Design and Implementation of an Interdepartmental Biotechnology Program Across Engineering Technology Curricula

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Abstract

The health industry is an important and growing economic engine. Advances are being made in pharmaceutical and biotechnology discoveries and their applications (including manufacturing), as well as in health care services. As a result, there is an increasing sophistication of the products and services available and being developed, with an ever-widening scale of applications and marketing, producing an ever-expanding need for college graduates who have knowledge of life science-based products and processes. There have been numerous reports of current and projected shortages of human resources possessing the required knowledge in the growing industry. The objectives of this paper are to describe the implementation of a biotechnology program that crosses discipline boundaries, integrates science and technology, and attracts a diverse group of students. The curriculum addresses critical workforce needs and teaches students the content knowledge and skills of emerging biotechnology industries.

Introduction

The health industry is an important and growing economic engine. Advances are being made in pharmaceutical and biotechnology discoveries and their applications (including manufacturing), as well as in health care services. As a result, there is an increasing sophistication of the products and services that are both available and being developed, with an ever-widening scale of applications and marketing, producing an ever-expanding need for college graduates who have knowledge of life science-based products and processes.

The field of biotechnology relies on harnessing the properties of a living organism to develop and manufacture products that benefit human life. Innovative research has the power to create new industries that drive the nation's economy (National Research Council [NRC], 2007; U.S. Department of Energy [DOE], 2005) and the synergy of biological sciences with numerous technologies is predicted to provide solutions to major national problems in the 21st century by creating new generations of industrial biotechnology with great potential for economic impact (Commission on Life Sciences, 2000; Herrara, 2004; Littlehales, 2004; USDOE, 2005). Scientific advances, such as elucidating the structure and molecular mechanisms of DNA, have caused exponential growth in the biotechnology industry over the past decade. The acquisition of vast amounts of information generated by the decoding of the sequence of the human genome, as well as multiple other eukaryotes, prokaryotes and viruses have been generated by "-omics" -type experiments such as genomics, proteomics and inonomics. The advances in science and technology are affecting the health industry, including pharmaceutical applications, and workforce needs in biotechnology manufacturing are anticipated to grow as illustrated by the following quote:

> The biotechnology industry is still in its adolescence, but it is about to have a major impact on health care. A third of drugs in phase III clinical trials are proteins. . . . biotech companies are gearing up to manufacture product but they face a shortage of talent, as most young scientists interested in biotechnology have congregated to research. (Kling, 2004, p. 1)

The field of biotechnology extends beyond the health industry and into applications of energy. Due to continuous economic and industry growth, world energy consumption is expected to increase 71 percent from 2003 to 2030 (AEO, 2006). The energy solutions of the future will require a significant amount of research and development in energy technologies. Alternative energy solutions in the form of biofuels could help meet the emerging energy needs (Abraham, 2004; Pacala & Socolow, 2004; Socolow, 2005). Biofuels could be produced using plants, microbes, or even engineered nanobiostructures; in fact, biotechnology-based energy use could equal current global fossil energy use by 2100 (DOE, 2005). Thus, there is a need to promote an educated and skilled workforce capable of understanding and working with emerging areas of biotechnology, such as alternative energy technologies, both in the development of new energy sources and the use and maintenance of emerging developments. As reported in the meeting summary for the Pan-Organizational Summit on the U.S. Science and Engineering Workforce, technical skills combined with a strong math and science background and integrated with problem-solving, critical-thinking, and teamwork skills are sorely needed by modern manufacturing as well as by other sectors (Fox, 2003; NRC, 2007; Pearson, 2002). Industrial applications of biotechnology and effective solutions to global health and energy problems will cross discipline boundaries and require an adequately prepared workforce (NRC, 2007). Students need programs and curriculum that will educate them beyond their single discipline in order to help them meaningfully embrace interdisciplinary conceptual systems and ways of thinking and help prepare them for the future. In order to address the gap between education and workforce, Purdue University approved an academic minor in Biotechnology, an interdisciplinary effort among the Colleges of Pharmacy, Science, and Technology. Through this partnership, multidisciplinary laboratory activities were implemented, which use appropriate instrumentation and cover technologies currently employed in biotechnological research.

