AC 2009-1189: DESIGN AND DEVELOPMENT OF EDUCATIONAL MODULES FOR BIOPROCESS ENGINEERING

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Abstract

East Carolina University's new general engineering program is built around the goal of excellence in undergraduate education. The faculty members of the program are encouraged to pursue novel approaches to engineering education in order to achieve this goal. The newly created concentration in bioprocess engineering provides an excellent opportunity to develop and implement a novel curriculum based upon proven pedagogical approaches designed to engage the students and improve their mastery of concepts. There are four main objectives of this NSF funded (DUE-0737198) Course, Curriculum, and Laboratory Improvement project: utilize proven techniques to develop nine instructional modules for three bioprocess engineering courses (three modules per course); develop common themes to integrate subsets of these modules between two or more courses, while ensuring portability to other programs; assess the effectiveness of the instructional modules; and disseminate the results so other programs can incorporate the modules into their curriculum. This paper provides a first year update of this two year project and includes a description of each of the nine newly developed modules, the assessment plan, and the results of the assessments to date.

Project Introduction and Objectives

East Carolina University (ECU) is a large regional university that serves eastern rural North Carolina and the eastern region of the United States. The industries and businesses located among the small towns of eastern North Carolina have a need for a broadly skilled general engineer. The rationale for a general engineering program at ECU is made by Kauffmann et al.[1] "Instead of the traditional engineering disciplines, these operations require engineering generalists with a strong theoretical background, broad knowledge in a range of areas, and specific skills in problem solving to give them a sound but flexible base for managing and implementing technology change and operations." In 2004, East Carolina University initiated a bachelor's degree program in general engineering (BSE) to fulfill this requirement. The BSE curriculum is implemented "through a concept and program identified as the Integrated Collaborative Engineering Educational Environment (ICEE). The ICEE program… emphasizes a broad but highly integrated foundation of engineering fundamentals and engineering sciences necessary for a general engineer."[1]

The ECU engineering program features a common core that develops the fundamental engineering skills and four concentrations that build specialized knowledge: systems engineering, engineering management, biomedical engineering, and bioprocess engineering. The engineering graduates that specialize in the bioprocessing concentration will work in one of the fastest growing segments of the eastern North Carolina's economy; bioprocessing and pharmaceutical manufacturing. These engineers will require the skills to support, operate, and improve these biomanufacturing processes. The current bioprocessing curriculum has six additional courses beyond the engineering core curriculum: Microbiology, Organic Chemistry, Introduction to Bioprocess Engineering (BIOE 3000), Bioprocess Validation and Quality (BIOE 4000), Bioprocess Separation Engineering (BIOE 4010), Bioprocess Plant Design, and

Simulation and Analysis (BIOE 4020). The bioprocess engineering concentration courses are in addition to the two semester capstone design sequence that will also have some bioprocess related component.

The faculty of ECU's engineering program are encouraged to pursue novel approaches to engineering education. The newly created concentration in bioprocess engineering provides an excellent opportunity to develop and implement a novel curriculum based upon proven pedagogical approaches designed to engage the students and improve their mastery of concepts. The objectives of this project are:

1. Utilize proven techniques to develop nine instructional modules for three bioprocess engineering courses (three modules per course).
2. Develop common themes to integrate subsets of these modules between two or more courses, while ensuring portability to other programs.
3. Assess the effectiveness of the instructional modules.
4. Disseminate the results so other programs can incorporate the modules into their curriculum.

Project Background

In 1999, the National Research Council published *How People Learn: Mind, Brain, Experience, and School* [2] as the summary of what we know from research about the first three words of this title. This document proposed four "centerednesses" that, taken together, optimize learning: *knowledge-centeredness*, *student-centeredness*, *assessment-centeredness*, and *community-centeredness.* When these four are in place, studies show that students increase both their content knowledge and their ability to apply that knowledge in new situations – i.e., their *adaptive expertise*.[3-8] First, the learning environment must be *knowledge-centered*; that is, appropriate information should be presented in an appropriately sequenced and organized way. Second, the environment must be *student-centered*. Lessons should seek out students' prior conceptions and misconceptions, help students make connections with prior knowledge, and be relevant to students' own lives. Third, the learning environment must be *assessment-centered*; it should include opportunities for formative feedback for both students and instructors. Students benefit from opportunities to check their own understanding and instructors benefit from opportunities to assess the effectiveness of their teaching. Finally, a learning environment must be *community-centered*, one in which students are provided opportunities to learn collaboratively.

