A COURSE ON BIOTECHNOLOGY AND SOCIETY

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Many undergraduate curriculum committees around the country are seeking to create science and en gineering requirements in university curricula which were liberalized during the 1960s when technical requirements were the first to go.[1] National recognition that science and engineering classes are worthwhile for all undergraduates has created a renewed demand for these courses. The widening gap of technical literacy between science or engineering majors and non-science majors is due, in part, to preexisting academic and administrative structures. In fact, the National Science Foundation has identified the development of "mechanisms to enhance the technological literacy of all students" as an important goal. The challenge is to create nontrivial engineering courses which

- *Emphasize the basic tenants and practice of science, engineering, and technology without loss of technical content*
- *Are suitable for nonscience majors who attend the course*
- *Are intellectually stimulating for the students and instructor*

Engineering schools seeking to contribute to the university-wide educational mission should consider a course in biotechnology—a subject that naturally attracts students. As issues of health care costs become ever more critical, the general population strives to understand the pharmaceutical and biotechnology industries. Similarly, these industries are likely interested in communicating their activities and new products to a consumer who is educated and is not fearful of biotechnology.

The course described in this paper has proven successful with non-science majors, engineers in general, and our own chemical engineering undergraduates. Contrary to expectations, the technical course was of interest to a university-wide audience. This past spring we attracted twenty-three juniors and seniors from non-science majors ranging across the university: performing arts, management, economics, history, and legal studies.

Recognizing the novel makeup of this class, we carefully selected and tailored topics from our standard senior-level biochemical engineering course to suit non-majors who had little scientific background. As an overall goal, we wanted the students to understand in detail how biotechnology affects their lives in areas ranging from health care decisions to selections at the grocery store. We felt that issues such as AIDS, animal rights, and genetically engineered foods were relevant and would be interesting to this broad base of students. These topics served as a suitable "vector" to communicate scientific and engineering information such as viral genetics, recombinant DNA technology, large-scale pharmaceutical production, as well as experimental design and statistics. Along the way, important biotechnologies were presented, such as: immunodiagnostics and hybridoma culture, genetic diagnostics (DNA fingerprinting and PCR analysis), production and clinical testing of recombinant proteins, and agricultural biotechnology.

COURSE CONTENT

A novel approach we used in this course was avoiding the traditional lecture format. Instead, we used a *Case Study/ Group Learning* approach[2-5]—with much success, judging from student participation. The course outline is given in Table 1. Each case provided a framework in which students immediately understood the real world application of the technology. In this context, the material seemed less abstract, less intimidating, and more comprehensible.

At the beginning of the course, students were divided into permanent groups of four to six students each. As groups, they had to analyze raw data sets using their knowledge of the technical information, experimental design, and statistics. Before each case study a mini-lecture was given to expand on key concepts. Mini-lectures given during the first few weeks of the course included discussions of DNA-RNA-protein biochemistry, cell division, the human immune response, and antibodies. Throughout the entire course, emphasis on the applications of biotechnology made it identifiable as an engineering course as opposed to a pure science course. These real world applications, in part, helped enhance the students' willingness to work with such new technical concepts.

We covered cases which highlighted particular technologies or sciences of the biotechnology industry. The first case study was the use of enzyme-linked immunosorbent assay (ELISA) and Western blotting to detect HIV-associated antigens in human blood. Students debated a cost-benefit analysis of employer testing of employees[6] and evaluated the effects of false-positives on the analysis. This case was an excellent example of a naturally occurring biological molecule (an antibody) serving as a basis for a commercial application. Throughout the course, students repeatedly saw this paradigm of biomolecule discovery, characterization of structure and function, and final utilization of the biomolecule as a foundation for a technology. As the first case of the course, students extended their preexisting knowledge of viruses, immune response, and antibodies into new areas of measurement and detection of viral antigens. The case also reinforced the basic fundamental concepts of proteins, cells, and viruses which were to be used later in the course.

TABLE 1
Course Outline

Case Study	*Focus Issues*	*Science & Engineering*	*Refs.*
HIV Diagnostics	• HIV testing in the workplace	• Detection and measurement • Immunodiagnostics • Hybridomas	6
AIDS Treatments	• Reverse transcriptase inhibitors (AZT)	• Protein purification • Immunology and retroviruses	10
Phase I Trials	• Recombinant soluble CD4 • FDA parallel track testing	• Protein production systems • Experimental design	7-9
DNA Testing	• Forensic testing • Paternity testing • Gender testing (Olympics)	• RLFP analysis • PCR • DNA isolation and analysis • Genetics and chromosomes	11-12 13 30
Clot-Dissolving Therapy	• Costs and efficacy • Animal testing	• Cloning the tPA gene • *In vivo* vs. *in vitro* testing	14
Bovine Growth Hormone	• Evaluating health risks	• Hormones and receptors	15-16
Recombinant Tomatoes	• Safety of engineered foods	• Antisense RNA technology	17-19

To give an example of a more involved case study (which required four class sections of eighty minutes each), we explored recombinant CD4 (reCD4) therapy as a treatment against AIDS.[7-10] After hearing mini-lectures on retroviruses and receptor-ligand binding, students working in groups had to develop strategies for manufacturing a significant quantity of reCD4, design *in vitro* testing methodologies for evaluating reCD4 efficacy, and design a protocol for a Phase I trial. They had to apply their basic understanding of expression systems and protein purification/characterization toward an end goal of conducting a Phase I trial with reCD4.