Educational Objective of the Biotechnology Program

The educational objective of the biotechnology program is to create an interactive laboratory learning environment and immerse undergraduate students within action-based research. The curriculum was developed to address identified goals for laboratory experiences (Singer, Hilton, & Scweingruber, 2005):

- Enhancing mastery of subject matter
- Developing scientific reasoning
- Understanding the complexity and ambiguity of empirical work
- Developing practical skills
- Understanding of the nature of science
- Cultivating interest in science and interest in learning science
- Developing teamwork abilities.

A large body of recent research from educators and cognitive scientists has shown that by actively engaging undergraduate students in research, their retention of scientific principles and learning retention increases (Bransford, et al, 1999; Campbell, 2004). Recent articles have emphasized the need to revitalize educational practices (Bell, 2009; Mervis, 2008). Within the biotechnology program, students learn to pose authentic research questions and actively participate in the inquiry and discovery process. The students are directly involved in the experimental design, data analysis, and dissemination of the results. Higher order learning with action-based research and curriculum should increase analytical skills and better prepare students for real-world jobs by enabling them to transfer curriculum-based research experiences into the biotechnology industry.

Connection between Purdue University's College of Technology Strategic Plan and the Biotechnology Program

The biotechnology program helps support the strategic plan for Purdue University by improving the learning environment for students and encouraging interdisciplinary research connections among students and faculty. In addition, the program helps harness Purdue's strengths in life sciences and technology and provides graduates to help future growth and development in biotechnology. As stated in the strategic plan (College Of Technology, 2003), the College of Technology educates professional practitioners and managers of science and engineering-based technologies and community leaders, accelerates technology transfer to business and industry, and develops innovations in the application of emerging technology through learning, engagement, and discovery.

To fulfill its mission, the College of Technology strives to provide a student-centered learning environment in which "technology-intensive instructional laboratories are maintained at state-of-the-practice currency as the keystone of practitioner-focused learning (COT, 2003, p.5)." The College of Technology's strategic plan also puts importance on "support for programs that foster the development of innovative instructional strategies, curriculum and laboratory development." (COT, 2003, p.4) The biotechnology program is an example of a forward-thinking effort that helps fulfill the mission of the College of Technology; the courses enhance learning, discovery, and engagement in the following areas:

Technology and Life Sciences

Allow students to engage in hands-on genomic, proteomic, and bioinformatics life science applications within the biotechnology laboratory

Security and Forensics

Students interested in forensics benefit from biological understanding of the processes analyzed in a forensics laboratory, and they learn the life sciences applications within the biotechnology laboratory

Advanced Manufacturing

Industries need students who have life science skills coupled with manufacturing knowledge to prepare them for manufacturing biologically active (life science-based) products. Students that complete the biotechnology program have the unique skills required for life science industries

Workforce Development

Prepare graduates to achieve the integration and effective use of life science technology in the area of biotechnology through laboratory-based instruction, thus improving student learning and discovery

Impact of New Course (Biotechnology Lab I)

The biotechnology program integrates science and technology disciplines and includes the courses described in Table 1. The multidisciplinary program has been attractive to students across campus and students from several colleges have participated in the biotechnology program, as illustrated in Table 2. The background and experience level of the students varied widely and it has been challenging to design appropriate curriculum for this diverse group of learners. Interestingly, graduate students who are crossing discipline boundaries, also enrolled to learn biotechnology concepts and techniques.

Courses within the Biotechnology Program

As illustrated in Figure 1, Biotechnology Lab I serves as one of the primary entry points into the biotechnology program and also has a direct impact upon Biotechnology Lab II and Introduction to Bioinformatics. Biotechnology Lab I is a 2-hour course intended for undergraduate students, and it serves as a prerequisite for Biotechnology Lab II and Introduction to Bioinformatics, courses that compose new core curriculum in the biotechnology program. Biotechnology Lab I has no prerequisites and thus serves as one of the primary entry points into the biotechnology program.

