AC 2009-2325: BIOENGINEERING EDUCATIONAL MATERIALS BANK

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Abstract
The BioEngineering Educational Materials Bank is a web repository of biological applications that can be used in undergraduate chemical engineering courses. A Phase I Course, Curriculum and Laboratory Improvement project has been carried out including the development of the website and beta testing in chemical engineering programs across the country. The presentation will provide a description of the website, outcomes of the beta testing, the expansion of the project during the newly awarded Phase II project, and directions for the sustainability of the project following the NSF funding period.

Introduction

More and more chemical engineering (ChE) graduates are entering careers that involve applications in the life sciences[1]. Traditionally, ChE education focused on petrochemical or inorganic chemical processes. Many ChE departments have attempted to address the need to better prepare graduates by requiring biology courses or offering elective courses that apply the ChE principles to biological applications.

To facilitate the incorporation of biological applications in the ChE undergrad curriculum, a website has been constructed with solved problems to accompany popular ChE textbooks for the initial course that most students take on material and energy balance (MEB) analysis of chemical processes[2]. Because many chemical engineering faculty have little or no biological training, a workshop was offered during Summer '07 at SJSU to provide a "crash-course" in biology and biochemistry that is applicable to biochemical engineering.

The assessment of the project has been multi-faceted. Beta-test sites that incorporated some of the problems into their courses evaluated student performance during the Fall '07 and '08 semesters. A statistical analysis of the data from the first round of beta testing showed that the evaluation strategy was not appropriate to demonstrate improved student learning from the use of the website materials. At the same time, student surveys suggested that students found the course more interesting with the inclusion of the biological problems. Likewise, faculty who used the website problems in their courses were polled about their experience with the website and their observations about student learning. Finally, statistics of the web usage were collected as an indicator of the utility of the website in the ChE courses. In particular, the number of problems used by the faculty who attended the workshop suggests the workshop enabled them to use the website problems in their courses.

Methods and Results

Construction of Website: In January of 2007 the project began with the construction of the website and development and collection of problems for the MEB course. The design of the website includes the bank of solved problems that are accessible to registered users. The website, Bioengineering Educational Materials Bank, or BioEMB, is hosted on the SJSU server and is a MySQL secure database that enables students, faculty and others access to applications in biological engineering. The problem statements, key word lists, abstracts describing the problem

context, and a link to a downloadable word file of the problem are accessible to all registered users. In addition, links to pop-up definitions can facilitate students and faculty, who may be unfamiliar with the biology, to obtain background information as needed for understanding more about the systems they are analyzing. The problem solutions, ratings and comments by faculty can only be viewed by registered faculty users. The registration process is brief and includes acceptance of a shared use agreement, and for faculty, the process also includes activation by the web administrator upon recognition of the validity of the faculty status. The website (http://www.bioemb.net) was launched close to the time of the workshop that was held in July 2007. There are currently 47 MEB problems on the website.

The website has been organized to facilitate busy faculty to identify appropriate problems for their MEB courses. Specifically, by choosing "problem bank" from the front page (after logging in), a page is opened that lists the set of courses for which the website hosts problems. If the faculty clicks on "Material and Energy Balances" a page opens that displays two of the most popular texts that are used for the course[3, 4]. Upon choosing one of the two books, the table of contents will appear from the chosen text with links to problems dispersed through the list as would be appropriate to assign to students when covering that section of the text. Thus, faculty do not need to analyze the problems at length prior to assigning them to students as they have already been organized according to the chemical engineering topic areas.

After choosing a problem based on the problem title, the page opens with the problem. Next to the title of the problem, the problem rating is shown. The difficultly rating system rates problems from 1 () to 3 () pluses, as rated by the problem authors. The higher the plus count, the more difficult the problem. The guideline for rating problems based on difficulty is shown in Table I. Below the problem title and rating are listed the book chapter, problem author, abstract, keywords, link to downloadable word file, and finally, the problem statement followed by the problem solution. Below the solution there is a space for faculty to post comments about the problem as well as the opportunity to rate the problems for effectiveness. The effectiveness rating scale rates problems from 1 () to 5 () stars. The ratings are suggested by professors who use or review the problems. The higher the star count, the more effective the problem has been as a learning experience. Finally, the history of problem modification is shown at the very bottom of the page, to let faculty know if the problem has been modified recently.

