

Institutionalizing the Multidisciplinary Lab Experience

R. Mark Worden Daina Briedis
Michigan State University

Introduction

Biology is becoming increasingly relevant to industries that hire chemical engineers. In the past few years, several of the world's largest chemical companies have announced major new businesses based on biobased raw materials¹⁻³, and have invested heavily in agricultural biotechnology⁴. The pharmaceutical industry will increasingly draw on chemical engineering skills for rapid and successful commercialization⁵. Moreover, the recent mapping of the human genome may provide additional opportunities for life-science-minded engineers in the rapidly growing biotechnology industry. These trends suggest the need for increased biological content in the chemical-engineering curriculum.

Over the past several years, the Department of Chemical Engineering and Materials Science at Michigan State University (MSU) has been developing educational programs to better prepare students for employment at the interface between chemical engineering and biology. 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 Biochemical Engineering Teaching Laboratory (BETL), 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 professional and extracurricular benefits for the students. These programs are intended not only to provide additional exposure to biological concepts but also to prepare chemical engineering graduates to communicate and interact effectively with co-workers trained in different disciplines.

Accreditation requirements have added to the pedagogical mix through the requirement that engineering graduates have the ability to function on multidisciplinary teams (Criterion 3(d)).⁶ Several models have been used to help students develop this skill, including assigning same-discipline students to different team roles and engaging students in true multidisciplinary teamwork involving students from other disciplines.^{7,8} The latter approach clearly can provide direct evidence of Outcome 3(d) and ties directly to the needs of the biotechnology industry that have been described above. This paper addresses the challenges involved in incorporating and maintaining a true multidisciplinary course as an important element of a curriculum.

Multidisciplinary Bioprocessing Laboratory Course

Many industries operate with multidisciplinary teams as a basic functional unit⁹, but traditional curricula do not train students to work effectively in such teams. Several years ago, as part of an

NSF-sponsored Combined Research/Curriculum Development (CRCD) project, MSU established a Multidisciplinary Bioprocessing Laboratory (MBL) course to help prepare students for a multidisciplinary work environment. The goal of this course is to teach students how to work effectively in multidisciplinary teams in a research environment. Students are recruited into the MBL course from several science and engineering departments and assigned to multidisciplinary research teams of about three students. Although there is a weekly recitation that all students attend, most of the work consists of a semester-long, mentored research project carried out by the team in a participating faculty member's research lab. Twice during the term, the teams report on their research progress in both written and oral formats.

Grading is based on a number of factors, including the team's performance in the lab (as judged by the faculty advisor and mentor), the final oral and written reports, a few homework and in-class assignments, and the team's research journal(s). More details on the course objectives, format, and recitation topics are presented in other papers^{8,10}, as well as in an on-line poster that may be viewed at the URL (<http://www.egr.msu.edu/bio/pdfs/mblposter.pdf>).

The student teams contain different combinations of disciplines and work in different research laboratories on different research projects. Consequently, the students encounter a broad range of research topics, personalities, and learning opportunities. By design, students learn primarily from one another and from their research mentors. For example, a typical MBL project might entail developing a recombinant microorganism that produces a desired protein, and then overexpressing that protein in a fed-batch fermentation. Biology students in the team would learn mass balance, process-control, and reaction-kinetics concepts from the engineering students, and the engineers would learn molecular-biology concepts and cloning methods from the biologists. In our experience, the students who get the most out of the course are those who view the diversity of backgrounds within their team and research lab as an advantage, and seek to learn concepts outside of their own disciplines. Students also learn the true nature of research and how it differs from typical undergraduate assignments, where assigned problems can usually be solved quickly.

To prepare students to carry out their projects efficiently, the MBL course also introduces students to project-management concepts. Students learn how to set up projects as a system of discrete steps in series or parallel, to identify rate-limiting steps, and to schedule the steps to minimize the time required to complete the project. Teams are then asked to apply this approach in planning their research in order to maximize progress during the semester. Because these planning activities require consideration of both the scientific and engineering components of the project, students must be able to communicate effectively, even in the early phases of their projects.

Challenges to Institutionalization of the MBL Course

Institutionalization of truly multidisciplinary offerings like the MBL course presents significant challenges, particularly if departments rely on such courses to help satisfy ABET accreditation requirements. Through several years of teaching the MBL course, we have identified some of these challenges and have developed strategies to address them, as described below.

Student Recruitment. A primary challenge is recruitment of a proper balance of students from the participating departments. We have had little trouble recruiting enough chemical engineering students into the MBL class; this year, twelve of the 19 students are chemical-engineering undergraduates. However, recruiting from science departments has been more challenging. Because the course is currently listed as a senior-level chemical-engineering elective (CHE 491, Special Topics), students from other departments are understandably cautious about enrolling. This is particularly true for students who have heard that engineering courses are math-intensive and consider themselves weak in math.

