Why Engineering Biology Matters

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Abstract –**With the up-coming focus in the future on nanotechnology, bioelectronics and smart electronic systems, an underlying understanding of biology will be fundamental to the development of these new systems for all engineering majors. The Viterbi School of Engineering at the University of Southern California (USC) has developed an undergraduate level course entitled *Engineering Biology Matters* to address how the engineering curriculum must adapt. The course includes new knowledge domains to keep pace with advances in technology that blur the intersection of traditional disciplines. *Engineering Biology Matters* introduces fundamental concepts from the science of biology to the undergraduate engineering student. Not only will *Engineering Biology Matters* use biological phenomena to illustrate concepts relevant to engineers, it will highlight engineering and computer science approaches applied to emerging areas of biological research. Addressed are challenges in identifying relevant content to undergraduates that represent the range of engineering sub-disciplines, as well as the issues the course encountered as it evolved from a special topics course offering to a full fledge curriculum offering.**

Index Terms – Engineering education, bioengineering, biology, undergraduate curriculum.

INTRODUCTION

Biology is getting the attention from the engineering community and is clearly gaining momentum within a broad range of engineering subdisciplines. In fact, the 2004 National Academy of Engineering report *The Engineer of 2020: Visions of Engineering in the New Century* identified the areas of bioengineering, biotechnology and nanotechnology as technology drivers that will fuel advancements to improve the quality of our lives [1].

The completion of the human genome project in 2002 and other recent whole organism genome project efforts have opened the doors to new areas of research, requiring expertise in both biology and engineering disciplines. The book of life now has to be interpreted and researchers are increasingly curious about the communication protocols of molecular systems. This intersection of communication theory and molecular biology can be the quantitative framework for engineering fault-tolerant genes, proteins, and genomes that approach an organism's communication capacity [2]. In addition, this area of research creates huge repositories of data that present opportunities to apply engineering principles towards the acquisition, analysis, visualization, and management of biological information. For example, microfabrication, robotics automation, control systems, imaging and signal processing technologies are technologies that have converged to change the way biological research is designed and conducted as well as impacting the nature of massively parallel data analysis.

We are also observing funding trend increases for interdisciplinary research areas associated with the life science fields. For example, leveraging from the advancements in molecular biology and old-fashioned genetic engineering, the use of biological compounds and systems to create logical circuits is becoming the hottest area in the biological sciences known as synthetic biology. The National Science Foundation in 2006 made the research investment in establishing an Engineering Research Center named SynBERC to lay the foundation for the nascent field of synthetic biology where biologists and engineers are brought together to make advances in complex engineered systems and systems-level technologies that have the potential to spawn new industries or to radically transform product lines, processing technologies, or service delivery methodologies of current industries [3]. Another NSF sponsored center called the Center for Biologically Inspired Materials and Material Systems is taking an engineer's look at nature in order to learn how to improve on its designs for human uses [4]. These interdisciplinary research centers rely heavily on students who are fluent not only in engineering and math speak, but in biology and genetics as well [5].

The content domain clearly extends beyond the traditional confines of a biomedical engineer, especially with the emergence of new interdisciplinary research areas in bioinformatics, computational biology and systems biology. According to the ASEE, among the 73,602 bachelor's degree in engineering awarded in 2005, only 3.27% comes from the subdiscipline of biomedical engineering, with mechanical (20.3%) and the combined subdisciplines of electrical engineering, computer science, and electrical/computer engineering (39.8%) making up the majority of bachelor's degree in engineering [6]. These emerging interdisciplinary research areas on genomics, proteonomics, nanotechnology, bioelectronics, smart electronic systems, and renewable energy present an opportunity to retool the engineer's repertoire to better serve out undergraduates for these new and emerging areas. The time is ripe to broaden our engineering education foundation to include an understanding of biology for all undergraduate engineering majors.

In this paper, I share the lessons learned in designing and implementing *Engineering Biology Matters*, a knowledge-centered 3 unit course curriculum for teaching biology concepts to engineering undergraduate students in a traditional lecture setting.

COURSE DESIGN METHOD AND IMPLEMENTATION

The Viterbi School of Engineering at the University of Southern California recognizes the importance of biology and embarked upon the challenge of designing a useful semester biology course for undergraduate engineers. The premise of such an engineering course is to engage undergraduate engineers to the importance of the intersection of biology and engineering. Similar efforts can be found within academia [7] as well as continuing education and summer short courses in industry [8,9] to name a few, with some of the content geared towards graduate level students.

One of the challenges in developing such a course we encountered was identifying relevant biology content that will appeal to the broad range of engineering sub-disciplines. In addition, this course must be uniquely different to minimize redundancy in traditional introductory course offerings from biology, biomedical engineering, as well as biotechnology and environmental engineering. Furthermore, given the breadth of the life sciences, where should the focus of the biology content lie? Should it emphasize physiological aspects, cell biology, developmental biology, molecular biology, or some combination of the above? The content challenge is further confounded with the assumption that the student will have very little if any previous exposure to biology.

