Incorporation of Biology Knowledge and Skills into a Chemical Engineering Laboratory Course to Address a Biotechnology Professional Profile

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ABSTRACT: *In recent years, the discovery, development and commercialization of products in biotechnology has been a major driving force for the establishment of interdisciplinary programs among the fields of science and engineering. Engineers with the basic understanding of microbial behaviour and genetic engineering techniques, as well as science majors with understanding of bioprocesses are among the most desirable professional profiles in the biotechnology industry. As a result, curricula and programs need to be revised in order to respond to this emerging need.*

The Unit Operations III Laboratory course of the Department of Chemical Engineering at the University of Puerto Rico, Mayagüez Campus, was revised and modified to mimic the manufacture environment of a biotechnology product. Key areas of science were introduced into the laboratory outline to ensure student understanding of the biological aspects of the engineering process.

From the biology discipline, exercises were designed to expose the course students to the biology of micro-organisms, genetic expression, genetic engineering, sterilization, aseptic behaviour, environmental monitoring, and gowning. From the field of bio-processing, the students developed skills in recombinant protein production and recovery: fermentation, centrifugation, and tangential flow filtration.

In addition, teaching strategies were designed according to the student learning profile as determined by the Felder and Silverman learning style model. The model suggested a predominance of sensorial, visual, sequential, and active learners. Assessment of the laboratory course was achieved by student portfolios. The portfolios documented the knowledge and skills developed across the course with emphasis in data analysis and communication skills.

1 INTRODUCTION: THE EMERGING ROLE OF BIOLOGICAL SCIENCES IN CHEMICAL ENGINEERING EDUCATION

Ever since its inception near 1888, the profession of chemical engineering has evolved alongside the development of industrial, large-scale production processes to synthesize chemical compounds of commercial value [1]. Furthermore, along the 20th century, chemical engineering education always led a cutting edge in the advancement of chemical processing technologies due to the adoption of a few key scientific-based concepts that have differentiated chemical engineering from other engineering disciplines. The first chemical engineering paradigm consisted in the conceptualization of unit operations, named so by Arthur D. Little in 1915; who established that all chemical processes can be described by a limited number of unit operations that are ruled by specific physical and chemical laws [1]. The second paradigm was the recognition of analogies between momentum, heat, and mass transfer processes, known as transport phenomena; and the utilization of mathematical modelling to quantitatively describe chemical processes [1]. These paradigms adopted by the chemical engineering curricula, have shaped the profession in that its students and practitioners had to acquire and apply knowledge from physics, chemistry, and mathematics to solve chemical engineering-related problems [1]. We can conclude that the chemical engineering profession has been characterized by a dynamic adoption and application of scientific concepts along with a co-current contribution to the advancement of the industrial production of value-added chemical products.

The birth of the 21st century is offering new and interesting challenges to the profession of chemical engineering. These challenges are, for instance, motivating changes in the traditional chemical engineering approach of "scaling up" to produce industrial quantities of a valuable chemical compound to the novel approach of "scaling down," and produce small particles or molecular structures [1]. The breakthroughs in nanotechnology and biotechnology are scientific advancements that promise new uncharted lands for research and development, and chemical engineering must accordingly run along these ventures as it did in the past two centuries. These technologies are actually developing at a fast rate, and are being funded by recognized research institutions, like the National Science Foundation in the USA and its equivalent in other nations. Biotechnology, after the conclusion of the human genome project, will play a vital role in the development of new therapeutic treatments, in which chemical engineering can share its contribution in biotechnology process development and commercial production. For this reason, probably one of the new chemical engineering paradigms will be the incorporation of biological sciences to the body of scientific knowledge that the profession must add. This new paradigm is not easy to implement. Chemical engineering curricula are very constrained in course requirements, so the addition of biology courses will not be an easy task. Furthermore, not all faculty members are prepared to get involved in the teaching of biology-related topics in their chemical engineering courses. Chemical engineering departments worldwide must introduce biological sciences into their curricula in a wise and timely manner [2].

