Training Chemical Engineers in Bioprocessing

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Introduction

Over the past several years, the Department of Chemical Engineering at Michigan State University (MSU) has been developing a comprehensive set of courses in biochemical engineering and biotechnology for both undergraduate and graduate students. Beginning with a fairly standard biochemical engineering reactor design course that has been taught over the past sixteen years, the course offerings have expanded to include undergraduate research opportunities, a state-of-the-art teaching laboratory, two higher level bioprocessing courses, a seminar course, and a multidisciplinary graduate training program. An undergraduate-run student chapter of the International Society of Pharmaceutical Engineers (ISPE) was also initiated and has provided extracurricular benefits for the students. The department has obtained both equipment donations and federal grants for these efforts. One of the authors (CP) is currently a graduate student who was involved as an undergraduate in almost all phases of this program and will provide his perspectives on the program effectiveness and its benefits to a student. The other two authors are faculty members who have been involved in the development of the courses and coordination of the program.

Rationale from a student perspective

For an engineering student interested in biotechnology or the pharmaceutical industry, an undergraduate biochemical engineering program is very important. Biotechnology is a field that is expected to grow and provide employment opportunities to college graduates. Recently, several of the world's largest chemical companies have announced major new businesses based on the life science instead of traditional petrochemical processing[1,2]. The recent mapping of the human genome may also open opportunities for life-science-minded engineers.

MSU provides a comprehensive program to prepare chemical engineering graduates to immediately be effective in the biotechnology industry. In addition, the program also offers students in other bio-related disciplines the opportunity to expand their expertise and to become more effective in this interdisciplinary field. Biotechnology companies have a good appreciation for how a person trained in chemical engineering can be an important part of their workforce. While biochemists and scientists are important to the industry, chemical engineers have been taught important skills in process development and modeling of chemical reactions. The addition of specific training in understanding of microorganisms and enzymatic processes allows engineers to apply their basic skills and

knowledge to the design and control of bioreactors and bioprocesses. Often, biochemists and microbiologists have not been taught the mathematical techniques that allow them to model bioprocesses and to design controllers that operate them. Therefore, biotechnology companies often seek to hire engineering graduates with a background in biochemical engineering.

Biochemical engineering requires special skills and knowledge that cannot be found in traditional chemical engineering classes. Simply offering biotechnologically related problems in traditional chemical engineering courses has not provided sufficient depth for training in this area. For example, a typical reaction-engineering course deals with specific molecules reacting under relatively constant conditions. Applying reaction-engineering concepts to bioprocesses requires the engineer to model cell growth and the changes in the cell that occur within the bioreactor. Also, while bioprocesses can generally be modeled with a simple reaction scheme, the underlying complexity of the processes in the cell that lead to the final product must also be understood. Even if the bioprocess deals with an isolated protein being used to catalyze a reaction, proteins behave much differently than inorganic catalysts. Therefore, if a chemical engineering department wants to prepare its graduates for the biotechnology industry, specific courses and programs should be implemented. The following are some of the opportunities that have been made available to students at MSU.

Biochemical Engineering Laboratory

Since the early 1990s, students at MSU have been given the choice of taking either a biochemical engineering laboratory class or a composite materials laboratory class to fulfill the advanced laboratory requirements for graduation. These two tracks have been based on the program's educational objectives and the expertise of the program faculty. Both courses consist of two parts, a lecture section and a laboratory section.

In the lecture portion of the biochemical engineering course, the students are given a broad overview of microbiology and biochemistry and are taught how to apply reaction engineering to bioprocesses. While more detailed knowledge of the multidisciplinary features of this course could be gained by taking separate courses in reaction engineering, biochemistry, and microbiology, the biochemical engineering synthesizes the knowledge requirements of the three areas in a way that allows the student to best combine the separate disciplines. Even if an engineering student already has a good knowledge of cell growth, enzyme catalysis, and reaction modeling, it is not immediately apparent how the three can be integrated without additional knowledge and application. Microbiology classes lead students to picture a cell as a massive, complex, and nearly indecipherable interlocked system of reactions. In the biochemical engineering course, the students learn which assumptions make a bioprocess mathematically manageable. In addition, the course teaches specialized types of energy and material balances (e.g., available electron balances) that are not covered in other engineering courses. The skills that students gain specifically from this course are of great benefit in a student's ability to work with bioreactors.

The laboratory section of the course may be even more valuable to a student than the lecture portion. By working directly with cells and enzymes, a student is given experiences that cannot be gained in a traditional chemistry or chemical engineering laboratory class. Until the student has had experience with bioprocesses, he/she may be often surprised at the inherent variability of cell growth and metabolite production. The laboratory course also familiarizes students with sterilization and contamination issues that are essential to the biotechnology and pharmaceutical industries. Furthermore, bioprocesses involve unique safety concerns that differ from those in a traditional chemistry laboratory class. Students learn that cell cultures can potentially be hazardous to both people and the environment. By learning these concepts at the undergraduate level, an engineer will be better prepared to deal with bioprocesses in industry or graduate school.

International Society of Pharmaceutical Engineers (ISPE)

In the early 1990s, MSU chemical engineering students established one of the few student chapters of ISPE in the country. The chapter has provided excellent learning and networking opportunities. The student-organized activities include monthly meetings with industrial speakers who cover a variety of topics from home brewing to patent law. These presentations have introduced students to the multiple career options available to a chemical engineer in the pharmaceutical industry. Networking opportunities arranged through ISPE functions have led to employment opportunities, including internship, co-operative education, and full-time jobs. Students have attended, and even presented papers at, ISPE conventions. Industrial representatives have commended MSU for organizing the ISPE chapter, and have said that having an ISPE chapter makes MSU more attractive as a recruiting site.

