Biology for Engineers

Arthur T. Johnson
University of Maryland
College Park, MD

Introduction

There is a long history of basic science courses taught to engineers by practitioners of those sciences. Thus, basic physics has traditionally been taught by physicists, chemistry by chemists, and calculus by mathematicians. As it becomes more and more clear that all modern biology should be added to the list of basic sciences that all engineers should be introduced to, it is thus natural that introductory biology courses should be taught by biologists. Or should they?

There was a time when physics, natural science, and philosophy were all part of the same study of the workings of the universe. When chemistry began to develop its own set of studies, and theology separated from the natural sciences, but the life sciences were still largely unknown, physics became the science to encompass the broadest applications. So were born specialties such as physical chemistry; applications of physics to the life sciences continue to this day. Indeed, the Bernoulli equation partitioning energy within a moving fluid was originally developed for the flow of blood. Physics, therefore, based on a set of relatively simple principles, is expansive enough to be relevant to engineering and other sciences, even when taught by physicists.

Mathematics falls into another category. Whereas physics attempts to explain the workings of the natural world, mathematics attempts to idealize the world. Thus, mathematics taught without real-world applications can become self-absorbed.

Chemistry and biology are largely descriptive sciences, not idealized like mathematics, nor succeeding in reducing their sciences to a small number of basic principles like physics. Thus, both chemistry and biology are relevant to engineering, but often fail to excite engineering students because a general framework in which scientific facts may be categorized has not been established. Unlike physics and mathematics, that can be understood and learned with a relatively simple set of principles mixed with logical reasoning, chemistry and biology are sciences that rely heavily on memorization of volumes of descriptive facts and nomenclature.

Engineering is part science and part art. Scientific knowledge used by engineers is classified and organized in a way that allows easy recall when the art component of engineering requires it. It is no wonder, then, that engineering is based on the relatively simple studies of physics and mathematics.

For engineering students to truly appreciate chemistry and biology, these two sciences should be taught as much as possible with a small set of simple, but universal, principles, like physics, and with relevant and interesting applications, like mathematics. It is highly unusual

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that either chemists or biologists have structured their understanding in this way or appreciate the world of engineering practice. To expect that an electrical or mechanical engineering student possesses the ability to translate introductory chemistry or biology course material into a meaningful form is not realistic. This translation is best done by instructors familiar both with the basic sciences and with engineering, and not by specialists in either science or engineering.

It is becoming apparent that applications of engineering to the life sciences are important enough that all engineers should know something about biology. Those engineers who wish to specialize in biological engineering must go beyond just knowing something about biology, and they must take other courses to bolster their biological knowledge. Advanced biology courses should be taken from biological scientists.

Introductory biological science courses meant for engineers, however, need to meet several objectives in addition to the presentation of life science. These courses should:

1. present life science information in as simplified a form as possible, preferably in universal principle form.
2. emphasize logical connections over nomenclature and taxonomy.
3. illustrate the many possible means to utilize living things.
4. demonstrate the relevance to engineering.
5. be interesting

In this paper will be described progress in achieving this set of goals.

Course Approach

A course, presently called "Engineering in Biology," has been taught for several years at the University of Maryland. This is a survey of the entire field of biology from an engineering perspective. The course has evolved based upon comprehensive and detailed survey data from students who have taken the course. Some included material, therefore, may reflect shortcomings of other courses taken or not taken at Maryland, about which the students felt they needed to know. However, the attempt was made to account for more universal needs and to be useful outside the Biological Resources Engineering program at Maryland.

The approach to biology is to impart perspective. Some of the material covered may have been covered in other courses, and, in those other courses, more details would have been presented. For those topics, material in this course provides a review. Some of the material in this course is new, and will be covered in courses taken after. For these topics, material in this course provides a preview. Some of the material in this course is new, and there is no expectation that later courses will cover it. For these topics, material in this course provides context. The idea is for this course to demonstrate the full range of interactions between engineering and biology.