The new technology developments are shaping the world economy as a knowledge-based one: molecular biology, drug delivery systems, DNA chips, and nanotechnology are just a few of the technologies on the pipeline. Chemical engineering education must adopt new paradigms that will allow it to evolve to the light of these new discoveries, while still keep its fundamental essence of existence as a discipline that adopts new scientific advancements. The world economy and its actual driving forces based on global marketing and high-technologies will likely help in shaping the new paradigms for chemical engineers.

Small countries are not excluded from the global trends. In the case of Puerto Rico, a small island in the Caribbean Sea, its government is making a big effort to switch its economic development from a low-tech, low wage manufacturing environment into a high-tech one. It is well known that Puerto Rico hosts the world's largest pharmaceutical manufacturing infrastructure and one of its main drives is to attract biotechnology manufacture and product development to the island to improve its global competitiveness. So far, the government has been successful in attracting new investments from internationally recognized biotechnology companies, and it continues to search for new investments in the biotechnology arena. In order to become a world class biotechnology site, there is the need to provide a skilled workforce consisting of both new graduate professionals and re-trained pharmaceutical employees.

The University of Puerto Rico, Mayagüez Campus (UPRM), is responding to the needs in workforce development. First, UPRM offers a series of BS degrees that are strongly connected to the biotechnology manufacturing industry. These degrees are in Industrial Biotechnology and in Chemical Engineering, which provide young professionals to the work market. Second, UPRM has established an Industrial Biotechnology Learning Center (IBLC), which provides customized curricula to train experienced personnel with no basic knowledge in the area of biotechnology [3].

Even though the Industrial Biotechnology and Chemical Engineering BS programs have been offered for quite some time, we feel that the new paradigm of introducing biological sciences into the chemical engineering curriculum should be put into action, and the way we proceeded was to modify one of the existing courses as an exploratory test. In this paper, we describe how we attempted to do so with the Unit Operations Laboratory III course.

2 UNIT OPERATIONS LABORATORY III COURSE: BEFORE & AFTER MODIFICATIONS

The unit operations laboratory III course was designed 15 years ago to provide students with hands-on experience in unit operations normally found in biotechnology-based industries. Unit operations to be addressed include fermentation, product recovery, and separation. This is a one-credit course, which amounts to a total of 45 hours of laboratory and instruction time per semester, roughly three hours a week. This course is open to both chemical engineering and industrial biotechnology majors at the senior level. It is a required course for Industrial Biotechnology students, and is an elective course for chemical engineering students. The course was first offered in the spring of 1996 and has been offered ever since in a regular basis.

In the beginning, because of the lack of appropriate equipment and assigned laboratory space, the extent to which experiments were performed was seriously affected. Experiments were limited to a few, which were: enzyme kinetics, alcoholic fermentations, and operation of a pilot-scale double evaporator unit. Course assessment was strictly based on the instructor grading of the following requirements: student performance in experiments, written report submission, and a final term exam. Skills to be developed consisted on written and oral communication, teamwork, following of laboratory safety measures, and data analysis. The underlying theory and fundamental scientific aspects of the experiments were assigned as reading subjects or a short mini-lecture was dictated by the instructor before the actual laboratory was performed. Not much fundamental science or theory was covered in order to have more time to perform the laboratory experiences. This approach followed the classical one used in the more traditional Unit Operations Laboratories I and II, which are required in the chemical engineering undergraduate curriculum. No biological science concepts were discussed or lectured by the course instructor.

The purpose of incorporating knowledge and skills in biology into the Unit Operations Laboratory III course obeys to the driving forces explained in the introduction of this paper, as well as to responding to the needs of a new student profile. This new profile must comply with the new global demand for professionals with knowledge-based, interdisciplinary skills, able to communicate with scientists and engineers alike. The new student profile will cover skills, such as oral and written communication, teamwork, knowledge of learning styles and self-criticism, and knowledge of biology topics which are relevant to bioprocess engineering issues.

