applied research. This has turned engineering research decidedly toward scientific research, and made the two often indistinguishable.

`In order for an applicant to fill a new faculty position, it has now become commonplace that post-doctoral experiences are necessary, and the more the better. It used to be unusual for a PhD engineer to have post-doctoral experiences when they joined a faculty. The reason for the change is this: PhD candidates used to be the ones determining the topics and methods used in their doctoral researches. Advisors were there to guide and suggest, but the major decisions were made by the PhD candidate him-, or her-self. There was a learning process involved in this, and the student developed mature judgment that allowed him or her to be qualified to develop a new research program immediately after the dissertation was completed.

Nowadays, PhD candidates are hired as supertechnicians to carry out the work promised on the grants for which they were recruited. They have little to say about the broad aspects of their research, and, as such, are not given the opportunity to develop the skills needed to initiate new research projects. They can only develop these skills as post-docs.

Course grade inflation has been seen to be occurring in the extreme since dollars snagged have become so important in the tenure process. There is a simple explanation for this. An assistant professor cannot take a lot of time away from proposal writing to spend with his or her courses. Students expect an education, but they are satisfied by good grades. So, it is a lot simpler to give a lot of high grades than to answer students who complain about either the course or the grade that they got. All of this is because time must be spent snagging dollars.

And, if we turn our attention to the proposal writing process itself, how many of us can expect our proposals to be funded upon the first submission? None? Thus, a lot of time writing proposals is spent revising past submissions to satisfy comments of reviewers who may or may not have given quality reviews. There is not much creativity or inspiration involved in revising a proposal. This turns into drudge work. Talk about the dulling of the faculty mind!

There is no easy solution to this problem. Perhaps we ought to begin to expect that faculty publish papers and educate students if they are lucky enough to receive outside funds.

Veterans' Day

Arthur T. Johnson

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Every November we commemorate those who have served in the U.S. military. We also have a day in May that we call Memorial Day. The difference between the two is that Memorial Day is to remember those who have died, whereas Veterans' Day is to celebrate those who have come back alive. I am one of the survivors, and so Veterans' Day is special for me.

It was not easy for any of us to leave our homes and our families to be sent half a world away to face an uncertain fate. Would we even return? Would we be disabled? Would we ever see our families again? The steep descent of our airplane into Long Binh Air Force Base filled us with anxieties. Would we be attacked as soon as we landed? What would be required of us? Could we survive a year of this war without front lines and borders?

Fortunately, the scene at the air base was a lot more normal and tranquil than I had expected, and I survived that first day. One down, three hundred and change to go.

Before I served in Vietnam, I was generally in favor of our nation's actions there. I accepted, for the most part, the domino theory that if one more country fell to communism then all the rest of southeast Asia would also fall. A sizable number of people my age supported the war; contrarily, there were many who were vehemently against it, and our nation was in turmoil.

Once in Vietnam, however, I began to see the other side of war, the terrible toll it exacts. It wasn't just the killing and the maiming, and there certainly were those. After a while, each of us either went mad or developed a bit of fatalistic callous. We had to accept the realization that we were never going to be in control of our own fates; whatever was going to happen, would happen. That was the only attitude to get us through this.

Aside from this, the war ruined a lot of American (to say nothing of the South Vietnamese) lives, leading to drug addiction, alcoholism, sexually-transmitted diseases, depression, and apathy. I saw Vietnamese children in school, boy scouts playing games (in the midst of war!), and families trying to survive. The war negatively affected all of these. I gradually changed my mind about the war.

Today, I am troubled by our nation's wars. War may be necessary, but only as the very, very, very last resort. There are so many options to be exhausted before that last step is taken. My heroes today are no longer military greats; they are people like Mahatma Gandhi and Rosa Parks. I am saddened when soldiers have to leave their spouses and children, and I am truly joyous when they return.

The University of Maryland sponsors an annual celebration of Veterans' Day in the chapel on campus. Every student, staff member, and faculty member who has served is individually invited and honored on a day just for them. We can celebrate the sacrifices each of us has made, but, even better, we can celebrate that we are here to celebrate among those who understand because we all share the same general experiences. And, for me, it means a reaffirmation of the truth that it is much harder to make peace than it is to make war.

Father's Day

Arthur T. Johnson

A female friend of mine the other day asked me what I wanted for Father's Day. I hesitated to answer. I thought a few moments and really didn't know how to respond. Finally, I said, "I don't know, nothing really."

So, I thought about it, and when my thoughts had congealed, I thought I'd presume to speak for other fathers as well as for myself.

What fathers want most is that their children do well. They want to know that what they did for their children was, for the most part, good enough so that their children could grow to be successful, happy, and responsible adults. They want to know that the safe environment that they helped to provide allowed their children to explore and mature. They want to know that their adult children are capable of doing the same for their own children. They want respect for that.

There really shouldn't even be a Father's Day, because fathers don't deal with days at a time; they deal with lifetimes. Their timelines stretch from way back when to the far foreseeable future. A day is nothing; a lifetime is everything.

Don't try to make fathers rest on Father's Day. We are used to doing something all the time. We don't want to stop just because someone decided, against our own inclination, to name a generic day for us. Let us be busy. We are happiest that way.

