New designs on teaching biological engineering

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Abstract

The field of biological engineering has evolved tremendously in recent years due to advances in both fundamental understanding of biological systems and in application of engineering methods to utilize this information. To be competitive in the field, graduates of biological engineering programs must have a diverse background which not only is grounded in engineering fundamentals, but also mindful of biological advances. Such requirements of new professionals bring continuing demands on how biological engineering should be taught.

At The University of Arizona, the Agricultural and Biosystems Engineering (ABE) Department has revised its course offerings in the biological engineering area. This presentation will discuss how two courses have been revised to integrate: use of the internet, discussions of recent technological advances, design projects, and laboratory exercises. After several years of poorly-received use of the internet, an improved approach was developed resulting in nearly all students making use of the information on a more than weekly basis. Students responded positively to these changes and performed well compared to students in previous offerings.

Biosystems engineering courses

The approach we have used at The University of Arizona to teaching biological (or biosystems) engineering courses has been to incorporate engineering fundamentals with biological concepts into practical applications and demonstrations. This manuscript will focus on two courses titled Agricultural Bioengineering (a course on fermentations and industrial scale microbiology, bioseparations, and biosensors) and Engineering of Biological Processes (a broader course on bioreactors, bioprocessing, enzymatic conversions, and cell culture (animal and plant)). The first course is a technical elective, whereas the second one is required of all ABE undergraduates. The goals of these courses are similar: to provide experience in analyzing biological systems and in designing processes which provide the optimal environment for use of the biological entity.

A difficulty in teaching these courses is the varied level of preparation of the students in this area. Undergraduate students in our department focus on biosystems, soil and water resources, or power and machinery. This provides a sizeable challenge in selecting topics in the

Engineering of Biological Processes course which is required of all students. Topics which rely on substantial biological science background require either too much or too little background knowledge. Approximately half of the students enter this course having already taken a fundamental cell biology course, while the remaining students have taken more applied courses in plant or soil sciences. To address this challenge, substantial portions of each course are dedicated to topics which differ from the academic experiences of most students but for which most students may have some practical, out-of-the-classroom experience.

Course material is divided into several self-contained modules which include presentation of chemical and biological fundamentals, engineering fundamentals and applications (laboratory exercises, design projects, or demonstrations). Table I provides the topics presented.

Topic	Biological Aspects	Engineering Analysis	Design
Fermentation	cell growth & metabolism	kinetics	fermentation equipment
Microbes & food	spoilage & sterilization	heat transfer	sterilization equipment
Bioprocess	cell-environment, interactions	separations, biosensors, and control	removal of cells from fuel
Biological degradation	biofilms, cell adhesion and motility	mass transport	oxygen transfer requirements
Rheology	food processing	fluid mechanics	pumping of non-Newtonian fluids
Mixing	shear sensitivity, oxygen requirements	fluid mechanics	mixing power requirements
Conversion processes	enzymes – aqueous solutions, immobilized, non-aqueous solutions	kinetics	starch conversion; non-aqueous enzymology
Cell culture	immunology, toxicology, and animal cell growth	kinetics, bioreactors	bioreactor scale up

Table I: Topics presented in two biosystems engineering courses highlighting the biological and engineering aspects of each.

For each module, course material begins with the chemical and biological fundamentals required for a basic understanding of the system, followed by engineering analysis approaches or tools. These two aspects are brought together in a final capstone project which is either a small design project, a laboratory exercise, a demonstration or a combination. Laboratory exercises which have recently been used are presented in Table II. In such projects, ties are made between traditional techniques (fermentation) to new methods and recent developments in the field (such as the use of metabolic engineering to improve production strains).

As an example, here is a summary of the topics covered in the mixing module. An introductory lecture focuses on the purpose of controlled mixing in biological processes such as improved oxygen transfer and delivery of nutrients, but also covers the impact of cellular sensitivity to shear stresses and how this may be modulated by cellular factors such as the presence of serum, viral transfection, or attachment of cells to surfaces. Next, the engineering analysis of mixing is presented covering theory, engineering approximations, and equipment (impeller design). Particularly in the mixing area, ties can be made to applications for which students have practical experience such as mixing cookie dough. New methods including the use of chaos theory and non-linear dynamics to improve mixing are discussed. Finally, the students perform a laboratory exercise determining the time to mix dye molecules in water using stir bars of varying size and shape. A second experiment characterizes heat transfer and the attainment of a steady solution temperature with varying mixing conditions. The experimental results for the entire class are posted on the course web site which the students visit to access a sizeable data set which they analyze using the theory presented at the beginning of this module. This analysis and interpretation of the class' data set represents a major portion of their laboratory write-up.