Consequently, effective marketing of the course to students in the target departments is essential. We have tried a variety of approaches. First, we have prepared a course web site (<http://www.chems.msu.edu/php/class.php?page=67>). Although the course is currently listed as a chemical engineering elective, the site accurately portrays it as an interdisciplinary course developed by faculty from five departments. To further stimulate student interest, the site also includes descriptions of projects carried out by previous student teams, photographs of teams working in their respective labs, photographs of industrial speakers giving presentations, electronic slides from the industrial presentations, and a related-links page that includes many interesting biotechnology sites and tutorials. We believe the web site is a significant asset in recruiting, so we include its URL on all documents and presentations describing the course.

Second, we advertise the course through a variety of traditional and nontraditional methods. We have posted course announcements on bulletin boards in departmental offices. Supportive faculty and academic advisers from other departments have widely distributed course announcements to target audiences through e-mail aliases. We have given presentations describing the course in other departments' faculty meetings, seminar series, and courses. We are also investigating cross listing the course as a graduate offering in the participating departments. However, to date, the most effective form of advertising has been word-of-mouth recommendations by faculty champions in the other departments.

Third, we have prepared posters and pedagogical papers that describe the course^{8,10}, its role in multidisciplinary education¹¹, and some of the research projects that have been conducted as part of the course. Some of these posters and papers have been presented by MBL students at national ASEE and ISPE conferences. Two posters that took first place in the multistate ISPE student poster competitions and were entered in the national ISPE competition have been published on-line (<http://www.egr.msu.edu/ispe/events.html>) and are linked from our course site. The publications inform prospective students about the course and provide additional credibility that helps convince students to enroll. Moreover, the prospect of having conference trips and publications result from the course participation has been a significant enticement.

Faculty Recruitment. The MBL course was developed by faculty from five departments--biochemistry, microbiology, chemistry, botany, and chemical engineering. The budget of the NSF CRCD grant was largely dedicated to supporting graduate students (mentors) in the faculty members' research labs. The role of the mentors is to work closely with the student teams in the research lab, teach them advanced research methods, and help them interpret results. The prospect of having graduate student support helped us initially recruit renowned researchers into the program. The budget was front-end loaded, so that funding for graduate students decreased

over time. Consequently, continued participation by the original faculty, and recruitment of new ones, requires other types of incentives.

In some schools, it may be possible to negotiate with department heads that participation in multidisciplinary courses will be recognized as part of the teaching load. However, we have elected not to pursue this approach. Instead, our strategy has been to make participation intrinsically attractive to faculty from the standpoint of enhancing their research programs. Toward this end, we have sought out faculty from other departments whose research foci would be synergistic with those of current MBL faculty. We discuss with them ideas for mutually beneficial collaborative projects and then request their participation in the course to explore the ideas. For example, faculty participating in the MBL course from the biochemistry and chemical engineering departments have been collaborating on production of recombinant proteins. Recognizing that the recombinant proteins could be used to develop biosensors, we have recently recruited an electrical engineering professor to host an MBL student team. The students assigned to that laboratory are working in a cleanroom to fabricate electrode arrays. Recombinant proteins produced by other MBL teams will then be immobilized onto the electrode arrays to generate novel biosensors. Preliminary results obtained by the student teams could be used in new multidisciplinary research proposals and possibly publications. Through this sort of synergism between the teaching and research programs, faculty participation in the MBL course can be viewed as a seed investment that will benefit the research program. A similarly enticing, albeit somewhat less immediate, benefit of having students working in a faculty member's lab is that their projects may be used to address exploratory research for which a faculty member may not be willing to commit a graduate student's time.

Scheduling. When students from multiple departments enroll in a course, scheduling issues can be problematic. In scheduling the MBL recitation, we surveyed the schedules of graduate courses from the five participating departments and selected a time that minimized conflicts. In addition, during the first recitation, we collect class schedules from all students. Insofar as possible, we assemble teams having compatible schedules. In general, we do not mandate a fixed number of hours the students must spend in the lab. However, we explain that grades will be assigned based on results and effort level, and we have each team's mentor assess the team's performance. Our experience has been that the students typically become enthusiastic about their projects and work hard, particularly later in the semester, when they have become fully immersed in the research routine.

Facilities and Resources. In times of limited resources, finding laboratory facilities and supplies is challenging. In some MSU departments, there is a trend to reduce laboratory offerings, because of their high cost relative to lecture courses. The fact that some of the laboratory expenses must be covered by faculty participants is a disincentive to participation. While some faculty may participate out of an intrinsic desire to support education, we have explored ways to ensure that the benefits of participation clearly outweigh the resource costs.