Many efforts are underway within STEM education to move away from traditional lecture methods of delivery towards more novel methods designed to engage the students in the learning process.[9-12] In many cases, these methods are taking the How People Learn concepts from theory to practice. The highlights of two specific programs, Project Galileo[11] and VaNTH[12] follow.

Project Galileo has developed two novel pedagogical approaches: Peer Instruction and Just-in-Time Teaching. These approaches are designed to provide students "with greater opportunity for synthesizing concepts while instructors get timely feedback that can help focus instruction on the points that are most difficult to learn."[13] The strategies also maximize the efficacy of the classroom session, where human instructors are present, structure the out-of-class time for maximum learning benefit, and create and sustain team spirit.[14]

In their study of ten years of peer instruction, Crouch and Mazur[11] report: "Peer Instruction engages students during class through activities that require each student to apply core concepts being presented and then explain these concepts to fellow students. Unlike the traditional method of asking informal questions during lecture, which often only engages a few highly motivated students, Peer Instruction is more structured and designed to engage every student in the classroom." Peer Instruction consists of (1) preclass reading, (2) mini-lectures, (3) concept tests, and (4) discussion, and can be combined with both traditional lecture and other interactive techniques.[13]

Novak[14] describes Just-in-Time Teaching (JiTT for short) as "a teaching and learning strategy based on the interaction between web-based study assignments and an active learner classroom. Students respond electronically to carefully constructed web-based assignments which are due shortly before class. The instructor reads the student submissions 'just-in-time' to adjust the classroom lesson to suit the students' needs. Thus, the heart of JiTT is the 'feedback loop' formed by the students' outside-of-class preparation that fundamentally affects what happens during the subsequent in-class time together." JiTT can be viewed as a technology that facilitates the preclass reading and, to some extent, the concept tests in the Peer Learning environment. JiTT makes use of the web; however, it should not be confused with distance learning or computer-aided instruction since nearly all the instruction still occurs face-to-face in the classroom. JiTT content is typically classified into three categories: student assignments such as warm-ups and puzzles in preparation for classroom activity; enrichment pages such as short essay or URL links highlighting practical, everyday applications of the subject matter or other interesting related material; and stand-alone instructional material such as simulations or spreadsheet programs.

The approach taken by VaNTH has focused more directly on HPL theory in developing an approach to improve the efficacy of teaching STEM material. According to HPL theory, students learn best when (1) presented with organized information that (2) relates in some way to their own experiences, and they are given the opportunity to (3) test themselves on their own understanding and to (4) work to develop their understanding with other students. The STAR.Legacy Cycle (Figure 1 – note that the terms "Legacy Cycle" and "STAR.Legacy Cycle" are used interchangeably) was created as a means of implementing the HPL ideas in the classroom.[15] The Legacy cycle incorporates these four influences on learning by providing a rich, contextually-based problem, relevant in some way

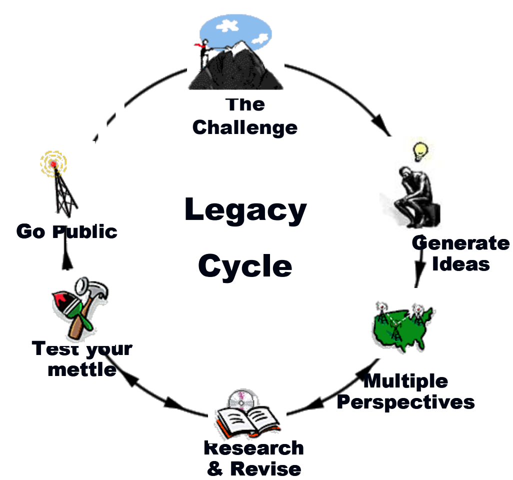


Figure 1: STAR Legacy Cycle Diagram[15]

to students' lives, and allowing students to engage deeply with that problem in ways that include opportunities for collaboration with other students and for self-assessment.

