An Engineering Approach to Teaching Biotechnology Concepts

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Abstract

Biotechnology concepts will be a key skill set for future chemical engineers. However, when biological concepts are conveyed to chemical engineering students in a traditional manner, the students often end up lacking the ability to translate these ideas to engineering applications. This discrepancy arises in part from the different way in which engineering students think and approach problems relative to their natural science colleagues. Due to this, the chemical engineering department of Texas A&M has introduced a new course in biology which emphasizes student ability to apply biological concepts to solving engineering problems. Results from survey evaluation of student ability to apply learned biotechnology concepts to new problems indicates that the application oriented approach to teaching biotechnology concepts is effective and should be further developed.

Introduction

The next generation of chemical engineers will be expected to have an understanding of basic biotechnology concepts. Even students entering careers in more traditional chemical engineering fields, such as oil and gas, will be exposed to and likely be required to draw on an understanding of biological processes. In recognition of this, institutions considered to be leaders in undergraduate engineering education, such as MIT, have now made biology a required course for all undergraduate students.[1] The Texas A&M chemical engineering department has recently followed suit. However, when biological concepts are conveyed to chemical engineering students in a traditional manner, the students often end up lacking the ability to translate these ideas to engineering applications. This discrepancy arises in part from the different way in which engineering students think and approach problems relative to their natural science counterparts.

Students who choose to major in engineering tend to think in terms of application. Concepts therefore are most effectively conveyed to engineers in a fashion which emphasizes application and utility, an approach which is contrary to the manner in which biological ideas are often taught. Therefore, in designing our core biology course, we at A&M have chosen to develop an internal engineering-focused biology course, CHEN 282, rather than ask our students to take a biology course from natural sciences. This new course in engineering biology emphasizes the application of the biological concepts to solving engineering problems.

Approach

Scaling up the production of proteins and new pharmaceuticals are key biotechnology areas in which chemical engineers are being hired. To properly scale-up biological production requires an understanding of cellular behavior and of methods to manipulate cellular gene expression.

Although the basic concepts of gene expression form a major focus of any introductory biology course, engineering students completing the natural science biology courses often leave lacking the ability to use these concepts to actually manipulate gene expression. In other words, they leave without attaining a skill that was a key reason for the institution of the biology requirement within the engineering curriculum. To ensure that students taking CHEN 282 gain these key concepts, we at A&M have designed the course so that the concepts of gene expression are couched within industrial examples of gene expression manipulation (for example, insulin production). Furthermore, homework problems and exams have been designed to emphasize the application of learned biological concepts. This basic approach to biological instruction has been applied to all key concepts in the course. End of course surveys were given to assess the effectiveness of this approach.

Examples of this approach are given below.

Example 1. In as standard introductory biology course, the differences between gram-positive and gram-negative bacteria would generally focus on the specific chemical differences in the composition of the cell wall as well as how this distinction can be used as an indicator of virulence.

However, in biotechnology we are interested in the distinction between gram negative and gram positive bacteria for very different reasons. Specifically, it is generally easier to isolate proteins from gram-positive bacteria than from gram-negative bacteria, and therefore gram-negative bacteria are generally preferred over gram-positive bacteria in biotechnology applications.

In teaching the distinction between gram-positive and gram-negative bacteria, our lectures and assessment tools (homeworks and exams) therefore focus on the utility of the concept in biotechnology.

Example homework question: What are the differences in the cell envelope structure between gram negative and gram-positive bacteria? Why are these distinctions important to bioprocess engineering?

Example 2. Proteins produced in eukaryotic cells often undergo complex post-translational modifications. Some of these post-translational modifications have arisen because of the need to specifically direct the proteins to specific organelles. Bacteria do not have organelles, and therefore do not need post-translational tags indicating for a protein to "go to the nuclear membrane," for example.

In a standard biology course, the differences between eukaryotic and prokaryotic post-translational modifications are generally taught as facts. Their specific relevance to bioprocess engineering is generally not conveyed.

In our Engineering Biology course, we emphasize the concept of post-translational protein modifications in terms of its specific implications for biotechnology. Namely, if we want to produce a specific human protein using biotechnology, we have to select the host organism used to over-express this protein so that it has appropriate post-translational tags. If we produce a

human protein that normally has a post-translational tag saying "go to the mitochondria" and express this protein in bacteria, the bacteria will not give it an appropriate post-translational tag. This is because bacteria do not possess mitochondria and therefore won't have the machinery to generate this tag. If we take this recombinant protein and place it in a human, it will not go to the appropriate organelle and will therefore likely not have the desired effect.

Example homework question: Your friend donated $1000 in support of cancer research but is rather shocked to learn that it was used to fund research on baker's yeast. How could you put her mind at ease?