Table I. Problem difficulty rating system

 - This problem tests basic chemical engineering fundamentals and no additional bio background is needed.

 - Problem is challenging but students should be able to solve this problem without additional bio background.

 - Students may need additional bio background to solve this problem.

Table II. Problem effectiveness rating system

 - Problem needs modification to be effective

 - A few students in the class benefited from the problem but overall it was not an effective learning experience

 - A good exercise. some students benefited from the problem, it was an average problem

★★★★☆- A very good exercise. Many students learned from this problem and it was an effective learning experience
★★★★★- An excellent exercise. The exercise was a good learning experience for the class as a whole and was an interesting application of bioX.

Submission of Problems: One goal of the project has been to provide peer-reviewed materials to faculty for use in their courses. To facilitate the peer reviewed, a license to Manuscript Central software was purchased and a submission process was designed. The use of the submission site has been hardly used, except by students who have generated problems. In spite of several offers by faculty to submit problems, few have followed through with their offers and none of them have submitted problems onto the Manuscript Central site. Problems from faculty have been received and posted, provided that they stated that the problems had already been used in their course.

Summer Workshop at SJSU: To advertise the workshop, a single e-mail was sent to department chairs through the AIChE listserve and the response was overwhelming. Nineteen schools sent a faculty representative to the workshop, even though there was only budget for 16 attendees. Only non-bio faculty were accepted. The additional faculty paid all of their own expenses.

The workshop included two half-days of lectures covering a range of topics in biology and biochemistry that are basic principles for biochemical engineering, in addition to a 3-hour workshop on active learning. During the final portion of the workshop faculty were assigned to teams and challenged to solve 16 problems posted on the website. Two of the teams were able to solve nine of the problems correctly. In the end-of-workshop survey, 75% of the attendees agreed that the problem solving session was useful. For the project team, the problem solving sessions facilitated the crafting of clearer problem statements, taking into account the needs of the non-bio users, and helped to identify aspects of the problems that were more challenging for those without bio backgrounds.

At the end of the workshop, the faculty were surveyed and 85% agreed that the *bioX* lectures addressed their concerns about lack of familiarity with *bioX* concepts, 100% agreed that the bio lectures were effectively presented, 90% agreed or strongly agreed that the BioEMB website appeared to be user friendly and effective, and 95% agreed or strongly agreed that they would recommend the workshop to a colleague. Comments from the workshop have been posted on the BioEMB website.

Incorporation of BioEMB materials into MEB courses Fall '07: During the first round of testing in Fall '07, four test sites participated: San Jose State, U. Tennessee, U. MD Baltimore County and Colorado State University. All four of the faculty beta testers had attended the workshop and thus did not have any formal education in biochemical engineering. One negative control site, UC Santa Barbara, participated, where the evaluations were given but no website problems had been assigned during the semester. Exemptions from full IRB review were obtained prior to administering student tests. A Roadmap document was provided for the faculty that stated four very general learning objectives: (1) Apply ChE MEB principles to processes involving proteins as catalysts, (2) Perform material balances on processes involving whole cells

represented by stoichiometric ratios in the chemical reaction equation, (3) Perform material balance on processes involving separation/purification of proteins, and (4) Perform an energy balance on a whole-cell biocatalytic process. Problems were suggested for each learning objective, but faculty were not required to use any particular problems for their courses, and were not monitored to ensure how many or which problems they assigned.

To assess student learning on these objectives, students were challenged with tests consisting of one MEB problem with a bio context and one MEB problem involving a non-bio application. Although *interpretation and use of bioprocess terminology* would be a reasonable learning objective (students must learn chemical process terminology in current MEB courses) the focus of the exercise was to test students' ability to apply ChE principles in a bio vs. a non-bio context. Consequently, the biological problems did not include special biochemical terminology, or it was clarified on the tests. The problems addressed the general learning objectives of a) Solve a material balance problem on a reactive process and b) Solve a material balance problem on a non-reactive process.

The test and accompanying survey (on the back of page with bio problem) were administered in a 50 minute period. The first few minutes were used to explain briefly the research project and students were given the informed consent forms to review and sign. Students were allowed 20 minutes to solve first the bio problem and then another 20 minutes to solve the non-bio problem.