Another challenge faced was the complexity of managing the course requirements in a curricular. How can we motivate students to enroll in an experimental course when essentially there is zero degrees of freedom in course scheduling for the student?

Taking these constraints into consideration, *Engineering Biology Matters* was offered as a pilot course in the spring semesters of 2004 and 2005, allowing students to fulfill degree requirements as optional technical elective. Lectures were twice a week for one and a half hours each. *Engineering Biology Matters* illustrate biological phenomena in the context of engineering principles, using the notion that the introduction of concepts and knowledge are best scaffolded when students can see the application and the relationship to other concepts [10].

To ensure that there would be an interesting topic for any engineering subdiscipline, I examined course syllabi from different engineering schools and departments, focusing on introductory courses for biomedical/biotechnology, transport phenomenon, material science, environmental engineering, physiology and systems, sensors and bioinstrumentation, and traditional life science offering in biology, biochemistry, cell biology, genetics, and microbiology. These courses were then used to identify the extent of overlap among different departments. For example, the course topic transport phenomenon is common to bioengineering, chemical engineering, environmental engineering, and mechanical engineering majors from a list of 12 engineering schools surveyed. Using that strategy allowed for the identification of 6 module topics.

Module 1: ***Life's Matrix*** draws analogies between biological and electronic substrates: information process, transport, and control elements. The biological concepts and principles include fundamental units of life, biological components, and organizational hierarchy to be able to create libraries of interchangeable DNA parts. Relevance to engineering subdisciplines of biomedical engineering (BME), chemical engineering (ChemE), computer science (CS), electrical engineering (EE) and industrial and systems engineering (ISE).

Module 2: ***Biological Circuits and Biological Information Theory*** uses the central dogma as biological information theory and the exploration of biomolecules and DNA based finite state machine to conduct simple computing logic. The biological concepts and principles include fundamental units of life and the metaphor to computing systems. Process of transcription and translation and regulation for smooth information flow. Application of nucleic acid hybridization for new computational paradigms. Relevance to engineering subdisciplines of biomedical engineering (BME), chemical engineering (ChemE), computer science (CS), electrical engineering (EE) and material science.

Module 3: ***Signal Transduction*** uses Cellular signaling pathways that resemble electronic circuits. Proteins and the protein kinase cascade act as amplifiers or switches. The biological concepts and principles include an understanding of the processes and structures needed in converting chemical signals from cell surface to the elicit appropriate cellular response at the molecular and protein level. Relevance to engineering subdisciplines of biomedical engineering (BME), computer science (CS), and electrical engineering (EE).

Module 4: ***Control Systems and Feedback Control*** reveals that control loops are ubiquitous and can be found from transcriptional (bacterial example) and physiological control (antagonistic hormones) to bioregulation. An introductory description of theoretical modeling, simulations, and bifurcation diagrams to inform and guide experimental design and predictions. The biological concepts and principles include regulatory elements and feedback control for cell cycle regulation, blood sugar regulation, and environmental nutrient sensing. Regulatory control points for DNA synthesis and understanding transport and movement of macromolecules across barriers Relevance to engineering subdisciplines of biomedical engineering (BME), chemical engineering (ChemE), computer science (CS), electrical engineering (EE), environmental engineering (EnvirnE), industrial and systems engineering (ISE) and material science.

Module 5: ***Sensors and Detectors*** conveys elements of communication circuits in bacterial systems as well as our immune system using computer security systems analogy. The biological concepts and principles include Biofilms: quorum sensing characteristics at the molecular level and novel applications to prevent and disrupt biofilm formation. Features of immune system to provide specificity, memory, diversity and self-nonself recognition. Regulation and interaction at the molecular level as well as the physiological perspective. Relevance to engineering subdisciplines of biomedical engineering (BME), chemical engineering (ChemE), computer science (CS), electrical engineering (EE), environmental engineering (EnvirnE), mechanical engineering (ME) and material science.

Module 6: *Human Genome Project* focuses on e nabling technology advancements in computing, informatics, wafer manufacturing and imaging techniques as well as novel computational tools. Application of computers, databases and computational methods for the acquisition, analysis, visualization and management of biological information. The biological concepts and principles include Molecular biology and genetic engineering techniques for cloning, DNA sequencing, DNA amplification, and hybridization experiments. Microarray applications for personalized medicine. Relevance to engineering subdisciplines of biomedical engineering (BME), chemical engineering (ChemE), computer science (CS), electrical engineering (EE), mechanical engineering (ME) and material science.

The content also allowed for the exploration of mechanisms and processes of biological systems that can be used as analogies for designing engineered systems. Grading criteria consisted of essay exams (75%), quizzes (15%), and participation (10%).

Although there was no formal textbook for the course, any general biology textbook will serve as a good reference. Reading for the course included current journal articles as well as numerous interactive web resources.