Topic	Laboratory exercise
Fermentation	Impact of sugar, ammonia, and oxygen on yeast cell growth. Quantify bakers yeast by uv/vis spectroscopy absorbance after 24 hours.
Microbes & food	Prevention of food spoilage.
Bioprocess	Separation of proteins. Recovery of cells using centrifugation.
Rheology	Measurement of viscosity of food products. Determine the terminal velocity of a ball bearing in the food product.
Mixing	Measure power requirements to mix aqueous materials. Determine the time to mix dye droplets in water while varying the stir bar type (straight or cross), size, and rotation rate. Compare to theoretical relationships and to manufacturers specifications for bioreactors.
Enzymatic conversion processes	Enzymatic conversion of starch. Determine optimal temperature and pH of conversion using iodine as reagent to quantify percent of conversion.
Enzymatic conversion processes	Removal of protein stains from cloth using varying washing conditions (temperature, pH).
Cell culture	Evaluate the impact of toxins on cell growth. Quantify cell growth rates of hybridoma cells subjected to varying levels of ammonia. Develop cell growth inhibition models.

Table II. Experiments associated with course modules.

Laboratory exercises are an important component of these courses. Not only do they provide students with hands-on experience, but they also are used to demonstrate the challenges in applying theoretical analyses to "real" data. Table II above presents the topics studied and the specific laboratory exercises employed in this area. Each set of experiments can be conducted by 8-10 students in approximately 90 minutes. Typically the labs are run in shifts so that 20-30 students can complete the lab in one afternoon. Equipment and supply requirements for each are minimal.

This approach has several benefits. Students are exposed to both theory and application and compare experimental measurements to theoretical predictions. Such a combined approach is not often encountered by our students and so provides a greater appreciation for the strengths and weaknesses of each approach. By covering material in self-contained modules, a student's prior background is not directly correlated to their appreciation of the material. Experiments are relatively easy to organize, perform, and analyze. The laboratory exercises also expose students to state-of-the-art techniques and equipment used in the biological engineering area. By posting laboratory data to the course web site, students are encouraged to access on-line material.

The lecture approach employed in these courses is designed to increase student interaction and involvement in the course material. Each lecture has some time designated to asking the students questions about course material at deeper intellectual levels of thinking beyond memorization. They are asked what would happen if some of the constraints were lifted (no gravity?) or how this information could be applied to something useful. Sometimes the correct answer to these questions is, "It is not useful," or "Lifting a constraint is the only way for this to work in a practical system." By gauging whether or not the students can answer such practical questions, one learns about their depth of comprehension of the material and so can adjust the lecture level accordingly. After several weeks of such frequent back and forth discussion with the students, one is able to get them to lose some of their inhibitions on making intuitive leaps regarding application of material which is still somewhat foreign. Oftentimes, relaxing some of the constraints leads to an absurd position or statement, but that is not without merit, as long as the students realize that the point is absurd.

Use of the internet

After several years of unsuccessful use of the internet in improving educational experiences, a new approach was developed for the most recent offering of the Engineering of Biological Processes course. For previous offerings, web sites were maintained with the course syllabus, policies, and peripheral information. As the students had little motivation to seek out the information on the web site, they infrequently utilized the material, and so placing this material on the internet was unfortunately a waste of time. Clearly, a new approach was needed.

For the Spring 2001 offering of Engineering of Biological Processes, a web site was integrated into the daily activities of the course. Lecture notes were placed on the web site with all the equations, figures, graphs, and some additional background information. Example problems and some other relevant material was purposely neglected so as to motivate students to come to class. With this approach, students would benefit from coming to class, but would not need to copy down equations while digesting the lecture material. Some of the notes were also hyper linked to additional web material to provide more in-depth information about the lecture topic. Nearly all of the students would download the notes prior to class so that they could write their own comments directly on the lecture note material. It became clear how many students accessed this material by one occasion in which the notes were improperly hyper linked for one lecture. On the day of the lecture the classroom was filled with students upset with their sudden lack of access to notes. This problem was quickly rectified.

Also presented on the course web site were instructions for laboratory exercises, tabulated results from laboratories (which were needed to complete the laboratory write-up), and current grades (using a randomly-generated number to designate students and thus avoid privacy issues). Placing this information on the web site gave students easy access to this information.

In the previous offerings of this and other courses, electronic notes were used for presentation in lecture. However, this led to poor pacing in lecture and apparently to lower student comprehension. The electronic presentation of equations, diagrams, and notes led to presentation of concepts too quickly without providing time for the students to digest the material. In the recent offering, lectures were made using a white board as if there were no electronic notes. Students found this method much easier to follow, and lecture pacing returned to a more learning conducive level. An example of several sets of web accessible notes can be found at: http://ag.arizona.edu/classes/abe485/ or http://ag.arizona.edu/classes/abe487/. Placing all of the class notes on the internet was a sizeable endeavor, typically requiring approximately 3-4 hours per hour of lecture.

During the Spring of 2001 offering of Engineering of Biological Processes a mid-semester review was performed by the UA testing and evaluation office. Student feedback for these course modifications were quite positive. In the review, "All groups were unanimous in their perception that the notes made available on the internet are a great help. The class also agreed that labs had been a very beneficial part of the course, stating that labs were not only fun, but helped reinforce material from the lectures."

Summary

The approaches presented here reflect an attempt to combine biological science with engineering application in a series of modules. These methods will continue to be revised as new developments on the biological and the engineering side come to fruition and as new equipment becomes available, permitting inclusion of new experimental techniques in laboratory exercises.

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Biographical Information

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