Tests were collected and graded by project faculty. One challenge with assigning students large problems to solve is determining how to grade the problems. Because the students in almost 100% of the tests did not get a final correct answer on any of the problems, the need arose to grade based on partial credit. Because there was a need to make a comparison between the bio vs. non-bio problems, the breakdown of partial credit should be divided by equal portions on all the tests. It was not foreseen that the students would all do so poorly on the test and planning ahead of the partial credit would have facilitated the grading process. In the end, it was not possible to break down the credit on an even basis between bio and non-bio problems.

Statistical analysis of the results was performed by the UVA Center for Survey Research. As described above, the students performed very poorly on all of the tests (average scores across institutions ranged from 0.13 ± 0.03 to 0.36 ± 0.04 as the lowest and highest average scores out of 1.0) Because of limitations in our first round of evaluation, it is not possible to provide evidence that the inclusion of materials from the BioEMB website enabled students to apply ChE principles to biological problems more effectively than in classes where the materials were excluded. It was clear from grading the exams that the problems were too complex for the time allotted. Further, both required extensive application of generic MEB skills and tested specific *bioX* objectives less. Also, there were unfamiliar units and processes in the bio problems that students were likely not exposed to because the intervention was uncontrolled between sites.

Based on the results of the testing, new evaluation instruments were designed that were used for the beta testing during Fall '08. In addition, beta testers were requested to include a set of eleven problems in their courses, either as homework or in-class problems for the students to solve in groups. The roadmap document was modified to describe the specific learning objectives and the 11 problems were organized according to the learning objectives. Table III lists the learning

objectives and titles of the problems. The results of this beta testing will be presented in a separate paper.

Table III. **Revised MEB Learning Objectives for Beta Test Sites**

1. Units and terminology

· Work with common biological units

Addition of inducer to bacterial culture: F&R* section 3.1 Mass & Volume

Protein molecular weight: F&R section 2.5 Numerical Calculation

Calculation of nitrogen uptake in a fermentor: F&R section 3.1 Mass & Volume

· Learn and use basic bioprocess terminology just as MEB students now learn chemical process terminology

Plot of bacterial growth data: F&R section 2.7 Process data representation and analysis

(terminology addressed adequately in the entire set of problems)

2. Material balances on bioprocesses

· Use chemical formulas to represent cellular composition and cellular transformations.

Calculation of carbon from optical density: F&R section 3.3 Chemical Composition

Lactic acid production with immobilized cells: F&R section 4.7 Balances on Reactive Processes

· Explain why there will be CO_2 among the products of a whole cell bioprocess

Calculation of oxygen uptake rate in a fermentor: F&R section 5.2 Ideal Gases

· Explain the significance of respiratory quotient

Production of biomass on arabinose: F&R section 4.6 Chemical Reaction Stoichiometry

· Demonstrate MEB-level familiarity with bioprocess unit operations

Partial purification of rhDNase I from contaminant proteins by ultrafiltration F&R 4.3 Mat'l Bal. Calcs.

Ion exchange chromatography: purification of rhDNase I F&R section 4.3 Material Bal. Calcs.

Calculation of fermentor water balance: F&R 6.3 Gas-Liquid Systems: One condensable component

*F&R = Felder & Rousseau, authors of Elementary Principles of Chemical Processes[3]

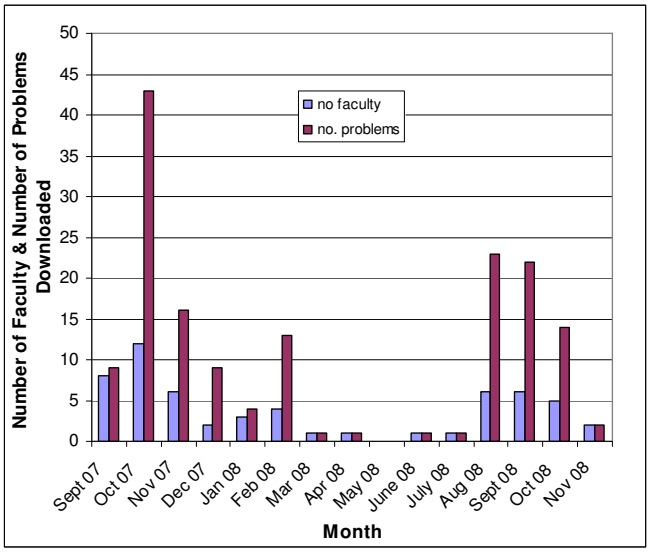
Surveys of faculty and students about impact on students' learning and attitudes: Faculty perceptions of the impact of the problems were positive. Among β test sites: 60% of β test faculty and 68% of all Fall 07 users somewhat agreed or strongly agreed that the BioEMB problems helped students learn how to solve MEB problems with a biotech context. Faculty had a strong sense that students were interested in the biotechnology material: 80%, 100%, and 76% of β-test, workshop, and other site users, agreed that their students in MEB would be very interested in the biotechnology problems.