3 ADDRESSING A NEW STUDENT PROFILE

Traditional chemical engineering curricula have been characterized by lack of courses and learning experiences that will expose students to the basic understanding of biology and its applications to industrial processes in which chemical engineers are key professionals. In addition, understanding of learning styles among the student population is not regularly considered in a teaching methodology when a course is offered. The Felder & Solomon learning style model [4] was used to determine learning styles among the students enrolled in the Unit Operations Laboratory III course. A predominance of visual, sequential, sensorial, and active learners was found among the students. Interestingly, this tendency has been observed in previous courses [5]. This information was used to design course activities to address the learning styles diversity among the student population, emphasizing in activities for the predominant learning styles, but not neglecting the least dominant, neither.

With the emergence of biotechnology and bioprocess engineering as a major industry, a new chemical engineering profile must be conceptualized. This profile should be characterized by knowledge in basic understanding of (1) prokaryotic and eukaryotic metabolic pathways that are key in industrial processes, (2) environmental monitoring in working under aseptic conditions, and (3) molecular biology for generation of recombinant proteins. In addition, skills such as aseptic behaviour and gowning must be mastered by chemical engineers, where the understanding of microbiology becomes essential. In the Unit Operations Laboratory III, this profile was incorporated using as a model key processes that occur in a typical biotechnology manufacturing facility. This model was generated as part of a customized training that the Industrial Biotechnology Program at UPRM offered during May-April 2003 to new hires of a major biotechnology industry which is starting up its biotechnology manufacturing operations in Puerto Rico [3].

Knowledge of environmental monitoring is an essential concept for professionals in the biotechnology field since production in biotechnology must be performed under aseptic conditions. As a result, our students need to understand the microbiology concepts that address this topic. In the course, students became aware of the role of the micro-organisms as contaminants in an aseptic manufacturing environment, and techniques that are commercially available to determine the level of environmental control in the working areas. The students performed a wet lab in which they monitored and quantified particulates present in a room, using the Climet approach, an industry standard procedure. In addition, quantification of microbial bio-burden was performed using R2S and "Slit to Agar" techniques. Students performed calculations to determine microbial loads and particulate counts, as well as characterization of the isolated microbial colonies. This lab experience enabled students to understand the biological concept that represents the need of aseptic behaviour according to clean room environment in an industrial process. Within this aseptic behaviour, students were required to perform gowning exercises while they were videotaped. Students were handed-in a digital copy of their gowning exercises and were asked to self-evaluate their experience. Validation of the ability of the students to perform aseptic behaviour was monitored in a class 100 environment by working in a laminar flow hood. Determination of the aseptic behaviour was performed by previous description of environmental monitoring procedures in addition to RODAC plate and swap sampling of microbial loads over work and gown surface areas. The learning activities described above benefited visual, sensorial, global, active and sequential learners.

Since working in a biotechnology industry involves the strict follow-up of regulations as those enforced in the USA by the Food and Drug Administration (FDA), our students were exposed to good manufacturing practices (GMP) and standard operating procedures (SOP). They were lectured by a Chemistry faculty member who has previous pharmaceutical experience and is knowledgeable of the GMP and SOP practices. The SOPs were presented from two perspectives: to follow them and to write them. The second perspective allowed students to practice the development of SOPs. Students were requested to write generic SOPs as well as to prepare SOPs for equipment such as pH meters, dissolved oxygen meters, tangential flow filtration units, and bioreactors, which they needed to become familiar with in order to correctly operate them. The SOPs would eventually be used for the actual operation of the lab equipment. Student SOPs were submitted to peer and faculty evaluations. The evaluations allowed students to improve communication skills and teamwork with their peers. This learning activity benefited active and sequential learners.

With a clear understanding of a working scenario in which a controlled, regulated, and continually monitored facility operates, the course made a transition from micro-organisms as contaminants to micro-organisms as producing species. In this transition, it was required to familiarize students with mammalian and bacterial production cell lines, including their structural, genetic, and metabolic differences. This basic understanding of cell biology using industrial strains as an example allowed the incorporation of the following topics: gene expression, regulation, and recombinant DNA. These concepts were presented within the framework of an industrial recombinant protein production facility. This biological framework prepared the students to better perform the experiments in bioreactor operation, and the downstream processing steps of centrifugation, and tangential flow filtration to concentrate biological products. The learning activities described benefited sensorial, global, active, reflective, and sequential learners.