Undergraduate research

Author CP participated in undergraduate research at MSU. In his first three years at MSU, he was funded to participate in biochemical engineering research in the research laboratory of a chemical engineering faculty member. He views that experience as having been so valuable that it should be considered as a requirement for any truly excellent B.S. program in engineering. Research gives the opportunity to learn and apply in more detail the concepts a student is taught in his or her classes. Also, the research experience has proven valuable in obtaining internship employment in biochemical engineering. Even more importantly, by working with or around graduate students and professors, a student absorbs practical skills and knowledge that cannot be learned from coursework.

Biochemical engineering is an ideal discipline for undergraduate research experience. Students can gain experience and knowledge in biotechnology, while helping with repetitive, time intensive work, such as the maintenance of cell lines. Research experience can be valuable in career planning, by helping students determine whether they enjoy research and what strengths and weaknesses they may have. Involving undergraduates in research is also an excellent recruiting tool for graduate school.

Multidisciplinary Bioprocessing Laboratory—a capstone course

Two years ago, as part of an NSF-sponsored Combined Research Curriculum Development (CRCD) project, the Department of Chemical Engineering established a Multidisciplinary Bioprocessing Laboratory (MBL) course. The express purpose of this course is to teach students how to work in multidisciplinary teams to solve research problems in biotechnology. The fact that that most industries operate with multidisciplinary teams as a basic functional unit[3], but traditional curricula do not train students to work effectively in such teams motivated the course's development.

The format of the MBL course is unique in the MSU chemical engineering program. Although there is a weekly lecture that all students attend, most of the work comprises a mentored research project performed in teams of about three engineering and life sciences students. The course operates, in effect, as a capstone course for the biochemical engineering course offerings. Additional details of this course are presented in other papers[4,5] and at the web site (http://www.egr.msu.edu/che/classes/491/index.html). A poster on the MBL course that was presented at the 2000 National ISPE meeting can be viewed at the web site (http://www.egr.msu.edu/bio/pdfs/mblposter.pdf).

The MBL course focuses on active learning in the classroom. Students are specifically trained in effective teamwork skills, with an emphasis on multidisciplinary interaction and on project management. The students are assigned to multidisciplinary teams and are then required to use the skills learned in class to complete their projects efficiently as a team. More than any other course in the chemical engineering program, this course truly requires strong teamwork skills. Technical knowledge is gained largely from the teams' research experience. Many of the students have never before been forced to find journal articles and books that will give them the technical knowledge to aid in the completion of their project.

The teams have different combinations of disciplines and work in different research laboratories on different research projects. Consequently, there is typically a broad range of team experiences and dynamics. For example, biology students may feel that it is outside of their skill set to understand the math involved in a PID control algorithm for a bioreactor, so they may prefer to leave the process-oriented responsibilities to the engineering students. Similarly, engineering students with little lab experience may wish to defer the detailed cell-culture work to the biologists. Students who get the most out of the course are those who view the diversity of backgrounds within their team as an advantage, and seek to learn concepts outside of their own disciplines.

The MBL course also exposes students to team management concepts that they do not see in their other courses in the chemical engineering or life sciences curricula. Students learn how to identify critical paths and arrange their schedules in order to make as much research progress as possible within the time constraints.

The ability to work in teams and the capability of performing self-motivated and self-directed research are excellent skills to have in any career, but they are especially valuable in biochemical engineering. The biotechnology and pharmaceutical industries require the synthesis of knowledge from different disciplines; the only way that students may succeed is through true teamwork and learning by doing.

Biochemical Engineering Option

As the various elements of the biochemical engineering thrust have solidified as a regular part of the chemical engineering program offerings, the MSU Department of Chemical Engineering recently instituted an option in biochemical engineering. In fact, the department recently added several option tracks to its undergraduate curriculum in response to both industrial demand and student interest. While the participating students still earn a B.S. degree in chemical engineering, the option certifies that they have also completed a set of elective courses that provide a specialization. The requirements for the biochemical engineering option include courses in microbiology, biochemistry, and biological science, the biochemical engineering laboratory course, and their choice of either the MBL course or a graduate seminar series in biochemical engineering. However, fulfilling the option does not require the student to take additional credits—only to be judicious selection of the elective courses. In addition to demonstrating a specialization, the option provides guidance on what science courses might be useful for future employment in the biotechnology industry. As a graduate student in the area of biochemical engineering, author CP has found the courses required for the undergraduate option to be extremely helpful in his decision to continue in graduate school and in understanding of his graduate research.

Graduate programs

The successful beginnings of the comprehensive biochemical engineering program at the undergraduate level have been a part of a long history of fruitful collaboration between chemical engineering faculty and their colleagues in other disciplines. Faculty members in the Department of Chemical Engineering have many collaborative research projects with faculty in the Departments of Botany and Plant Pathology, Chemistry, Biochemistry, and Microbiology. Coupled with the strong biotechnology-based course offerings in chemical engineering, the collaborative research programs have naturally led to the extension of the undergraduate program to biotechnology training programs at the graduate level. The aforementioned departments participate in a Multidisciplinary Graduate Training Program on Technologies for a Biobased Economy (http://www.egr.msu.edu/bio/tbe.html). This program is sponsored by the Department of Education Graduate Assistance in Areas of National Need (GAANN) program as well as the Department of Energy Biobased Products Industry program. We speculate that this graduate program would not have been funded had it not been for the strong undergirding that has been provided by the undergraduate biochemical engineering program.

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Biographical Information

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