The students confirmed these impacts on their survey; 84% of β-tested students agreed that the biotech problems made the MEB course more interesting. Likewise, 80% of minority students polled (31 underrepresented minority students in population) agreed that the inclusion of bio problems made the course more interesting. Additionally, 36% of the β-tested students stated that their interest in a biotech career was increased by having the problems included, while 11% reported decreased interest. This indicates the problems helped students refine their career interests about this growing part of ChE.

Effectiveness of BioEMB in enabling faculty to incorporate *bioX* material: BioEMB faculty web site users were surveyed about obstacles to using *bioX* material and the ability of the BioEMB materials to overcome them. With regard to the concern that students would need too much background knowledge in biotechnology, 80% of β test faculty, 67% of workshop attendees, and 71% of all site users disagreed that this was an issue. 65% of respondents did acknowledge their own limited knowledge of biotechnology was a potential obstacle. However, 71% of all Fall '07 users described themselves as comfortable presenting and discussing problems. Further, 56% of workshop attendees who used BioEMB problems in a MEB course during the Fall '07 semester described themselves as comfortable, suggesting that the workshop helped to address this issue. Consistent with the above, 73% of all Fall 07 users agreed that the BioEMB web site alone was sufficient to enable use of the problems.

Despite the potential barriers, faculty were resounding that the experience was a valuable one. 100% of respondents that taught MEB in Fall '07 used problems. 95% of these users reported they enjoyed incorporating the BioEMB problems. When asked whether they would use the problems again in the future, 100% of β test sites said they definitely would, and 90% of workshop participants and other site users said they probably or definitely would. The Fall '07 users responding to the survey already represent 22 ChE departments that had adopted and planned to continue to use the materials.

Website Usage Statistics



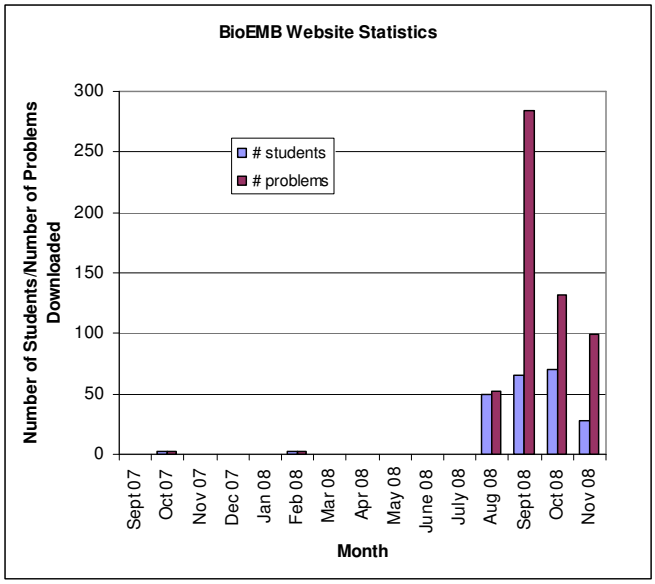


Figure 1. Problem downloads by faculty and students by month. (Figure 1a (top). Number of faculty who downloaded problems and the total number of problems downloaded by faculty; Figure 1b (bottom). Number of students who downloaded problems and the total number of problems downloaded by students)

After the launch of the website in September of 2007, there was an initial surge of interested faculty following an informational e-mail sent to the ChE department chairs. The use of the website has been analyzed by counting both the total number of problems that have been downloaded by faculty and by the number of faculty downloading problems. The data of faculty downloads is shown in Figure 1(a). Clearly, this is an indirect measure, as it is not an analysis of the total number of downloaded problems that were assigned to students, and it is also not a measure of how the problems were used in the classes. The number of US institutions that have downloaded problems as of December, 2008, was 32 chemical engineering departments, representing over 20% of the total number of departments. In addition, faculty from Turkey, Mexico, UK, Norway and Colombia have also downloaded problems for their courses, along with one high school teacher and one community college instructor. The students who downloaded problems have, for the most part, been assigned to do the problem for homework. The β-test sites were asked to have their students download the problems. We have not yet requested specific feedback from the faculty as to whether this feature was useful to them. Between September and December of 2008, 95 different students downloaded 567 problems from the website.