But don't remind us of all the things that have to be done. We already know that list, and even some that aren't on it yet. Let us be free to do something we really enjoy today. The others we'll get to tomorrow or the day after.

So, don't treat us too much differently today than yesterday. We are still the same guys that we were then and will be tomorrow. We don't want a lot of extra attention; we don't want to be kings, just us for another day. Anything else is embarrassing.

So, what do fathers really want for Father's Day? Not a lot, and yet everything that matters. It would be nice to have just a short little report from our kids saying that everything with them is OK.

Going Solar

Arthur T. Johnson

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Since 2008, solar generating capacity in the U.S. has increased by 1200%, and the Johnson household has been one to add to these. Last spring we had solar panels installed on the roof of our house. Since then, sunny days have more meaning than before. There are 50 panels with a nominal total generating capacity of 12.5 kW. They are supposed to supply three quarters of our total electrical needs for the year.

The panels belong to the company that installed them. That means that we had no financial outlay to buy them, and we buy electricity from the panel owner as well as from our previous electrical supplier utility. Power from the panels costs us less than from the power company because there is no distribution fee associated with the solar electricity, and the rate of power cost from the panels is guaranteed for 20 years. That means that, over time, our self-generated electrical power should become comparatively cheaper and cheaper compared to that from the electric utility.

When we generate power in excess of our use, the extra power goes into the grid, and we are then assisting the power company to supply electricity to all of you. When we use more than we generate, we buy from the grid. This does not make us independent of the grid. When electrical service from the grid is interrupted, say during a severe storm, we do not continue to have electric to our house because the solar panel controls shut down the output from the panels; to keep them live would pose an electrical hazard to linemen working to restore service.

The first full month after we installed the panels, our new digital electric meter registered a net electrical use from the power company of negative 1000 kWh. The company sent a meter reader man to our house to check that it was correct. It was. So far, each succeeding summer month has added to the total electrical power deficit. We will likely make up for this shortfall in the winter, when temperatures are colder, sunlight is shorter and weaker, and electrical heating kicks in, but, for now, we are very well pleased.

There is one additional benefit to having solar panels located on the roof of our house. The panels are mounted on standoffs so that they do not rest directly on the roof. That means that they intercept solar radiant energy and cooling air can flow between the panels and the roof. This should reduce the amount of heat coming into the house through the roof. In the summer, this is a considerable benefit. Additionally, solar deterioration of roof shingles should be diminished under the panels.

All this has me thinking about alternative energy sources. They all sound so appealing, but I wonder about the consequences of using them. “There is no such thing as a free lunch”, so alternative energy sources must have some downsides; all technologies do. The first consideration is possible reaction from electric power companies. If too many solar panels or wind generators are installed, and more electric power is generated in this way, then electric companies may have a difficult time providing economical base load to their customers during times when local alternative power generation cannot meet demand. Electrical power suppliers are either destined to have to make a drastic change in their means of generation, or they may choose to try to limit the amount of alternative power that can be generated in their supply region.

Looking at the larger picture, world power consumption is about 20 TeraWatts, giving an annual energy use of about 175×10^3 TWh, increasing by more than 2% per year. Fossil fuel is burned to supply 86% this power, and this causes more than 30 billion metric tonnes of CO_2 to be added to the atmosphere each year. As we know, this causes an unsustainable condition trapping heat in the atmosphere and contributing to apparent climate changes.

It is not likely that human power consumption will decrease any time soon. So, the search is on for practical alternative power sources. Solar energy is one of these, with an estimated annual potential of 440×10^3 TWh, enough to supply twice the annual energy needs of the world if we could capture it all. What would be the downside of converting to solar? Installing panels on roofs makes dual use of the roof area, but installing panels on open land significantly reduces the possibility to use the land for other purposes, including raising food.

Wind power has been estimated as being able to produce 180×10^3 TWh annually. High altitude wind may have 16×10^6 TWh of potential. This sounds good, but extracting energy from the wind will most likely cause turbulence, and could have profound climate effects of its own.

Hydrogen is a possible energy source to replace fossil fuels. Some auto manufacturers are readying cars powered by hydrogen to sell in the years to come. Burning hydrogen has the advantage that the only product of combustion is water vapor instead of carbon dioxide. Burning hydrogen produces more than four times the amount of energy as burning an equal mass of carbon (142 MJ/kg vs. 33 MJ/kg). But wait! Commercial quantities of hydrogen must be formed through electrolysis of water, requiring additional energy use, and water vapor is a more potent greenhouse gas than is carbon dioxide, contributing 36-70% of the Earth's greenhouse warming, compared to 9-26% for carbon dioxide, so adding large quantities of water vapor to the atmosphere may make climate change even worse than it is.

There are other alternative energy sources under consideration: geothermal (1.4×10^6 TWh potential), biomass (77×10^3 TWh), hydro-generation (14×10^3 TWh), and the ocean (280 TWh). Each of these has some advantages and some disadvantages. The challenge for the future will be to harness the energy we need without compromising our ability to live sustainably on this planet. But, then again, producing systems and processes within limitations is what engineering is all about.

All this came from installing a few solar panels. We may never produce enough energy in the forms that we need it without some costs that must be overcome, but, with some ingenuity and awareness, I have no doubt that we will make significant progress. We just need the sun to keep shining on my roof.