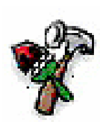
The Legacy cycle consists of six phases as illustrated in Fig. 1. In the *Challenge* phase, students are presented a problem that they are to solve. From the problem statement, the students are encouraged to generate ideas in a brainstorming session. During this *Generate Ideas* phase, the instructor accepts all ideas without criticism or comment. Following the *Generate Ideas* phase, the students are steered towards the desired path by receiving multiple perspectives on the subject. These could be opinion such as pre-recorded opinions of known experts, excerpts from journal articles, or a quick visit to a website. In any case, the *Multiple Perspectives* phase is intended to be short and immediate, and requires pre-planning from the instructor (it is not a literature review done by the students). After the students obtain the additional insight and intended steering of the multiple perspectives, they move into the *Research and Revise* phase. This is the phase in which most of the learning and teaching occurs. This phase could consist of student-driven research and experimentation, passive lectures, homework assignments, or any other combination of concept delivery. During the *Research and Revise* phase, the students will occasionally test their mettle. In the *Test Your Mettle* phase, the instructor will implement formative assessment to evaluate the students' understanding of various concepts. Finally, the students answer the challenge through the *Go Public* phase. The *Go Public* phase is intended to provide summative assessment of the students' performance of the challenge. Table 1 provides a summary of each phase with examples of activities.[16]

Case-based learning has been used in other fields such as medicine and law with success in learning for some time now.[17] These cases are similar to the Legacy Cycle in the use of an initial "challenge" or problem that must be solved. However, Legacy Cycle lesson design adds more specific structure to the traditional problem-based learning format, as after the stated Challenge and following the Generate Ideas activity, students examine selected thoughts from experts that relate to the problem and direct their thoughts in the desired direction(s) before engaging in "Research and Revise" activities. These steps are supported by additional research that has demonstrated improved learning when students first generate their own ideas and then hear experts' ideas prior to consulting resources or learning new material.[18] Formative assessment or feedback is useful to students and instructors as well in generating actual learning[19] and is incorporated in the Legacy Cycle at the Test Your Mettle stage. Lastly, students are motivated by creating a product or answering an authentic question[20,21] as is done in the "Go Public" stage of the Legacy Cycle.

Engineering curricula utilizing the STAR.Legacy Cycle design have been developed and implemented with great success in the college engineering classroom.[16,22] Roselli[23] and Pandy[24] have demonstrated the efficacy of the Legacy Cycle in biomechanics education. Measures in Roselli's biomechanics class show an increase in both student ratings of the course and instructor on evaluations as well as an increase in the understanding of difficult concepts. In other engineering courses, concepts such as Fourier analysis and signal processing have been taught effectively.[25,26] Measures in Greenberg's[26] physiology course show a statistically significant improvement in Fourier spectral analysis skills. These examples, along with studies at the high school level all illustrate a mastery of science concepts beyond that of control classrooms for concepts taught using the Legacy Cycle design.[7-8,27-29]

The techniques of the Peer Instruction and Just-in-Time Teaching dovetail well with Legacy Cycle approach. As illustrated in Table 1, the Research and Revise and Test Your Mettle phases of the Legacy Cycle contain activities such as lectures, readings, and student to student teaching that can be enhanced by using the Peer Instruction and Just-in-Time techniques.

Table 1: STAR.Legacy Cycle, Phase Summary and Examples[16]

Challenge 	A question that causes students to wonder about the topic and become engaged with it. The question frames the module and requires students to bring to bear their current knowledge and preconceptions about the topic.	Examples (science): • Your grandmother is recovering from a broken hip. In which hand should she hold a cane to help her balance? • Assume you are a living cell in a bioreactor. What things will influence/determine how long you live?
Generate Ideas 	A whole-class activity that causes students to display and compile their current knowledge/ideas/perceptions. Note that this can also be done in the form of questions: What things would you need to know to answer this question? What additional information would you like to have to help you answer this question?	Possible activities (all should include some type of written record): • Individually writing a narrative • Whole-group brainstorming • Small group brainstorming with public sharing • Think-write-pair-share • Think-write-pair-shared-squared with public sharing.
Multiple Perspectives 	Two or more outside resources that provide information related to the topic of the challenge. (These tend to "point students in the right direction" for further inquiry.)	Possible sources: • Outside expert (live, on video, or in transcribed paragraph[s]) • Web site(s) • Textbook excerpt • Magazine article • Clip from scientific video
Research & Revise 	Additional information that students receive/seek. This may be in the form of lecture, readings, websites, etc. Students revise their original ideas based on new information (often includes students' journaling regularly).	Possible venues: • In-class lectures • Textbook and other readings • All others listed in Multiple Perspectives
Test Your Mettle 	A set of activities in which students engage to help them explore their depth of knowledge. The goal is to create formative assessment situations that help them evaluate what they do not know so that they may return to the Research & Revise step again to learn more.	Possible venues: • Seek feedback from other students on product • Seek feedback from the instructor on product (poster, essay, game, practice test, role play, etc.)
Go Public 	Final conclusion(s) that students display.	Possible venues: • Test • Oral presentation • Poster/Project • Role play

