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Challenge-Based Learning in Biomedical Engineering: A Legacy Cycle for Biotechnology

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Abstract

The benefits of a challenge-based environment are recognized by experts in learning science but are infrequently translated to practice in engineering courses. Although individual instructor styles occasionally offer challenge-based instruction, rare is the engineering course in which challenge-based learning is a consistent focus. Few systematic methods for the creation of challenge-based learning materials exist, presenting an obstacle to adoption of this powerful educational technique.

We describe the development and implementation of a challenge-based learning mosaic for biotechnology based on three coupled Legacy Cycle (LC) modules. LCs are templates for challenge-based instruction that use a convenient PowerPoint platform for development and distribution. Learning scientists and biotechnology domain experts worked together to:

- identify the broad (mosaic-level) challenge
- distill three specific (module-level) challenges from the broad challenge
- create materials supporting the creation of three challenge-based LCs
- refine the LCs using analysis from domain experts
- conduct a preliminary assessment of the LCs on biotechnology novices
- apply the LCs in BME 281: Biotechnology at Vanderbilt University
- assess the impact of challenge-based LCs on learner capabilities

The initial LC within the mosaic was based on qualitative observations of mammalian cell culture bioreactor design and operation. Subsequent LCs examined the quantitative aspects of mass and momentum transfer in bioreactors. The biological properties of mammalian cells were integrated with the engineering principles into the overall challenge to produce sufficient recombinant protein for formulation as a pharmaceutical agent suitable for commercial distribution.

Introduction

As an area of science, biotechnology is a combination of advances in our understanding of molecular and cellular biology applied to plant, animal and human genetics. Biotechnology advances are applied to manufacturing processes for use in health care, food and agriculture, industrial processes and environmental cleanup, among other applications. Engineering plays an increasingly important role in the development and practical application of biotechnology principles. A new biotechnology course, designed for fourth-year undergraduate and graduate students was developed at Vanderbilt University as Biomedical Engineering 281 (BME 281) and delivered annually since 1998.

Engineering education of biotechnology mandates a multidisciplinary approach that attracts a heterogeneous learner population. Diverse academic backgrounds complicate the biotechnology learning environment, motivating the application of powerful educational strategies. However, recent research in education has provided some insights into how to design a learning environment that centers on issues of the learner and the knowledge to be learned. A recent report called How People Learn: Mind, Brain, Experience and School[1] has synthesized current research on how people learn and effective classroom practice to create a framework called the HPL Framework. This report indicates that all effective learning environments posses four common dimensions including a focus on knowledge centeredness, learner centeredness, assessments centeredness and community centeredness. Each of these dimensions has a set of principles associated with it that need to be considered when designing a learning environment (see Brophy & Bransford[2] in this proceedings). Briefly, every learning environment is knowledge centered. The application of knowledge to specific activities is one of the major goals of instruction. Learner centeredness takes into account what background knowledge students bring to the learning environment. Assessment centeredness relates to providing students with the opportunity to monitor their progress toward understanding the domain knowledge. Finally, community centeredness focuses on methods to help students leverage their peers as a learning resource and to have instructors use these networks. This includes small group problem solving and in class discussion. Also, community centeredness can include the effects of the university and professional societies in facilitating students' growth as engineers.

These principles have been encapsulated in a software template called STAR.Legacy that we have used to help organize our design of a learning module for biotechnology. Figure 1 shows the main screen of the STAR.Legacy framework (where STAR stands for Software Technology for Action and Reflection) represented as a "Learning Cycle" (or an inquiry cycle for learning). The cycle begins with the presentation of "The Challenge" which is designed to engage students into exploring multiple concepts of the domain knowledge. Students begin by "Generating Ideas" about potential solutions to the challenge and identifying additional information they need