Table 2. Students Participating in the Minor and Their College

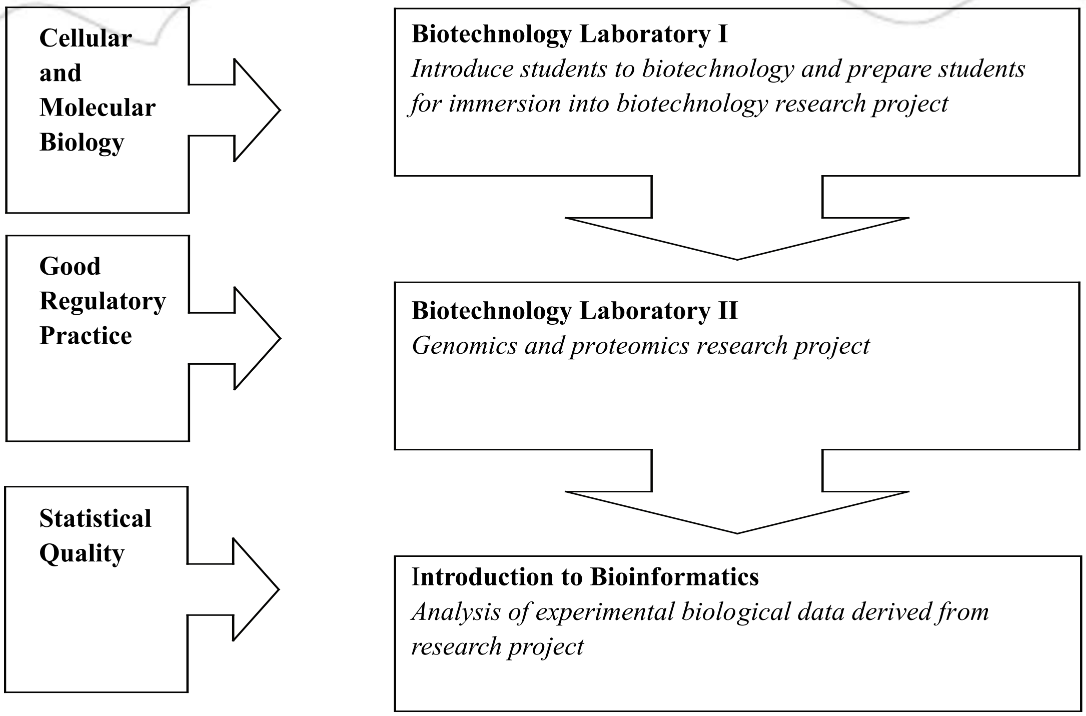
College	Number of students
Agriculture	3
Engineering	4
Liberal Arts	5
Management	5
Pharmacy	10
Science	33
Technology	29
Graduate	4

Collaborations with other programs, departments, and centers on campus have been instrumental to the growth of the program and have helped create a unique learning environment for the students. Most significantly, a recent partnership with Bindley Bioscience Center at Discovery Park has provided access to unique instrumentation for the biotechnology laboratory courses. Purdue University's Discovery Park is an administrative unit outside the traditional academic departments that is a model for the conduct of interdisciplinary discovery, learning, and engagement with society. The Bindley Bioscience Center [BBC] at this Discovery Park blends life sciences and engineering research to cultivate and support

Table 1. Biotechnology Courses within the Minor

Course Number	Course Name	Department
BIOL 112	Fundamentals of Biology I	Biology
BIOL 113	Fundamentals of Biology II	Biology
BIOL 241	Biology IV: Genetics and Molecular Biology	Biology
BIOL 295E	The Biology of the Living Cell	Biology
IT 226	Biotechnology Lab I	Industrial Technology
IT 227	Biotechnology Lab II	Industrial Technology
CPT 227	Introduction to Bioinformatics	Computer and Information Technology
IPPH 522	Good Regulatory Practice	Industrial and Physical Pharmacy
IT 342	Introduction to Statistical Quality	Industrial Technology

Figure 1. Interrelationships of biotechnology courses within the minor.



innovative, multi-investigator, interdisciplinary research teams. BBC engages biosciences in a broader perspective with applications of new or emerging technologies. The Center has established new research infrastructure to apply analytical methods, precision measurement technologies and high throughput approaches to biological systems. BBC research activities are organized around four research core facilities in which multiple high-end technologies are applied to biological systems in the context of senior BBC research scientists with deep expertise in these technologies. A major push is to assemble the requisite expertise to apply and develop technologies for a fuller approach to the complexity of biological systems.

Course Activities: Bioinformatics Modules

Introductory bioinformatics modules were completed before beginning laboratory work at the bench. Bioinformatics case studies were developed to help address the students' preconceived ideas of what scientific research is and what the field of biotechnology involves. The bioinformatics modules helped illustrate the following:

- Biotechnology research does not start at a lab bench; research begins by exploring the background, discovering what other scientists have already published, and determining what research questions remain unanswered.
- Inquiry and discovery within the field of biotechnology involves analysis of complex biological systems with many interacting molecules.

The specific objectives for the Biotechnology Lab I course are shown in Table 3.