First, we have sought supplemental funds to offset supplies costs. A portion of the initial NSF grant has been used for this purpose. Second, we have tried to align the student projects with ongoing, funded research projects. In this way, the student teams contribute toward the project goals. As mentioned above, the MBL students can evaluate new, exploratory approaches, which,

if unsuccessful, would not set back a graduate student's progress toward his/her degree. Third, we add value by providing the MBL students with access to our well-equipped BETL. While it is possible for the MBL teams to conduct all of their research in the faculty advisors' labs, having them conduct some work in the BETL reduces the team's impact on the research labs. The BETL contains a variety of equipment but is especially well equipped to conduct fermentations. Consequently, we try to recruit bioscience faculty whose research programs would benefit from engineering expertise related to fermentation.

Incorporation of the MBL Course into Program Requirements

Inclusion of multidisciplinary laboratory courses as degree requirements can help ensure sufficient participation by students and faculty. Recently, the MBL course has been adopted as either a required course or an elective that counts toward the requirements of three campus programs. It is a required course for the Multidisciplinary Graduate Training Program on Technologies for a Biobased Economy (TBE). The purpose of the TBE program (<http://www.egr.msu.edu/bio/tbe.html>) is to produce a diverse group of Ph.D. scientists and engineers who have broad training related to biobased industrial product formation, have strong research skills, and are able to work effectively in multidisciplinary teams. The MBL course is also required by the M.S. Professional degree offered by the MSU Microbiology and Molecular Genetics Department. The objective of this program is to train microbiologists that combine practical skills and strong research experience so that they can succeed in venues such as pharmaceutical manufacturing, food processing, biotechnology, and bioremediation. Finally, either the MBL course or a graduate Biochemical Engineering course must be taken to fulfill the Biochemical Engineering Option in the MSU Chemical Engineering B.S. program. This option certifies that the student has completed a set of elective courses that provide a specialization in biochemical engineering.

Concluding Remarks

While development and institutionalization of a truly multidisciplinary laboratory course presents challenges in course management and recruitment of students and faculty, its benefits are significant. Beyond the contribution made to satisfying ABET requirements, the MBL course has prepared students for a multidisciplinary work environment, bred new research collaborations, and has supplied new approaches to our toolbox of teaching team skills. Once students and faculty have been convinced to participate, they have been uniformly enthusiastic about the MBL course. In addition, the conceptual model of the course is generic and could thus be adapted to virtually any multidisciplinary field (e.g., electronic materials) in which local research expertise exists.

Bibliography

1. Miller, J.A. and V. Nagarajan, "The Impact of Biotechnology on the Chemical Industry in the 21st Century, Trends in Biotechnology, 18(5):190-191, 2000.
2. "Life Sciences and Materials: A Successful Marriage is Possible," J. Polymer Sci: Part A: Polymer Chem., 38:667-678, 2000.
3. Thayer, A.M. "Chasing the Innovation Wave," Chem & Eng News, Feb. 8, 1999, 17-22.
4. Thayer, A.M., "Agbiotech," Chem & Eng News, Oct, 2, 2000, 21-29.
5. Cussler, E.L., D.W. Savage, A.P.J. Middelberg, and M. Kind, "Refocusing Chemical Engineering," Chem. Eng. Prog., Jan. 2002: 26S-31S.
6. ABET Engineering Criteria, www.abet.org.
7. Muscat, Anthony J., E. Allen, E.D.H. Green, L.S. Vanasupa, "Interdisciplinary Teaching and Learning in a Semiconductor Processing Course," J. Eng. Education, 87(4):413, 1998.
8. Briedis, D. and R. M. Worden, "Training in Multidisciplinarianism," Proc. of the 2000 ASEE Conference and Exposition, St. Louis, MO, June 18-21, 2000.
9. Parker, G.M "Cross-Functional Teams, Working with Allies, Enemies, and Other Strangers," Jossey-Bass Pub., San Francisco, 1994, 3-30.
10. Briedis, D. and R. M. Worden, "Development of a Multidisciplinary Bioprocessing Laboratory Course", presented at the 1999 Annual Meeting of the AIChE, Dallas, TX, October 31-November 4, 1999.
11. Preston, C., D. Briedis, and R. M. Worden, "Training Chemical Engineers in Bioprocessing," presented at the 2001 Annual Meeting of the AIChE, Albuquerque, NM, June 24-27, 2001.

Biographical Information

R. MARK WORDEN, Professor of Chemical Engineering, bridged to chemical engineering after earning a bachelors' degree with a double major in Chemistry and Cell Biology. His research is in the area of biochemical engineering, and he has been active in development of multidisciplinary training programs.

DAINA BRIEDIS is an Associate Professor in the Department of Chemical Engineering and Materials Science at Michigan State University. Dr. Briedis has conducted research in bioadhesion; she is currently studying development of effective learning tools for the multidisciplinary classroom. She is active nationally and internationally in engineering accreditation.