Example 3. Introductory biology courses generally give some level of instruction into enzyme kinetics, with an emphasis on Michelis-Menton (M-M) kinetics. However, once again, the utility of this information to a bioprocess engineer or in biotechnology in general is usually not discussed. Bioprocess engineers must be able to design reactors to produce desired proteins or conduct specific enzyme catalyzed reactions. Therefore, we have combined the instruction in M-M kinetics with reactor design principles.

After introducing the mass balances involved in batch reactors and chemostats, homework and exam problems such as the following were given:

Example homework question: The following data on substrate concentration and reaction rate were obtained in a batch reactor that was operated at constant enzyme concentration.

Substrate (mmol/L)	Initial reaction rate (mmol/L.min)
1	0.20
2	0.22
3	0.30
5	0.45
7	0.41
10	0.50
15	0.40
20	0.33

(a) Evaluate M-M parameters using the Lineweaver-Burke, Eadie Hofstee, and Hanes-Wolf plots.
(b) Based on what you have learnt about M-M kinetics, which data points will you omit? Can you attribute this to any process that you have learnt in class?
(c) Based on the observed reaction kinetics, what would be the merits of conducting the observed reaction in a chemostat versus a batch reactor?

Results

End of course surveys designed with the aid of the Texas A&M Measurement and Research Services office were administered on-line. Student were asked to rate their level of ability in several specific areas, each area focused on the ability to apply learned concepts. Of those responding, over 75% of students rated their ability to apply each core area as adequate to high (Figure 1).

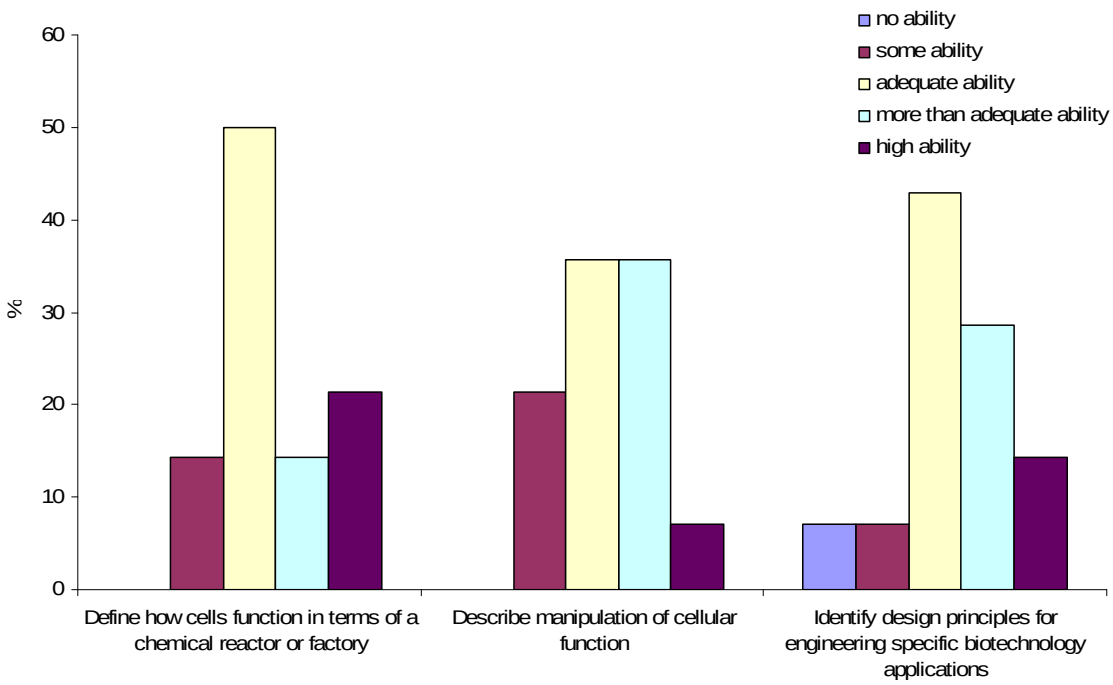

Figure 1. CHEN 282 student self assessment of ability to apply learned biological concepts.

Summary and Conclusions

In summary, a basic fluency in cell biology concepts will be required for the next generation of chemical engineers. As such, a number of universities now require their engineering undergraduates to be introduced to biology concepts. However, the manner in which these concepts are taught is key to the success of these courses. To ensure that student ability to apply biological concepts is emphasized, we at A&M have introduced a required engineering biology course, CHEN 282, into our core curriculum. Results from testing and survey evaluation of student ability to apply learned biotechnology concepts to new problems indicates that the application oriented approach to teaching biotechnology concepts is effective and should be further developed.

References

1. Khodor, J., 1004, - Grayson, L.P., 1980, — "A Hierarchical Biology Concept Framework: A Tool for Course Design." Cell Biology Education, Vol. 3, pp. 111-121.

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