AC 2007-868: BIOLOGY FOR ALL ENGINEERING DISCIPLINES.

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Biology for All Engineering Disciplines

Introduction:

This course is designed to provide an overview and introduction to biology and its interfaces with and applications to engineering. At the end of the semester, each student should have:

- A basic understanding of molecular biology with application to engineering design
- A basic understanding of cellular biology with application to engineering design
- A basic understanding of anatomy and physiology with application to engineering design
- A basic understanding of ecology with application to engineering design
- Knowledge about the interface between engineering and biology

Thus this course differs in several strategic ways from either a general survey course that can serve as a science requirement and from an introductory biology course for those majoring in the life sciences. There are more applications of physics and quantitative methods than is typical in most introductory biology courses. However because it is an overview course that is one semester in length, there is not the depth of detail concerning various biological processes that one would encounter in a course for majors that are usually one academic year in length. Finally, there is the discussion of how biology and engineering interact, both how various biological components can be used in engineering design and how engineering impacts biological and environmental processes and problems and how it might be used to solve such problems.

Course Architecture:

The course builds from a molecular level through cellular, organ, organismal, and then population/ community/ ecosystem level. This allows an analogy of "parts" to build devices that are then used in systems. Also presented is the idea that biological phenomena have emergent properties. Often, this is the first time that college students are presented with the concept of emergence. Some students easily accept this concept while others need time and multiple explanations in order to digest the idea. The concepts of evolution and adaptation have to be introduced and continually reinforced as well as the idea that the laws of physics are always relevant and affect physiology, evolution and adaptation at all times.

At the molecular level there is a discussion of amino acids, nucleotides, sugars and fatty acids/ lipids as building blocks with different properties and functions. The amino acids are used to build proteins with different three-dimensional structures that give the proteins their function. The properties and structural differences of DNA and RNA are detailed. The functions of lipids are described, as are the functions of sugars. They can then learn the overall chemical equations of glycolysis and the Kreb's cycle to synthesize ATP as the primary source of energy for cellular processes. The role of oxidative phosphorylation and ATP synthase in the mitochondria are introduced. The role of enzymes as catalysts and how their specificity is dependent upon their amino acid sequence and three-dimensional structure is stressed in this discussion of biochemistry.

The material science aspects of biological materials are introduced including stress-strain curves of proteins and bioceramics. The stress-strain curve of some tendons is related to the protein structure of collagen so that the students appreciate that the amino acid sequence folds into a 3D structure, and that this structure is critical to the functionality of tissues and organs.

The next section begins with a discussion of membranes and how they have emergent properties not expected of single lipid molecules. The membranes and their properties of controlling what molecules can traverse them then leads to discussions of osmosis and diffusion. The idea that membranes can form compartments allows subcellular organelles to be introduced. However the membranes are extremely flexible, so the construction of multicellular organisms requires internal scaffolding built by the actin and microtubles of the cytoskeleton and external scaffolding in the form of the extracellular matrix. The knowledge of membranes and their properties also leads to discussion of bioelectricity in nerves and the action potential. The Nernst equation is presented and the students learn the basic features of ion movement during the action potential and how this leads to nerve communication. Once they understand nerves, the students are presented with muscles and learn the basic details of muscle contraction. Cellular functions including mitosis, transcription, translation, and protein synthesis are covered. An overview of genetics is then done discussing genes, mutations, and control of gene expression.

The class then moves to an organismal level of biology. Fluid mechanics are examined both as to how organisms adapt to life in flowing fluids and fluid mechanics inside an organism, primarily in a mammalian circulatory system. The concepts introduced include the conservation of mass, laminar vs. turbulent flow, viscosity and Reynold's number, Venturi tubes, Poiseuille's equation, and flow rate equations as applied to mammalian circulatory systems. Capillary structure and function and the role of diffusion in promoting nutrient exchange are also discussed. The affect of flow of fluids on the external structure of organisms and where they chose to live is also presented.

The first topic at the organismal level is homeostasis. Feedback loops are explained and applied to water and salt balance with the kidneys as the controller. Once feedback loops are established, hormones can be introduced with an emphasis on insulin and glucagon. Immunity is introduced. Gametogenesis, reproduction, and a few of the main concepts of development are introduced. There is a discussion of stem cells and an introduction to the tissue engineering triad of cells, scaffolds, and signals.

Now that the students understand how an organism functions, they explore concepts concerning populations of species and how different populations interact to form communities. The communities must interact with nonliving aspects of the environment and affect the biogeochemical cycles of carbon, nitrogen, phosphorus, and water at the ecosystem level. These topics lead to discussion of ideas of sustainability and why these concepts must be incorporated into engineering design.

Logistics:

Currently the course is taught by one instructor from the BME department whose degree is in biology. The textbooks used are Steven Vogel's "Comparative Biomechanics" and "The Biology Coloring Book". The biomechanics book addresses the topics of materials, some structures, and fluid mechanics. The second book is an inexpensive book with two page summaries and diagrams on varies topics such as amino acids, proteins, glycolysis, muscle action, arteries and capillaries, genetic crosses, and communities. There are several books on reserve in the library including an introductory biology textbook and a physiology textbook.

The course software Blackboard is heavily used in presenting this course. All PowerPoint lectures are posted online. Many of the lectures have an accompanying online quiz as is detailed below. The external links section contains a number of articles from various sources on MEMS devices, tissue engineering, biosensors, imaging, and sustainability. There are also links to websites that discuss these topics. This permits students to be exposed to a greater variety of engineering applications that may be of interest to a subset of the students.