Project Scope and Benefits

The bioprocess engineering concentration consists of six courses beyond the general engineering core curriculum. Two of the courses, organic chemistry and microbiology, are valuable prerequisites for the bioprocess engineering courses that follow. Of the four remaining courses, we are creating novel content for three of the courses: Introduction to Bioprocess Engineering (BIOE 3000), Bioprocess Validation and Quality (BIOE 4000), and Bioprocess Separation Engineering (BIOE 4010). The first course, BIOE 3000 is a sixth semester course, while the other two courses are normally taken in the student's seventh semester. Specifically, three modules per course (nine modules total) utilizing the Legacy Cycle approach for engaging students are being developed. Each module will nominally represent two to three weeks of content such that about 50% of each course will be initially delivered utilizing the Legacy Cycle. In addition to the Legacy Cycle, both Peer Instruction and Just-in-Time Teaching will be incorporated into the modules to increase the learning effectiveness of these courses.

Consistent with ECU's adaptation of vertically integrated engineering modules[30], six of the developed Legacy Cycles contain some aspect of integration. In general, this integration will be through the use of a common theme. Thematically linking the modules across courses will help the students make connections between seemingly unrelated materials and reinforce selected concepts, thus enhancing their learning. The proposed plan for integrated modules is shown in Fig. 2. One of the Legacy Cycles from BIOE 3000 will serve as a stepping stone for a Legacy cycle utilized in BIOE 4000. A second Legacy Cycle from BIOE 3000 will serve as a stepping stone for a Legacy cycle utilized in BIOE 4010. Finally, a Legacy Cycle from BIOE 4000 will integrated into a Legacy cycle utilized in BIOE 4010.

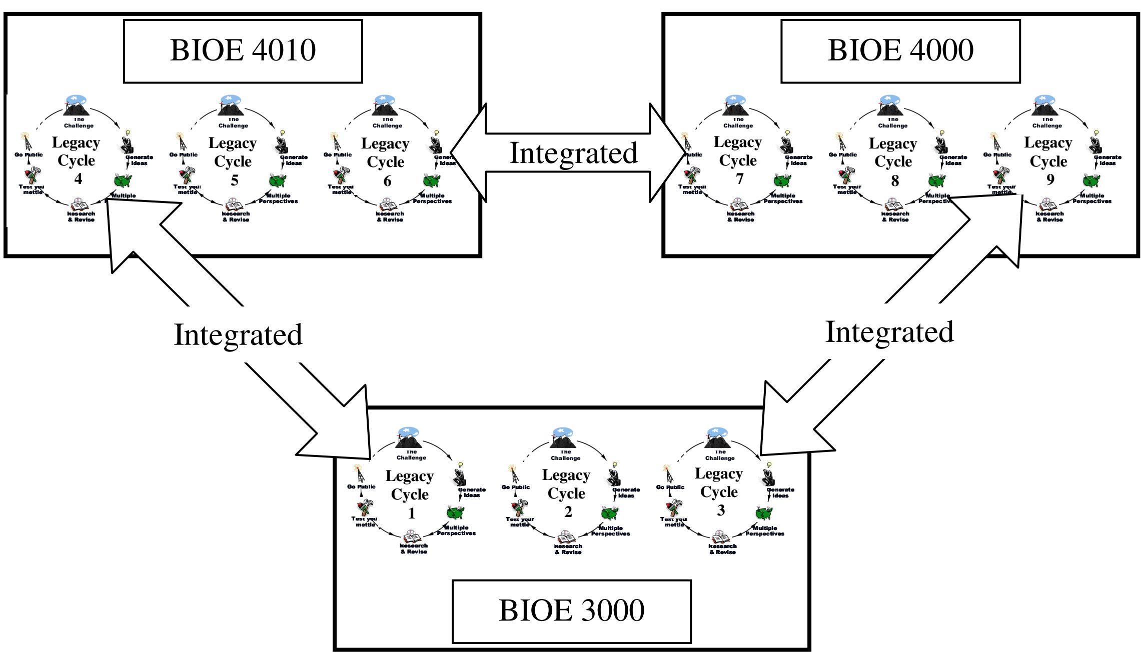


Figure 2: Proposed Legacy Cycle module implementation showing the integration between selected modules