Course Activities: Biotechnology Explorer Modules

The biotechnology lab modules that were incorporated into the course were obtained from the biological supply company, Bio-Rad. Bio-Rad has designed laboratory modules appropriate for an introductory biotechnology laboratory course as part of the Educational Explorer program (BIO-RAD, n.d.). The labs were selected for several reasons:

- They help address goals stated earlier for laboratory education especially understanding the complexity and ambiguity of empirical work, developing practical skills, and developing teamwork abilities (Singer, et al, 2005).
- They are affordable.
- They provide laboratory experience in a wide variety of biotechnology techniques with research quality instrumentation.
- They provide appropriate background material to explain the techniques employed and their impact on the current field of biotechnology.

- They have pre-lab and post-lab focus questions that help teach students critical thinking skills as part of the inquiry and discovery process.
- There is minimal lab preparation time investment.
- They have been validated by several other biotechnology programs.

During the first implementation of Biotechnology Lab I, the following biotechnology experiences were provided:

- Deoxyribonucleic acid (DNA) and protein fingerprint analysis.
- Polymerase chain reaction (PCR) informatics analysis.
- DNA and protein separation by electrophoresis.
- Enzyme-linked immunoabsorbant assay (ELISA) immunoassay.
- Bacterial transformation and recombinant gene expression.
- Protein chromatography.
- Nucleic acid isolation.

A laboratory notebook was maintained to record experimental data and organize information provided for laboratory activities. In addition, upon completion of each module, a laboratory report was prepared following the general format depicted in Table 4.

Course Activities: Critique of a Scientific Journal Article

As discussed earlier, it is important for students to develop scientific reasoning, understand the complexity and ambiguity of empirical work, understand the nature of science and cultivate an interest in science (Singer, et al., 2005). One of the activities developed to address these goals was the critique of a scientific journal article. Students were instructed to select an article on a current biotechnology topic that interested them from a secondary source. Then, they were instructed to find the original sources cited in the secondary source, and subsequently critique the primary source(s), comparing and contrasting to the secondary source. Students were encouraged to cultivate an interest in science by selecting a current topic that interested them. The student selections and subsequent critiques suggested they were addressing workforce needs identified earlier by integrating science and

Table 3. Biotechnology I Courses Objectives

General Objectives	Activities	Learner Outcomes and Assessment
The student will gain literacy in the basic methods and applications of bioinformatics	A. Bioinformatics Modules	Bioinformatics Lab Report
The student will be able to perform techniques currently molecular, and microbiology, while understanding the rationale behind the specific approaches	B. BioRad Biotechnology Explorer Modules	Participation in hands-on laboratoryactivities used in cell, and Lab Notebook
The student will be able to explain the experimental basis of techniques used, indicating the significance of the work, presenting, calculating, and discussing the data, and drawing conclusions	B. BioRad Biotechnology Explorer Modules	Lab Report
Given a specific biological question, the student will be able to determine appropriate applications of specific cell, molecular, and microbiological techniques	B. BioRad Biotechnology Explorer Modules	Lab Report
The student will gain experience in dissecting and extracting pertinent information from scientific journal articles	C. Class Discussion & Critique of Scientific Journal Article	Research Report on Scientific Journal Article

Table 4. Format for Lab Report

Section	Pertinent Information
Introduction	Provide background information including previous work by others (cite references), state the hypothesis for this current report, the significance of the project, and in general, the approach used
Methods	State each method used, the purpose of each method and, in sentence form, the method. Then add the page numbers from your lab notebook that reference the appropriate protocol.
Results	State each result and provide data in figures and tables
Discussion	Restate results, now interpreting the findings. Compare these findings to previous publications (cite references). State the significance of the current work and possible future directions.
References	Cite at least 5 references using APA format

technology. For example, although students often selected popular news sources as secondary sources, some students explored the assignment from a different perspective and selected unique secondary sources. For example, many chose to focus on papers that discussed new technology development that affected human health. Other students selected websites that disseminated science and technology information including genomics data from the Sorcerer II Global Ocean Sampling Expedition project (http://camera.calit2.net) and biotechnology intellectual property and patent information from an independent non-profit consultancy fostering innovation and creativity through the better use of intellectual property and its alternatives (The Innovation Partnership (http://www.theinnovationpartnership.org/en/).