An ecological approach is used. That is, living things are all influenced by their physical, chemical, and biological environments. Living things are, above all else, reactive creatures that modify their actions based upon sensory inputs. These inputs may be large-scale, or macroecological (as with interactions among species in biomes), or small-scale, or

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microecological (as with interactions among cells within a bioreactor). The principles upon which these interactions are based are similar no matter what the scale, so it is important to acquire foundational knowledge about what kinds of reactions can be expected for specific ecological conditions.

A conceptual approach is used. Topics are presented in a manner that de-emphasizes nomenclature, mathematics, and detailed mechanisms, but emphasizes how things work and how they fit together. An action-reaction approach gives expected outcomes for given sets of input conditions.

A broad range of engineering applications is given. There are applications illustrated for human factors, imaging, neural engineering, social organization, and biotechnology, to name a few. Engineers from different disciplines can all see where their specialty could interface with living things.

Important methods in biology are described. It is frequently true that methods developed by biologists are more direct and useful with living things than are standard engineering methods that could be adapted. Common methods such as the Polymerase Chain Reaction (PCR), the Ames test for mutagens, environmental biomarkers, electroporation, molecular sieves, competitive inhibition, and RNA interference are covered. Familiarity with these methods can be useful for the engineer who needs to interact with biologists.

A complete approach is used. Successful biological engineering designs require artistic, psychological, and sociological considerations in many cases, in addition to more quantitative design aspects. The attempt was made to include information from many different fields as a way to demonstrate that complex interactions are normal when dealing with living things.

Examples are drawn from a wide range of applications, including outsmarting beavers building dams, genetic causes of alcoholism and autism, measuring the change in plant trunk diameter as it gains or loses water, and watering a potted rose. Examples are meant to illustrate modeling as well as applications.

Conveying a sense of wonder and immense interest has been attempted. The world of biology is marvelously simple yet complex, wondrously interactive and reactive, self-regulating, and exquisitely designed. It is important for the biological engineer to realize that overall improvement in a biological system is not likely, although living things can be utilized for useful purposes.

Homework problems are mostly conceptual in nature and intended to encourage students to connect material that they cover in this course with their ultimate professional engineering goals. Problems are sufficiently broad, in most cases, to allow students to insert information about new advances in both engineering and biology. Homework is intended to promote thinking instead of blind calculation, and to broaden the context of biological influences on their engineering designs.

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Many engineers will not take a second biology course. Hence, exposure to a broad range of topics may be the only chance they have to be made aware of the many topics covered. Exposure to such topics as toxicology, personal space, animal consciousness, definitions of death, allometry, cellular stoichiometry, genetic computers, and dimensionless numbers can possibly lead to future creative products or processes using living things. Other biology courses that touch upon the range of topics in this course are highly unusual, if they are offered at all.

Course Structure

The course is divided into five parts:

1. an understanding of biological engineering and how it relates to biological science

2. the basic sciences and principles from each that relate to biology

3. biological responses that cannot be related directly back to scientific principles

4. scaling of biological measurements and response with size

5. biological engineering applications

Each of these has a particular purpose. The first is used to establish a familiarity with the discipline and its methods, including modeling. In this section are given the expectations for biological engineers:

1. the ability to use living things to produce useful products or processes

2. the ability to anticipate properties of an unfamiliar group of living things from knowledge about a familiar group

3. the ability to ameliorate the unintended consequences that result from using all living things

The second part discusses principles of physics, chemistry, calculus, statistics, control theory, information theory, and biology applicable to the understanding of living things. A finite set of principles is stated, and these are related to fundamental knowledge about biological beings. Examples are given for a wide range of applications.

Not all biological responses can be explained with simple principles. Yet, knowledge of the needs and responses of living things is useful for engineering designs. In part three are given Biological Responses in Context (BRIC) that explore input-output relationships in depth. It is in this section that a general context is developed to encompass most, if not all, environmental influences, including psychological and societal. These influences range from the simple to the

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sublime, from the basic need for water to the influence of evolutionary pressures on group survival.