The unique benefit of developing integrated Legacy Cycles is that it allows students to build upon the knowledge gained from the previous cycle, improving the efficiency of delivery of the second cycle, thus allowing more depth and breadth of coverage of the second cycle. The challenge of this approach is ensuring the ability to run the second cycle independent of the first cycle. We strongly believe that integrated modules must have some ability to stand alone to ensure portability to other programs and to allow for the case in which a student was not exposed to the earlier module within a series (perhaps due to receiving transfer credit for the earlier course). To affect this end, the modules must be loosely integrated so they can stand alone with only minor modifications.

The specific deliverables are the Legacy Cycle modules. Each module will include:

- The Challenge Question.
- Activities utilized during the Generate Ideas phase.
- Outside resources utilized during the Multiple Perspectives phase.
- All lecture material, mini-lectures, concept questions, JiTT material, assignments, and other content utilized during the Research and Revise phase.
- All activities in which students engage to help them explore their depth of knowledge during the Test Your Mettle phase.
- All tests, project descriptions, presentation descriptions, or other material utilized for summative assessment during the Go Public phase.

In addition to the above, each integrated module will include a description of the integration as well as recommendations on how to run the module so that integration is not a necessity. This information is important to ensure transportability to other programs that may want to make use of only a subset of the modules.

The direct benefits of providing challenging integrated bioprocess engineering modules are the critical thinking skills the students will develop for use throughout their careers. Successful graduates of a general engineering program, with concentrated studies on bioprocess engineering, will need to extend themselves and apply the fundamental concepts of engineering and mathematics they learn to a variety of conditions and situations. They will most likely be the cohesive component in a project requiring a multifaceted approach for successful completion. The more the students are engaged, as occurs with this proposed approach, the better the subject matter will be retained and applied. Utilizing the skills gained through completing Legacy Cycles, the graduates will be able to apply their experiences to tackle challenges, generate ideas, use their resources, and test hypotheses and ideas culminating in a successful approach to managing and solving problems.

Project Implementation Status

We have developed nine Legacy Cycle modules for the three bioprocess engineering courses. The first course, BIOE 3000, Introduction to Bioprocess Engineering, was administered in the Spring of 2008 as a control and did not utilize the instructional modules. This course is running during the Spring 2009 semester using newly developed instructional modules. The Legacy Cycle challenge questions for all three courses are shown in Table 2 and the corresponding Go Public assignments are shown in Table 3.

Table 2: Challenge Questions for Legacy Cycles

Legacy Cycle	**Legacy Cycle Challenge Question**
Course: BIOE 3000, Bioprocess Engineering Systems	
1	E. coli is often used as a host organism to produce recombinant proteins of interest. How do you genetically engineer bacteria, such as E. coli, to produce a desired recombinant protein?
2	Many protein production processes utilize bacteria as the host organism. How do you mass produce a recombinant protein using bacteria as the host organism?
3	The human plasma protein antithrombin is an anticoagulant that plays a key role in controlling clot formation. It is used as a therapeutic protein to prevent blood clots in patients who lack the natural anticoagulant protein. How do you mass produced this protein?
Course: BIOE 4010, Bioprocess Separations Engineering	
4	As a newly minted bioprocess engineer, you have been asked to develop a process to produce ethanol using locally grown feedstock. How will you go about selecting and testing to determine the best feedstock?
5	Many protein production processes utilize bacteria as the host organism. A new protein has been developed and will be massed produced using the bacteria *E. coli* in an industrial fermentation process. Determine the steps necessary to purify the protein.
6	The human plasma protein antithrombin is an anticoagulant that plays a key role in controlling clot formation. It is used as a therapeutic protein to prevent blood clots in patients who lack the natural anticoagulant protein. Transgenic female goats have been used to produce therapeutic recombinant human antithrombin (rhAT) in their milk. Milk from transgenic animals can be easily obtained in large-scale quantities from established technologies of the dairy industry and is a convenient starting material from which to purify recombinant therapeutic proteins. How can you purify a recombinant therapeutic protein from the milk produced from transgenic animals?
Course: BIOE 4000, Bioprocess Validation and Quality Engineering	
7	In your hometown, a manufacturing plant makes the same pain-killer that your Dad takes for his bad back. Who is responsible for insuring that the pain-killer produced there is safe?
8	Your sister has been diagnosed with asthma. Different types of medicines exist in order to both treat and maintain this disease, from steroid-based products to tablets (SINGULAIR®). Thus, these are manufactured in different manners. Some of the equipment used to manufacture these different products may be shared. Your sister cannot take a steroid-based product. What should be considered by the manufacturer in establishing cleaning processes that help insure that the tablets she takes will not be contaminated by the steroid product?
9	Miss Wormwood fell and broke her hip and has to have surgery. Due to her age, cigarette smoking habit, being overweight, and having been bed-ridden since the fall that caused the break, she is at risk for a pulmonary embolism. Although Calvin may present the attitude that he does not care about the course material, he now sees a legitimate reason why what he has learned in his class is so important. The hospital plans to give Miss Wormwood a recombinant therapeutic protein to prevent a pulmonary embolism. Calvin wants to do his best to understand how the pharmaceutical company that produces the protein (that also retained his father as a patent attorney) insures that the protein is not only effective but safe for her to take.