4 ASSESSMENT

Documentation of learning experiences by introducing key biology concepts in the revised course was performed by means of student portfolios. As part of the portfolio, students included the following items: (1) preparation of SOPs; (2) self-assessment of videotaped gowning procedures, (3) analysis of surveillance of a selected environment using environmental monitoring strategies with regard to particulates and microbial bio-burden; (4) documentation of aseptic behaviour skills by the ability of the students to work in a class 100 laminar flow hood environment with minimal microbial counts in surface and air sampling; (5) documentation and analysis of the growth curve of a genetically-engineered bacterial culture under appropriate aseptic conditions to maintain a pure culture during a scaling-up procedure; (6) documentation and analysis of the capability of the strain to produce a recombinant product; and (7) documentation and analysis of the operating performance of a tangential flow ultra-filtration system.

Understanding of cell biology and molecular biology was assessed by team presentations of an assigned industrial product case study using a genetically-engineered cell line. This team presentation was included in the portfolio with peer and faculty evaluation on oral communication skills.

5 CONCLUSIONS

Advances in science and technology, as well as the job market transition towards bio-products, require a re-conceptualization of chemical engineering courses in order to include fundamental biology concepts as part of the student profile. Key biology fundamentals include cell biology, molecular biology, microbiology, and cell metabolism. Knowledge in these areas becomes essential for all kind of professionals that are to work in a biotechnology manufacturing environment. To raise awareness of the connection between disciplines, the course provided students the benefit of connecting contents and skills between biology and chemical engineering. This is one of the major challenges that chemical engineers will experience not only because of previously mentioned driving forces, but also as one of ABET's 2000 accreditation criteria. A major barrier in the incorporation of biology in engineering is time constraints and instructor's preparation time. Recognizing that interdisciplinary approaches involve sharing expertise between different disciplines, the strategy followed in this course modification was team teaching between engineering and science instructors.

The incorporation of biology concepts into a chemical engineering course was attempted by modification of the course learning strategies. Biological concepts introduced have an industrial basis and were adopted from a training curriculum which was designed for a major biotechnology company. A major contribution of this course modification experiment was to provide students with some technical and soft skills so that in their future as professionals, they will be able to excel in knowledge in the emerging area of biotechnology and to acquire life-long learning skills.

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REFERENCES

VARMA, A. 2003. *Future Directions in Chemical Engineering Education: A new Path to Glory*. ConocoPhillips Lecture Series in Chemical Engineering, Oklahoma State University.

STEPHANOPOULOS, G. 2003. *Chemical and Biological Engineering.* Chemical Engineering Science, 58:3291.

SALICETI-PIAZZA, L., BUXEDA, R., RIVERA, E., HORMAZA, M., & MORELL, L. 2003.

FELDER, R.M., & SILVERMAN, L.K. 1988. *Learning and Teaching Styles in Engineering Education*. Engineering Education, 78(7):674.

SALICETI-PIAZZA, L., BUXEDA, R., & LÓPEZ-GARRIGA, J. 2004. *Transformation of the Teaching Methodology in a Laboratory Course of the Industrial Biotechnology Curriculum in Response to the Student Profile*. International Network for Engineering Education Research Special Volume for 2004, in press.

OSTAFIN, A.E., LACLAIR, D., & SCHMIDT, H.T. 2003. *A Course in Bioprocess Engineering: Engaging the Imagination of Students Using Experiences Outside the Classroom*. Chemical Engineering Education, 37(3):180.

PEEPLES, T.L. 2003. *Introduction to Biochemical Engineering: Synthesis, Resourcefulness, and Effective Communication in Group Learning*. Chemical Engineering Education, 37(3):174.

TAYLOR, S.C. 2003. *The Real Biomanufacturing Capacity Crisis: Stainless Steel or Flesh and Blood?* BioProcess International, 1(6):30.

VERMETTE, P., PROULX, P., & MARCOS, B. 2003. *Toward an Integrated Biotechnological Engineering Education Program: a Canadian Perspective*. Nature Biotechnology, 21(12):1525.