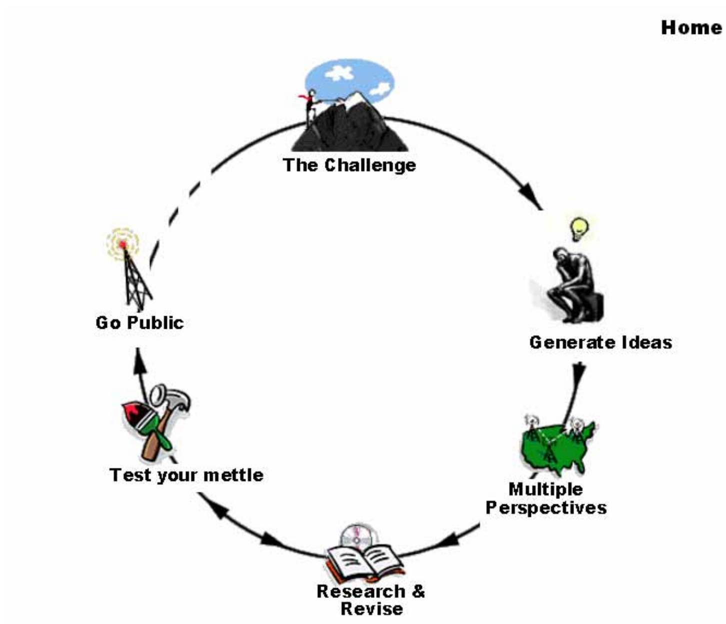

Figure 1 - STAR.Legacy Cycle (Software Technology for Action and Reflection)

to solve the challenge. They can record these ideas and return to them later to compare with what they now understand (assessment centeredness). Then students can compare their initial thought with people who have expertise with the concepts related to the challenge. Expert comments are not enough to solve the problem but provide insight into what should be considered. This primes the students to enter into a process of “Research and Revise”. In this phase, students explore concepts related to the challenge and continually reflect back on what they know and need to learn more about. Once they feel ready to solve the challenge, the can prove their readiness by going to “Test Your Mettle”. The activities in this section are designed to provide students with feedback on their understanding. This process of formative assessment can be done individually, or with small groups. The purpose is to provide students with an opportunity to monitor their own progress for understanding the domain. They can always return to the learning activities in “Research and Revise” to learn more. Once they are ready they can “Go Public” with what they have learned. This can be more of a summative assessment indication of their level of competence with the respect to the goals learning the challenge.
We have used the Legacy Cycle to create an instructional unit in biotechnology designed to teach students elements of bioreactor design for mammalian cell culture. The following outlines our process in creating these modules and a short description of how it works.

Method

Creation of challenge-based learning tools in engineering requires expertise from multiple fields that parallels the multidisciplinary nature of biotechnology education. In general, high-level interactions are required among experts from four perspectives: the engineering domain, learning science, learning technology and assessment. The primary obstacles that must be addressed include:

- identification of the learning objectives
- creation of materials supporting challenge-based instruction
- formulation of learning materials in a deliverable way
- integration of formative and summative assessment tools

Considerable effort is required to raise the awareness of each expert to the learning principles of the other experts. For example, few engineering domain experts are knowledgeable in learning science and expertise in assessment methods does not necessarily imply expertise in the development and delivery of electronic educational materials. Education of the experts – by the experts - in the various facets of the overall approach is an early event in the development of challenge-based educational tools. In our case, this was accomplished by conferences between the domain expert (TDG) and the learning science expert (SPB). Functionally, these meetings provided a forum to iteratively refine the broad expert notions toward a focused learning objective compatible with domain needs and prepared in a challenge-based context. We began our discussion by looking at how to take a challenge from a prior course, called “Design of a Bioreactor”, and convert it to the Legacy Cycle framework. Our initial discussions were designed to explore the nature of the knowledge to be learned and any potential problems. The domain expert explained the process of designing a bioreactor to manufacture a certain amount of product. The learning science expert acted as an “expert novice”. The expert novice is a person who understands when novices might have trouble and is not afraid to ask the expert to stop and explain. Through this process we were able to identify the core learning objectives for the challenge, potential difficulties for the majority of students (noting these points for additional resources) and the challenge, which was too large to be done as a single Legacy Cycle. We then spent several more sessions identifying what each challenge should include, how it should be stated and how much background information would be necessary to get the students into the game of solving the challenge.

Consultation with learning technology experts led to the adoption of a challenge-based LC delivered in the Microsoft PowerPoint environment. Advantages of this learning technology include:

- template-based creation reduces the development effort
- supports a wide range of multimedia
- linkable within the LC, to other LCs and outside the LCs (to internet resources)
- access within either the Windows or Apple operating systems
- deliverable via the internet or locally using CDs on individual computers or an intranet
- pre-existing learner familiarity

Challenges Related to Bioreactor Design

The design challenge requires balancing several constraints simultaneously in a way that maximizes cell growth. The process requires choosing the right reactor type to achieve the desired cell growth rate. Each reactor type has a different method of providing oxygen to the cells. Some reactor types use mechanical methods that increase the amount of available oxygen to the cells, but these methods also increase the risk of cell damage. Therefore, this series of modules needs to help students identify an optimal design for a reactor type to fulfill a desired cell production constraint. The fundamental learning objectives of this challenge might include

1. Identify the critical factors that influence the design of a reactor type.
2. Describe the metabolic rate of cells and how it relates to a reactor design
3. Calculate the rate of oxygen delivery for each reactor type and the oxygen consumption rate of the cells.
4. Determine the amount of mechanical damage for various configurations of different reactor types.