Table 3: Go Publics for Legacy Cycles

Legacy Cycle	**Legacy Cycle Go Public**
Course: BIOE 3000, Bioprocess Engineering Systems	
1	Create a visually appealing flowchart/schematic illustrating the processes required to genetically engineer an organism to express a desired protein. Start with the source DNA and finish with the genetically engineered organism.
2	Complete mini-project that analyzes cell growth kinetics and stoichiometry of microbial growth and product formation.
3	You work as a process engineer for a small bioprocess startup company. You have been asked to produce a therapeutic recombinant human protein. Select the appropriate production platform. Create a poster that illustrates your process design considering appropriate host organisms for post translational modifications, protein production, and downstream purification.
Course: BIOE 4010, Bioprocess Separations Engineering	
4	Create a laboratory manual describing how to produce ethanol from sweet potatoes with an objective of determining the ethanol yield of the process. The manual should provide sufficient detail including safety precautions, required equipment and materials, step-by-step instructions, any necessary data to record, any clarifying diagrams, and assays that are used to verify the process.
5	Given a set of ten proteins and their properties, determine the process steps required to extract the proteins from the bacterial cells and purify the target protein. For each separation process step, describe the step, explain why you chose the particular separation process, and any possible alternatives and why you did not choose the alternative. You must include all required steps such as buffer exchanges, elutions, and washings. Assume that the final product requires the purified protein in a salt-free buffer at a pH of 8.5. Assuming the yield of each separation process is 95%, calculate the overall process yield.
6	You work as the technical advisor for a small bioprocess startup company. Your company recently received the rights to process therapeutic recombinant human antithrombin (rhAT) produced in goat's milk. Your CEO has asked you to create a poster that he can use to explain the process to potential investors. Assignment: Create a poster using PowerPoint that explains the purification process required to obtain the protein.
Course: BIOE 4000, Bioprocess Validation and Quality Engineering	
7	You are an FDA Director and have new inspectors to train. You must develop a presentation and train these inspectors based on the developed FDA inspection guide applicable to your assigned area, as well as the latest information on this topic area. You must use at least two case studies to present to the class, which can be based on FDA 483s or Warning Letters or other information found in the public domain – from library resources such as books or journal articles.
8	Develop a cleaning validation protocol for a cooking process considering equipment/containers/pots/pans/sinks/food contact surfaces in your kitchen. Use the cleaning validation procedure VAL -104 as your guide. As part of your protocols, provide a description of your cooking process and "residues" that must be considered for cleaning process removal (i.e. grease, milk, acids, cleaning agents) as well as the materials of the surfaces you are cleaning (i.e. stainless steel/ceramic sink, countertop material, oven/stovetop surfaces), testing to be done, etc.
9	Develop a Process Validation Protocol for the BIOE 4010 Ethanol laboratory (for which you prepared a laboratory procedure). Use the process validation procedure VAL -106 as your guide. You may use as resources material provided for this module as well as additional library resources such as books or journal articles.

We have implemented six total Legacy Cycle modules for two bioprocess engineering courses (BIOE 4010, Bioprocess Separations Engineering; and BIOE 4000, Bioprocess Validation and Quality Engineering). For each of these legacy cycles, an instructor's guide that outlines the implementation to include Legacy Cycle steps, day-by-day objectives, recommended assignments, course content, and the final project (Go Public) is under development.