Project Phase II: In light of the considerable demand for biological applications, as demonstrated in the Phase I project, a Phase II project was proposed and funded to include the addition of solved problems for ChE courses for the remainder of the core undergraduate curriculum: Transport Phenomena (Fluids, Heat and Mass Transfer), Thermodynamics, Process Dynamics and Control, and Reactor Design and Kinetics. The materials developed for the MEB course, although valuable in themselves, are insufficient to prepare students for an eventual career in bioprocessing or biochemical engineering. It is necessary for students to learn *bioX* with the full complement of ChE courses, as the different courses complete the student

preparation in all the principles of transport phenomena, thermoodynamics, kinetics and process dynamics.

This project will contribute to the knowledge base of science, technology, engineering and mathematics education and practice through several strategies. In the first place, the project will create new learning materials and teaching strategies. Specifically, approximately 250 solved problems will be created to facilitate the incorporation of problems with *bioX* content into the undergraduate core curriculum. The problems will be generated by faculty from several different universities. In addition, students will be challenged with developing problems as part of elective biochemical engineering courses.

A key aspect to the effectiveness of the project, based on the experience from the Phase I project, will be the development of faculty expertise. Approximately 80 ChE faculty who do not have formal training in *bioX* will be prepared to incorporate problems with biological content into their core courses through workshops offered at San José State University. The workshops will be delivered in a problem-based learning format as a way to enhance instructional effectiveness. As compared with teaching basic biology to the students, the principal goal of this project is to enable faculty to expose students to relevant biological problems and processes, such as those used in biofuel or biopharmaceutical industries. Indeed, of the set of fourteen recommendations recently proposed by the National Academy of Engineering, only two call for content upgrades. One of the two states "Engineering schools should introduce interdisciplinary learning in the undergraduate environment, rather than having it as an exclusive feature of the graduate programs" [5]. This project hopes to achieve the enabling of faculty to include interdisciplinary materials in their courses through providing both the educational materials and faculty development opportunities for those whose expertise is not in the bio area.

Finally, the educational materials will be implemented in chemical engineering courses and student learning will be assessed. Students from at least 10 universities acting as beta test sites will have problems with a significant biological content incorporated in their courses. Approximately 20% of the assigned problems in these courses will address biological applications. This educational experience will help prepare them for careers in biotechnology, by giving them the opportunity to apply their ChE principles to biological applications. Impact of the educational materials on student learning as well as student and faculty attitudes will be assessed over multiple semesters of beta testing. We will test the hypothesis that students in courses where the BioEMB materials make up at least 20% of solved problems will perform better on tests designed to probe student achievement of specific *bioX* learning objectives than students in similar courses where BioEMB materials have not been included in the curriculum. We will also test the hypothesis that there will be positive impact on student attitudes.

Project Sustainability: The scaled up website will be a valuable resource for faculty and students, potentially for many years to come. The ability to update problems and bio content will be necessary to make it an enduring resource. Funds to support the website and updating must be obtained from government or industry. The possibility of working with a publishing company is not out of the question. For example, a tiered login could be established whereby faculty can access problems and solutions for no charge, but for a fee, additional content materials could be

made available. As the project develops, a concrete strategy for sustaining the resource will be explored.

Summary

A website was created to host problems addressing biological applications for the undergraduate MEB course. Faculty surveyed reported favorably about the use of the website and problems for their courses. As of December, 2008, the users of the website represent faculty from over 20% of US undergraduate chemical engineering programs, in addition to a handful from other countries. Student users were also tracked and were also very positive when surveyed about the BioEMB problems. Of particular importance, 84% of beta test students from Fall '07 agreed that the problems made their MEB course more interesting. The results of the Fall '08 beta testing will be reported in a separate paper, in addition to the Phase II project outcomes that will include problems for thermodynamics, process dynamics and control, heat and mass transfer, reactor design and kinetics, and fluid dynamics courses.

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