

Introduction, Objectives and Summary of the Workshop

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Introduction.

The Institute of Biological Engineering (IBE) is at a critical juncture! You might consider this an overused cliché and I agree, but I suggest that as we near the end of a second year as an independent professional Society we face numerous challenges that bring us to this point. It would be easy to cast these challenges as: a need to increase and expand the membership base, reduce IBE operational expenses, need to create a creditable refereed publication and need to differentiate IBE from other organizations in the arena of biological engineering. However, I believe the preeminent issue is a need to create an intellectual nexus for biological engineering as a discipline and to define the body of knowledge for the discipline. Therefore, the Workshop, “DNA of Biological Engineering: Defining the Body of Knowledge for the Discipline,” was planned for the purpose to engage persons in search of the “discipline”.

A fundamental question is whether biological engineering will become an engineering discipline (like ME, EE, Chem E, CE, etc.) or an applied area where engineering is applied to biological systems. There is not one answer to this question given different institutional cultures. It made sense, given that IBE was meeting jointly with ASAE (Society for Engineering in Agriculture, Food and Biological Systems) in July 2001, to engage representatives from ASAE departments and IBE members and guests in a workshop to address such fundamental questions as: what is biological engineering, what is the “body of knowledge” that makes up the discipline, what are perceptions of the industrial sector and how do we develop an understanding by the public of who we are and what we do?

Objectives.

The principal objectives of the Workshop were to:

- Define core concepts of biological engineering,
- Initiate discussions of concepts for a curriculum in biological engineering,
- Address advances in developing a course for thermodynamics of living systems,
- Seek the input and perspectives of the industrial sector about biological engineering, and
- Develop an agreement on the definition of biological engineering.

Workshop Summary.

James Dooley, Silverbrook Limited, opened the Workshop by presenting core concepts based on first principles in the context of living systems and at an object level appropriate for engineering problem solving. He listed core concepts for biological engineering as:

- Mass transport at and across interfaces,
- Proteins and surfaces,
- Kinetics,
- Bioenergetics,
- Locomotion
- Engineering properties of biological materials,
- Biology of cell, organs and organisms,
- Ecology of populations and assemblages, and
- Design of and within biological systems, and
- organic / biochemical synthesis and processes.

Moving from an articulation of core concepts, Kifle Gebremedhin of Cornell, offered an example curriculum for incorporating core concepts into a B.S. degree program in biological engineering. This proposed curriculum is a discipline-based program of undergraduate study, which consists of a coordinated array of courses (semester hours in parentheses):

- *Mathematics* (16),
- *Physics* (8),
- *Chemistry* (7),
- *Biology* (14),
 - Basic biology including molecular biology,
 - Biochemistry,
 - Cellular biology, and
 - Organismal biology.
- *Core-Engineering Courses* (13)
 - Computer programming,
 - Mechanics of solids,
 - Probability and statistics, and
 - Principles of biological engineering.
- *Core-biological engineering courses* (21)
 - Bio-kinetics and thermodynamics,
 - Biotransport (heat and mass),
 - Biofluids,
 - Biomaterials,
 - Bioinstrumentation,
 - Physiological engineering, and
 - Molecular and cellular engineering.
- *Biological engineering electives* (16)
 - Biomedical engineering,
 - Bioprocess engineering,

- Bioenvironmental engineering,
- Biological systems analysis and control, and
- Bioelectrical engineering.
- *Liberal studies* (24)
- *Electives* (6)

This summarization of a discipline-based biological engineering program is not precisely the same as that presented by Gebremedhin. I have taken the liberty to offer a few modifications to reflect the recently faculty approved biological engineering B.S. program at Cornell University.

John Cundiff, Virginia Tech, and George Meyer, University of Nebraska, have addressed the conundrum of an appropriate thermodynamics course for the biological engineer. For years our students have typically taken thermodynamics from mechanical engineering, or in some cases chemical engineering. John and George have developed, "Thermodynamics of Living Systems," which seeks to present thermodynamics as energy flows and cycles in the context of biological and environmental systems. Beyond the introduction of this concept of teaching thermodynamics to biological and environmental engineers in the IBE Workshop, a more in-depth Continuing Professional Development (CPD 17) session was held during the ASAE meeting. I am pleased to have received from several of the participants in CPD 17 their notes and include these (Meyer and Engler) in Appendix 1. For those of you who are thinking about teaching thermodynamics differently from that of traditional engineering thermodynamics you will find valuable insights by Meyer and Engler.

What expectations does industry have for biological engineers? Two participants from industry, Karen Brockwell, Genentech, and Carol Schembri, Agilent Technologies, provided significant insights from their experiences in two major biotechnology companies. Karen addressed changes and future trends in the biotech industry from the perspective of research, development, regulations, business and technology. Karen raised two broad issues; what is biological engineering and how does one develop a public understanding of the field? She did feel that the example biological engineering curriculum presented by Gebremedhin was a very appropriate degree program for graduates who would be employed in her division and similar divisions at Genentech.