In addition to the Legacy Cycle modules, techniques such as Personal Response Systems and Peer Instruction were developed and utilized to engage the students more effectively. These techniques were primarily used as formative assessment during the Research and Revise and Test Your Mettle phases of the Legacy Cycles and will be documented within the instructor's guide.

The project currently integrates three sets of modules across the three courses. Table 4 lists the integrated modules and the theme of the integration. Note that the integration scheme does not exactly match with the proposed plan illustrated in Fig. 2, however the intent to have three sets of integrated modules remains.

Table 4: Integrated Modules and the Integration Theme

Integrated Modules	**Integration Theme**
4-9	Production of ethanol. Create a lab manual in Module 4 and a validation protocol of the process in Module 9.
3-6-9	A therapeutic recombinant protein expressed in an animal's mammary glands. Used as the basis of the Legacy Cycles in all modules, as the Go Public in Modules 3 and 6, and as a Test-Your-Mettle Exercise in Module 9.
2-5	Production and purification of a protein expressed in a bacterial cell. Understand the production of the protein in Module 2 and the purification of the protein in Module 5.

Project Assessment

The effectiveness of the proposed modules will be assessed using three methods: *Concept Map Analysis*, *Individual Course Content Mastery Analysis, and HPL Survey*. A description and status of each technique is presented below. The assessment will also be used to review and evaluate effectiveness of each newly designed instructional unit at the mid-point of this project. Appropriate revisions will be made to all units and their assessments at this time.

Concept Map Analysis

Concept maps have been used for assessing a variety of outcomes in instruction since the early 1970s. More recent studies have shown that concept maps can be used for assessing declarative knowledge ('knowing that'), procedural knowledge ('knowing how'), and implicit knowledge.[31-33] Because students develop domain expertise and their knowledge becomes more like their teacher's or the domain expert's over time,[34] concept maps could be used for monitoring learning outcomes and goals.

A teacher-expert map can be created by the method described by Gordon et al.[31] where the expert is first asked a question and that free response is recorded. This response is translated into nodes and rules. Question probes are used to complete the response along with observation and induction about the expert's implicit knowledge. Student maps can then be compared to the teacher-expert map using a scoring system that focuses on the degree of accuracy of the relationship described in each proposition, or pair of concepts, and is based on stated objectives of the course.[32-35] This analysis includes three rubric scores on each map: pertinent items found on the map, relationship between the concepts in the stem and the correct answer, and misinformation.[32] Previous studies such as Rice's[32] have shown strong inter-rater reliability measures for this scoring method as well as strong correlations to demonstrably reliable criterion multiple choice tests, suggesting that concepts maps are a reliable test method. Concept mapping can be taught quickly and easily to students and the technique can be used by large classes with minimal assistance from teachers, making it also a relatively easy method of assessment.[33]

Using a concept map, the students are asked to answer the following question: "*How is a biologically based product produced and processed to ensure its safe distribution and use*?" Students complete a new concept map during four points in the curriculum; 1) at the beginning of BIOE 3000, 2) at the end of BIOE 3000, 3) at the beginning of BIOE 4000/4010, and 4) at the end of BIOE 4000/4010. In addition to the student generated concept maps, we generated an expert map utilizing inputs of the project investigators as well as three members of our advisory board. An excerpt from this expert map illustrated in Fig. 3. The expert map is being used as a basis in the development of an assessment rubric of the students' concept maps.