The students are from the disciplines of aerospace, mechanical, electrical, chemical, and industrial engineering and materials science. At this time, civil and environmental engineering and computer science have their students take a semester of the introductory biology course with those students majoring in life sciences. Bioengineering students who express a desire to apply to medical or dental school must take the biology course in the life sciences department while the remaining bioengineering students register for this course. Approximately 300 students took the course during the fall semester of 2006 and another 200 are registered for spring 2007.

In addition, the bioengineering students are required to take a 3 hour lab concurrently with the biology course. The lab contains modules on diffusion, biomaterials testing, restriction digest and electrophoresis of plasmid DNA, electrophoresis of fish proteins, polymerase chain reactions (PCR) bacterial DNA, fluid mechanics, microscopy, and homeostasis. Greater depth and details are given in the lab for some topics such as biolelectricity than is presented in the lecture.

Assessment:

Assessment is done by means of online quizzes and exams. Blackboard allows an instructor to set up a pool of questions from which a given number of questions can be randomly assigned to students for a quiz. These random pools are usually multiple choice or computational questions. Since the quizzes are online, little grading by the instructor is required. The quiz pool is based on a given lecture and the quizzes can be posted for the students to take at their convenience for several days after the lecture. Currently the quizzes are "open book/ open notes" and are meant to reinforce the lecture.

There are also several exams given during the semester that consist primarily of multiple choice questions. Each exam also includes a question of the short essay type on the interface between engineering and biology. Some examples of these questions are

- Describe how you would use F1 ATP synthase or the photosynthetic processes in a chloroplast in a nanochip or nanomachine

- Discuss how you would use the myosin motors (with or without actin) in a nano-sized electrical-mechanical device.
- Discuss what mechanical and material properties you would require in a material to be used for growing replacement jawbone, aorta or stomach muscle
- Discuss how you would build a container for a bee used for sensing explosive by airport security personnel. Remember that the bees must be able to sense the environment and that the airport personnel must be able to monitor the bee's response

Student's Views:

It is possible for students to fill out anonymous surveys on Blackboard and this has made it possible to obtain pre-class assessment and very honest comments on the class. Several unedited comments after the first exam were

- *The class is very thought provoking even though some of my Mars prokaryotes may seem a little far fetched.*
- *So far I am enjoying the class. All of the material is new for me, which makes it very difficult, while at the same time, very exciting. Unfortunately, I did not do as well on the last test as I expected that I would do, though I studied very, very hard for it.*
- *So far I like how engineering concepts are utilized to study the properties, behaviors, and functions of various organic structures. I especially enjoyed the biomaterials portion (Chapters 15-17) because it applied basic materials concepts to the adaptations biological systems make in order to create the most efficient forms and attributes.*
- *I can't see the relevance of any of the material so far, to electrical engineering.*

Unfortunately this last comment was often repeated by multiple students and some students were unable or unwilling to see the relevance of biology to engineering. Another survey taken approximately two-thirds of the way through the fall semester shows the following scales of response to the question "How interesting is this class?" as reported by the student's engineering discipline (Figure 1).

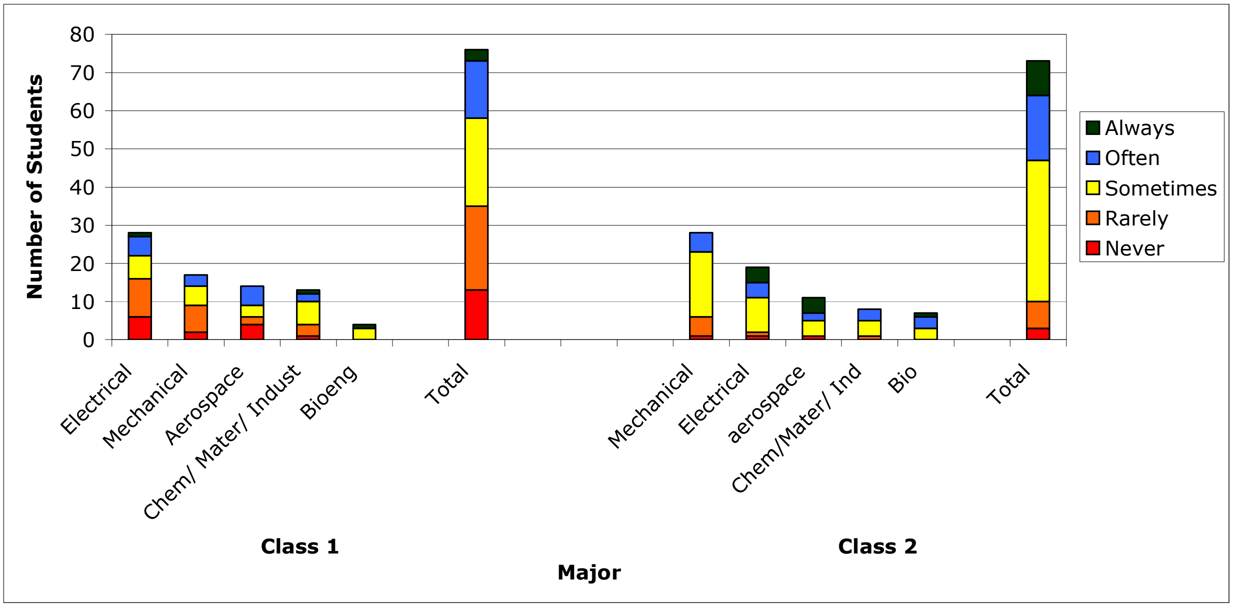

Figure 1. Likert Scale Responses of Two Classes to the Question "How Often did you find the class interesting?" as related to Engineering Discipline.

Future:

The class will be delivered to 200 students in the spring semester of 2007. There are several changes being made in the order of topics presented. More engineering topics and applications will be woven into the lectures in order to increase interest and allow the students to appreciate the vast spectrum of biological problems and how these problems interface with engineering.