Carol Schembri of Agilent Technologies explained that Agilent is an original portion of HP focused in the life sciences, electronics and communications. The life sciences division is largely oriented to sophisticated instrumentation for analysis and control. I encourage you to review Carol's answers to the question, "What engineering and scientific skills do we need in Bio-Research?" because it is a comprehensive response marked by significant insight. Carol's concluding slide offers a different perspective on biological engineering from that of the disciplinary-based orientation above. She suggests a bioengineering degree program as one where the student completes a standard engineering degree program to gain significant depth in one area (EE, ME, ChemE, etc.) and adds a "minor" interest in biological engineering (general biology, physiology, biochemistry, organic chemistry and molecular biology).

Following panel presentations the group divided into four breakout groups to address the specific questions:

1. Definition of biological engineering?
2. What are essential subjects that establish biological engineering as a discipline?
3. What are the knowledge expectations for a biological engineer entering first employment in industry?

The specific output of the four groups to these questions is a part of these proceedings and I will not repeat the deliberations of the groups here except to address the question of what is biological engineering? Each breakout group developed a thoughtful definition. From my perspective they have much more in common than differences. These are:

Biological engineering is the discipline of engineering that integrates life sciences with engineering principles in the advancement of fundamental concepts of biological systems from molecular to ecosystem levels.

Biological engineering is the biological-based engineering discipline that educates engineers to solve problems in living systems dealing with plants, animals, humans or the environment.

Biological Engineering is the discipline of engineering which integrates biology, physics, chemistry and math with engineering principles in the design of biologically based products and processes from the bio-molecular to organisms to the ecosystem.

Integrating Biological Science and Engineering Principles to meet societal needs.

The importance of developing one definition and a clear and crisp understanding of biological engineering is huge. Both of our speakers from industry expressed an uncertainty about what biological engineering is and reinforced the perception that the public is almost totally lacking of an understanding of this field. Following the Workshop Carol Schembri and I have had email communications and I want to share a bit of our exchange. Carol wrote, "*Your meeting was certainly thought provoking! After considering the "lightning rod," if unintended, effect of my final slide and the group's work in determining a definition of the field, I am wondering if the title of "biological engineering" is too broad..... The words "integration" and "system" kept resonating in the audience. I feel that I work in the world of biology and engineering, but my work did not fit with the audience's expectations.I wonder if the title "biological systems engineering" might better express the needs of the group. It speaks to systems from molecules to eco-systems. It speaks of life and integration. It does not speak of diagnostics and measurement and instrumentation.*

I share a portion of my response, "*It was great to have your different view. If we all agreed we would not need to have a panel, one could speak for all! As you heard, IBE is a small growing organization trying to establish a "defined" direction, which will meet a unique niche relative to other professional societies that are also working at the interface of engineering and biology. A fundamental question is whether biological engineering will be a discipline (like ME, EE, Chem.*

E, etc) or an applied area where engineering is applied to biological systems. There is not one answer to this question consistent with institutional cultures. Cornell is taking the path of a well-defined biological engineering curriculum as presented during the Workshop. This is not to say that other universities should or will follow this approach. Biological engineering is very broad, as you suggest and we agree that we must develop a definition that will “stick”. A definition that everyone can adopt and use collectively to help with the public understanding of biological engineering is our goal. You are absolutely right about the unifying ideas of integration and systems, but the question is whether we recognize these characteristics as a part of the process or also in the name of the program. I am inclined toward the recognition of these concepts within the process and not within the name, at least for now!”

With Arthur T. Johnson’s permission we include his thought provoking paper, “Bioengineering in the US: The Rush is On”, in Appendix 2. Art raises issues of a separate and distinct discipline, agreement about specific core knowledge and courses, and capabilities of bioengineering graduates. I strongly encourage you to read this short paper.

Concluding Comments.

I am absolutely convinced we have to adopt a definition of biological engineering and use it consistently in all of our communications. To do otherwise will continue a terrible history of fragmentation and confusion. Thus, I propose, at least for all IBE communications, we adopt ONE definition and use it without exception. As IBE President 2001, I will work with the IBE Council to send out the options above to IBE members for a vote and obtain member preference from which the selection will be made.

I believe departments and IBE members will find many nuggets of ideas and information in these Proceedings to engage faculty and colleagues to address the challenges. The Workshop successfully identified core concepts, a potential core curriculum, a new direction for thermodynamics courses, perspectives from industry and has established a foundation on which we can build. My fervent hope is that departments and IBE members think deeply about the content of this document and use it to initiate department and member-to-member discussions.