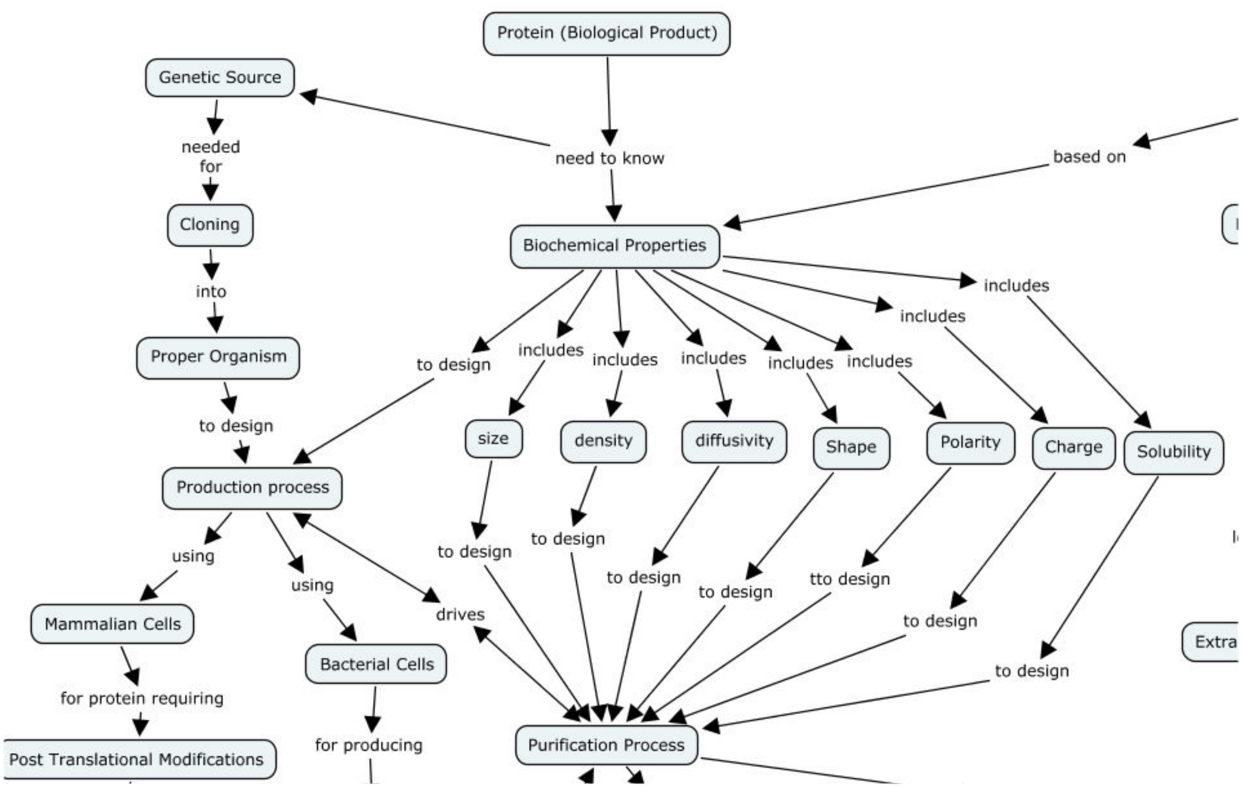


Figure 3: Excerpt from the Expert Concept Map

Individual Course Content Mastery Analysis

For each module that is created, a module-specific pre-test and post-test has been written. Each test includes questions that focus on basic terminology, problems and skills from the unit, and a near-transfer question. Pre-test and post-test scores are compared using a paired t-test.

Table 5 shows the results of the pre-test and post-test for BIOE 4010. The paired t-test indicates a significant difference of the student's comprehension of the material after the completion of each module. Since this was the first run of the course, there was not an opportunity for a control sample, thus making the ability to directly measure module effectiveness difficult. Therefore, all three assessment instruments will be utilized to draw conclusions regarding the effectiveness of the modules. The analysis of all three assessment instruments was not complete at the time of publication and will be published in a future article along with the assessment of the modules from BIOE 4000.

Table 5: BIOE 4010 Pre- and Post-test Results

Module Number	Pre-test Mean	Post-test Mean	P-value
4	5.9	12.7	<0.01
5	4.6	12.2	<0.01
6	6.3*	13.7	<0.02

* One person had to be excluded due to lack of pre-test
n=5; paired t-test

HPL Survey

The final assessment tool is the "How People Learn" survey developed by the VaNTH ERC. The purpose of this assessment is to measure how well the new instructional materials meet the areas of effective classroom instruction as described in the book *How People Learn*.[2] These areas include knowledge, assessment, learner-centered, and community. This assessment is administered in all classes using the Legacy Cycle approach. We expect to see improvement in the scores from the first year of BIOE 3000 to its second year when the newly created modules are introduced into it. These surveys will also serve as a means of feedback to the instructors about the effectiveness of their teaching and the instructional units themselves.

Conclusions

Nine learning modules for a bioprocess engineering curriculum have been developed using the Legacy Cycle approach. Six of these modules have been successfully implemented into the classroom during the fall of 2008. Assessment of the six implemented modules is ongoing through the use of module pre- and post-test, concept maps, and a How People Learn student survey. The analysis of the assessment data will be used to make improvements for the second offering of these six modules. The remaining three modules are being implemented during the spring of 2009. The newly implemented modules will provide additional integration of the modules from the junior year into the senior year.

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