In part four are allometric (scaling) relationships useful to fulfill the second expectation for biological engineers given previously. The fact that there are many properties of biological systems, including respiration, metabolism, space needs, life spans, and morphological proportions that are similar over 7-11 orders of magnitude is evidence of underlying evolutionary characteristics developed within physical and chemical constraints. This is by far the most mathematical section, and is treated most thoroughly because it is not likely that students will learn of these relationships elsewhere.

The fifth section is meant to cap the entire biological engineering design process. There is a classification of biological engineering interests, where the methods used are either biologically-based or not, and the object of the design is either biological or not. The fields of bionics (hybrid systems), biomedical engineering, biotechnology, and environmental engineering can be defined in this way. The design process is described in general in this section, and its biological engineering implementation is well illustrated.

Course Materials

A text has been written and revisions are currently being made. Version 5.2 of *Biology for Engineers* was posted on the web www.bre.umd.edu/johnson.htm for all to use in January 2005. As implied by the version number, this is the fifth version with major additions and revisions. Each year, students in the course have been requested to complete a questionnaire related to this book, what can be added, what can be deleted, what illustrations need to be there, and what revisions need to be made. In its initial year or two, students suggested many technical revisions and were generally not satisfied with the book in its form at that time. Lately, however, students have demonstrated positive attitudes toward the book and its objectives. Criticisms have lately been concerned mainly with details such as the quality of some figures and the placement of a section or two.

Because our students take five biological science courses, three chemistry courses, and three physics courses, one might think that students would protest that material in this book is too much review of introductory material. There have been some comments to that effect, but the context of the material, the interplay between biology and the engineering sciences, and the biological engineering applications are enough to make most student comments very positive. Many have expressed appreciation for collecting all this material together in one book.

The book is not trivial. It has grown to nearly 800 pages, single spaced. Illustrations are abundant, and color has been used lavishly in order to increase its attractiveness and to identify it as a biology book; most other biology texts are abundantly colored.

In contrast to other biology books presently available, this one is generally filled with more engineering, is more comprehensive than some purported to be written specifically for engineers, and lacks a good deal of the detail of general biology books. It is not intended to provide all facts, nor to be a biology reference book with detailed explanations. It is intended, however, to impart perspective and an introduction to a broad range of biological material in a context of utilization.

Biology Students Taught by Engineers

It has been suggested that seniors majoring in biology could very well learn about engineering from a course such as this. Biology majors would be more familiar with the biology but could use the biology as a vehicle to become familiar with engineering approaches. Just as it is becoming apparent that engineering students should be exposed to biology, the world of technology is forcing biologists to assume engineering approaches to the development and refinement of new products and processes. To learn engineering concepts within the familiar framework of biology would seem to be a relatively easy pedantic pathway.

An Opportunity Not To Be Missed

Courses on biology for all engineers need to be taught by some department or program. Despite the often apparent lack of enthusiasm for teaching by some institutions, the department or program that offers Biology for Engineers to all engineers derives several worthwhile benefits:

1. the identification of the program with biological engineering expertise

2. access to potential students

3. large numbers of student credit hours

At universities where there are several academic programs relating biology to engineering, such as Biological Engineering, Biomedical Engineering, Biosystems Engineering, Chemical and Biological Engineering, Bioengineering, and Environmental Engineering, these advantages can be considerable. At universities where budget constraints are forcing measures for increased faculty productivity, these advantages can be considerable, also.

The opportunity has been waiting. Up until this time, there was no clear indication about the way such a course should be taught, what should be included, or from where suitable course materials could be had. The experiences and materials from the University of Maryland are at least one answer to these concerns, and the reader is invited to explore what is now available. Any one interested in further information or assistance, including exams and projects, may contact the author of this paper.

Biographical Information

ARTHUR T. JOHNSON
Art Johnson has been involved with bioengineering since its early days in the 1960's. He has authored three original texts in bioengineering, including Biology for Engineers. He has been President of the Alliance for Engineering in Medicine and Biology, the Institute of Biological Engineers, and the International Society for

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Respiratory Protection. He is co-founder of the American Institute for Medical and Biological Engineering, and has served as its Executive Director. He is Secretary of the Biomedical Engineering Society. He is a Fellow of AIMBE, ASAE, ASEE, and BMES.

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