The first challenge for this design activity focuses on describing a qualitative model of bioreactor design. This will require students to revisit their studies in mass transport and provide an opportunity to learn about cell anatomy and other cell characteristics. Most undergraduates have little access to bioreactors; therefore, the initial challenge is a small design challenge around a simple bioreactor to grow a small quantity of cells. Students begin their inquiry by generating their initial thoughts about the major factors influencing the design of the reactor. Experts from research and industry provide their perspectives on several reactor types. The "Research and Revise" activities provide students with the opportunity to research each of the reactor types in more detail. The major objective is to help students develop a ***qualitative*** sense for how cells grow and how the reactor works. For example, students can view a reactor from multiple dimensions using a standard virtual QuickTime™ movie format. With this tool they can rotate the object in space and look it from various sides and angles. An interactive simulation allows students to control various factors of a reactor, such as volume and depth of fluid, to gain a sense for how these factors influence the cell production. Also, a short animation provides students with a mental model for how cells grow and how they receive oxygen in the different reactor types. Once students have reviewed these materials, they take a short online quiz to help them evaluate how well they understood the material. Once they pass this quiz in “Test your Mettle”, then they can place a vote for the best design in the “Go Public” portion of Legacy. As part of “Going Public”, they could write a short justification for their answer. This will be used to compare with the quantitative analysis they will perform in the second challenge.

So when do the students do these activities? This could easily be a teacher-guided activity where the students have access to a computer during class to use the interactive portion of “Research and Revise” activities (e.g. simulations, animations). However, for an undergraduate course, this could be just the kind of activity the students need to engage in prior to coming to class. The degree of difficulty for this first challenge is such that students could think through the major issues and explore the resources. Therefore, this module would take students an hour or two to go through. Pre-class activities like this one will prime students for the next challenge, which could be guided by the instructor during class.

The second challenge in this bioreactor design Mosaic takes a more quantitative approach to the design. This challenge changes the design constraint to require a higher production rate of the desired product. In “Generate Ideas” students can discuss whether their previous design will work or what they need to change to make it work. The experts in the “Multiple Perspectives” provide new insights into how to size a bioreactor to meet specific production rates and some of the pros and cons of the design. Now, as part of the “Research and Revise” section, an instructor provides a lecture to explore the types of calculations necessary to determine values such as oxygen delivery, oxygen consumption and minimization of cell damage in the process. This may take several lectures, but between each lecture, students could be assigned homework problems to apply the ideas demonstrated by the professor in class. The final “Go Public” would be for students to justify their original votes for a particular bioreactor design for the initial challenge, or refine their vote and substantiate it quantitatively.

A possible final challenge could focus on a challenge similar to the second challenge, but target the analysis for a different bioreactor type. For example, the optimal solution in the second challenge could be a stirred tank bioreactor. The third challenge could focus on a hollow fiber design. The objective of the challenges would be to explore the pros and cons of each design. One of the important goals of this third challenge is to provide an opportunity to apply fundamental principles of the domain to a new context. This use of multiple contexts should help students generalize the application of the knowledge they learned during the second challenge.

Results

This paper describes how learning materials for a diverse domain and student population can be created using a challenge based approach. The guidance learning theory and principles for designing an effective learning environment have helped us systematically reflect on the content to learn and to be sensitive to the needs of the students. This process has also identified various methods for students to assess their progress. The result of the collaboration between domain experts and learning science experts has helped to define an interesting set of challenge-based modules.

The original challenge 'Mammalian Cell Bioreactor Design' was too broad for effective use as a single LC. Three linked LCs were spawned from this original challenge that evolved into a Mosaic: 'Bioreactor Selection', 'Bioreactor Mass Transfer' and 'Bioreactor Momentum Transfer'. The first LC of the Mosaic, 'Bioreactor Selection', is ready for use in the Spring 2001 version of BME 281. The remaining LCs of the Mosaic are also expected to be classroom tested during Spring 2001. These results of these LCs will be compiled and assessed to assist in the development of additional challenge-based learning materials.

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