Course Evaluation

A Small Group Instructional Diagnosis (SGID) was conducted by the Center for Instructional Excellence at Purdue University to determine what components of the curriculum were effective and what components were ineffective. This method of formative assessment has been shown to improve student motivation and was developed by researchers at the University of Washington to "to generate student feedback to instructors about the courses' strengths, areas needing improvement, and suggestions for bringing about these improvements (Clark & Redmond, 1982). The SGID procedure is conducted in the following manner: "At the beginning of the class, the teacher introduces the guest evaluator and then leaves the room for 20 minutes. During that time, the evaluator asks students to cluster into groups of five or six and take 10 minutes to (a) select a spokesperson who will write down the group's comments, (b) name something in the course they find very helpful or worthwhile, (c) name something they would like to see changed, and (d) suggest how the course could be improved. After the groups have completed their work, the evaluator asks the spokesperson from each group to give a report. The evaluator summarizes the points of consensus for the entire class and also clarifies points of disagreement. The evaluator then provides an oral or written summary for the instructor (Fox & Hackman, 2003, p. 81)." The results from the SGIDs conducted in the biotechnology courses are summarized in Table 5.

The feedback from the SGID is encouraging, but it has also helped inform appropriate course adaptations. Many different textbooks have been tried, however, an appropriate textbook has not been found that truly integrates the life sciences with technology. Currently, the instructor is developing a laboratory packet that will provide the appropriate background theory for the interdisciplinary research projects. Student feedback also indicates that students prefer the use of technologies to enhance the classroom activities. Current work includes developing virtual reality modules for instruction and integrating the laboratory packet with online tutorials, animations and quizzes.

The Biotechnology courses have no prerequisites, and based upon the feedback from the SGID more theory must be provided prior to the hands-on activities in order to ensure that students from all disciplines feel prepared and knowledgeable. As noted previously, the student population within the biotechnology courses is diverse and it has been difficult to design a curriculum that is appropriate. Data is currently being collected on student content knowledge before and after the biotechnology courses to more adequately address the specific educational needs of the students. Both concept inventory tests and open-ended content knowledge

Table 5. Small Group Instructional Diagnosis (Biotechnology Lab)

I. What do you like about this course?	
Course Organization and Structure	The class size is small; The lab experiments are well designed; the course is cohesive with other courses (e.g., reinforces topics that were discussed in genetics classes)
Course Content	Course covers a wide range of topics and allows the students to experience many areas of study; Course uses current lab technologies and techniques and current projects; course provides students with different aspects of the content (theory —> application —> industrial application); there is updated technology used in the lab;
Instructor Characteristics	Instructor is easy to contact via email and responds quickly; instructor explains well; The instructor is knowledgeable, available, and cares about the students
Teaching Techniques	Course requires students to utilize different sources to find information; students learn to use the sources that are used by professionals in the field; students are encouraged to think outside the box and to use their creativity;
II. What specific suggestions do you have for changing this course?	
Course Organization and Structure	Use Web technology more often and don't require the book for class; provide students with a more detailed syllabus; have all protocols in one manual; better prepare students for the lab especially at the beginning of the semester; assure that students with no or little biology background are brought up to speed for the background knowledge in biology that is needed for the course;
Evaluation and Grading	Give ungraded/bonus quizzes that allow students to see how well they understand the material

questions designed to identify misconceptions are being used. Scoring of content knowledge questions will be adapted from the rubric developed by Emert and Parish and student answers will be scored using a Likert scale in the following manner:

- 3--conceptual understanding apparent; complete or near-complete solution/response.
- 2--conceptual understanding only adequate; incomplete solution/response.
- 1--conceptual understanding not adequate; poor response or no response to the questions posed.
- 0--does not attempt problem, or conceptual understanding totally lacking.

Student-learning gains will also be assessed using the "Student Assessment of Learning Gains" website (http://www.salgsite.org) developed by The National Institute for Science Education (NISE). Students will complete the survey online and statistics of students' responses will be provided. A questionnaire is currently being developed based upon the course activities and themes identified from the SGID to examine how specific aspects of the course are helping students learn.

The most significant change will be the addition of a lecture component to the laboratory. The lecture time will provide more time within the course to provide background information to explain the lab and expand upon how the lab integrates into the current field of biotechnology. In addition, the lecture time will help facilitate more class discussion time and the addition of student presentations to strengthen student group activities. Finally, guest seminars will be incorporated to allow the students to interact with professionals currently employed within various realms of the field of biotechnology.

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