After two consecutive offerings as a pilot special topics course, *Engineering Biology Matters* received university undergraduate curriculum approval in Spring 2006 and is now available every semester. One of the hurdles to receiving university curriculum committee approval was setting the necessary prerequisites so that the content level would not overwhelm students that may not have had biology since their high school years. Putting too many prerequisites can deter interested students especially since there is very little room in an already packed engineering curriculum schedule. As a compromise, the prerequisite listing for the course includes an introductory chemistry or material science course, or the equivalent. Also having AP biology credit can substitute for the prerequisuite.

RESULTS

Overall, the *Engineering Biology Matters* course offering was successful and that the students enjoyed the class based on formal course evaluation and informal written feedback. The distribution of engineering majors for students in *Engineering Biology Matters* include aerospace and mechanical engineering (4%), industrial and systems engineering (6%), chemical engineering (12%), electrical engineering (12%), and computer science (16%), with biomedical engineering majors (50%) representing the bulk of the students. In terms of student year, the distribution ranged from seniors (57%) and juniors (32%), to sophomores (6%) and freshmen (4%). In the precourse survey of students that are not biomedical engineers, the last time students took a biology course was in high school. Since the majority of students were seniors, that meant for some a gap of up to 6 years of having biology.

For the formal course evaluation for the Spring 2004 and 2005 courses, on a scale of 1 to 5 where 5 is excellent, students gave the course rating of:

- 4.11 for *stimulating student interest in the subject matter*
- 4.3 for *presenting subject matter in ways that were academically challenging*
- 3.7 for *providing students a valuable learning experience*
- 3.7 for *clearly articulated course goals*
- 3.9 for *organizing course to achieve goals*
- 4.2 for *overall instructor rating.*

Course evaluation for fall 2006 and spring 2007 are not yet available.

Additional written feedback was requested on the three best and worst aspects of the course. Among the comments received for what students liked least about *Engineering Biology Matters* are:

- Technical language and vocabulary
- Essay exams
- No text book
- Too many journal articles

Among the comments received for what students liked best about *Engineering Biology Matters* are:

- Engineering applications of microarrays, DNA sequencing, biofilms, molecular computing,
- Exposure to novel cutting edge research techniques
- Depiction of various aspects of industry
- Current journal articles

Students were also asked to rate the content level of the material in the course, ranging from elementary, adequate, advanced to too complicated. Self reported content ratings are shown in Figure 1. The majority of students gave a self reporting level of content to be advanced, but despite that, one student shared: “Topics were very interesting although it was difficult to adequately cover all the material in one semester.”

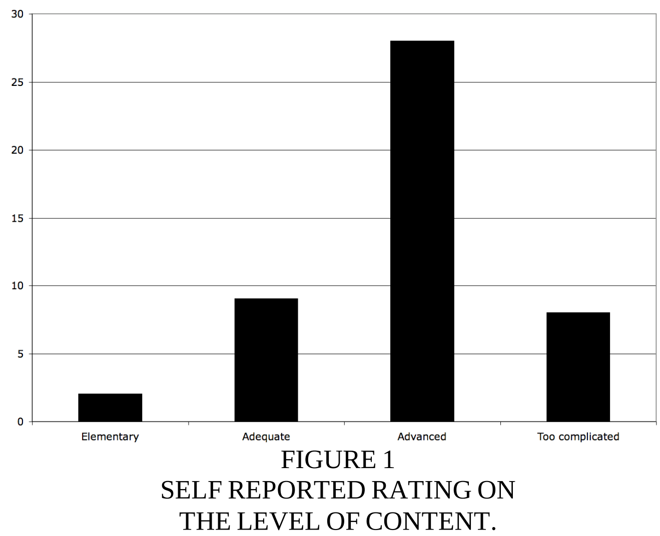

FIGURE 1
SELF REPORTED RATING ON THE LEVEL OF CONTENT.

Students definitely enjoyed the thematic modules to present biology and biological applications to the eyes of engineers, as reflected in these sentiments by written by students: “This class offered the chance to go beyond the biology aspect and tie everything into engineering applications – in essence, it defined my major” and “The biological systems that we studied were very relevant to ISE (Industrial and Systems Engineering) because the body is the most efficient, redundant and well-designed system ever. Studying it can only help in designing and refining other systems.”

Another student articulated: “I found this course extremely interesting and eye-opening, especially towards a whole new field of work and career opportunities.” “The course material gave me an idea of what the filed is about and the scope of knowledge it requires to have.”

One suggestion to improve the course is to add a team presentation element so that students can conduct research on a list of approved topics. In addition, student assessment for future course offerings could be complemented with cross functional peer assessment that trace expected and or unexpected advantages of the course based upon initial students’ course expectations. This could be an important methodolical circle to improve the course for future editions.

In summary, reflecting upon the positive feedback received and adjusting course reading materials, *Engineering Biology Matters* has embarked upon the journey of broadening the foundations of undergraduate engineering education.

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