Although topics of bioreactor and separation design were not suited for non-engineering majors, we discussed the manufacturing techniques at a level corresponding to an introductory chemical engineering course. As part of this case study the groups had to conduct a statistical analysis of raw data reported from real Phase I and II trials.[7,8]

By the end of the case study, students had some sense of how *in vitro* data and *in vivo* data could be in conflict.[9] They identified the sources of high costs associated with drug design and FDA approval. Through this case study, the learning process moved from the scientific observation that the HIV viral coat protein gp120 binds the T-cell membrane protein CD4 to the hypothesis that soluble CD4 may interfere with HIV virulence. To test the hypothesis required the manufacture and purification of reCD4, *in vitro* testing, and the design of Phase I trial.

At each stage of the discussion, the goal of drug design and AIDS treatment was appreciated by the students. A challenge for the students was deciding how to test CD4 given the existence of an FDA-approved reverse transcriptase inhibitor AZT. The benefits of AZT are transient and the use of placebo control groups would not likely be tolerated by AIDS patients enrolling in a clinical trial.[10]

Another case study in DNA fingerprinting involved the use of Restriction Fragment Length Polymorphism (RFLP) analysis of VNTRs (variable number of tandem

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repeat) to examine forensic evidence obtained at a rape crime scene and from potential suspects. A mini-lecture on DNA hybridization probes, chromosomal structure, and the human genome set the stage for this problem. The students reviewed copies of the autoradiographs that the jury saw in a real trial* of a 1985 rape/murder case in Arlington, Texas.[11] Issues of reagent quality control, interpretation of DNA bandshifting, and state regulation of RFLP became quite important in making final judgments using evidence that was originally claimed to identify a rapist with 1-in-50 billion certainty.

Also covered in this case was the rapidly expanding technology of Polymerase Chain Reaction (PCR) for DNA amplification. Chapters from the National Research Council on DNA Technology in Forensic Science[12] were very clear and useful for the students. Other forensic cases were drawn from the literature.[13] Although forensic DNA analysis is not a typical research area in chemical engineering, the case study was an exciting way of teaching about the human genome and the molecular biology techniques frequently used in biotechnology. With this appreciation of human chromosome structure, other topics such as the human genome project or patenting genes[14] could easily be covered.

The next case focused on blood clot dissolving therapy using recombinant tissue plasminogen activator (tPA). Again, students saw this pattern of a naturally occurring molecule being used as the foundation for an entire industry. Tissue plasminogen activator (whose functionality was described decades ago) was cloned in *E. coli* using reDNA techniques in 1983 and then expressed in CHO cells by Genentech for clinical trials. As part of this case study, students had to identify the limitations of *in vitro* testing of these recombinant compounds. They also had to design experimental protocols for the humane testing of recombinant blood clot dissolvers in animal models to gain data unattainable by *in vitro* tests.

Moving toward examples from agricultural biotechnology, we used a case study on bovine growth hormone (bgh) also known as bovine somatotropin (BST). This is an excellent example highlighting the role of societal influences on the ultimate use and acceptance of a biotechnology product.[15,16] Students had to debate the issues and write position papers from the points of view of the FDA, the consumer, the farmer, and the agricultural business. The use of bgh has been shown to be generally safe and effective for elevating milk production and improving the efficiency of production, but dairy cows with high milk production, regardless of bgh use, tend to have more infections of the udder (mastitis). This case reinforced previous understanding of gene cloning, expression systems, and receptor-mediated events of cell regulation by hormones. By this point in the semester, students readily appreciated the distinction between scientific information (bgh and human growth hormone effects on humans), scientifically based disputes such as increased bovine mastitis and antibiotic feeding, unsupported claims, and economic issues—matters which are typically jumbled together in media coverage.

The final case study of the course was on the use of antisense RNA technology for preventing tomato spoilage. A mini-lecture on energy metabolism in cells and the autocatalytic rise of ethylene production in ripening tomatoes helped formulate the problem. In this case, expression of antisense RNA against the rate-limiting enzyme ACC synthase was used to block ethylene synthesis and subsequent ripening in tomatoes.[17] The class discussed the safety of a transgenic plant and formulated some guidelines by which safety could be evaluated.[18] Through this case, issues of biochemical metabolism and gene regulation can be covered in a context which is easily approached by students.

GROUP LEARNING

We structured the course in a group-learning context modeled on a team-learning approach developed by Dr. Larry Michaelson at the University of Oklahoma.[3-5] The group structure consists of permanent small groups, group exam taking, and group-based assignments in the application phase of each case study. In addition to their group work, students also complete individual tests and assignments. Grading was based on group and individual performance in addition to peer evaluation. Although unusual to the students at first, they quickly learned to value the knowledge base of their peers and realized that the group's understanding of the material greatly exceeded the knowledge of any individual member. When students took the exam individually and then in the groups, the mean on the group exams was typically 15% points higher than the mean on the individual exam. Larger and broader assignments were given for group work, but care was taken to avoid assignments which could be easily partitioned by the groups, thus circumventing the goal of the group work. Perhaps it is too early to tell whether group-based learning is an educational fad or is relevant to the problem-solving orientation of the chemical engineering

* *Courtesy of Dr. Randall Shortridge, Department of Biological Sciences, SUNY at Buffalo*

curriculum. It is common for our seniors to cite their senior-year design project (a group experience) as a key element in their education. In this sense, chemical engineers have had group learning as part of the curriculum for years.

One challenge presented by the group approach assures equitable contributions from each member. Groups will invariably have at least one individual who tries to avoid doing work and at least one or two martyrs who are willing to carry the burden. The team-learning approach has a built-in system for peer evaluation.[3-5] From the first, students were told that a percentage of their course grade would be determined by the evaluation of their peers in their groups. This mechanism tends to reinforce group participation and is a natural self-policing mechanism that allows the groups to function without intervention from the instructor. In our experience, the Peer Evaluation at the end of the semester is an important motivation for the students to take their group work seriously, and it also has the indirect benefit of promoting high rates of attendance. In contrast to other general education courses typical at a large university (which may have attendance levels under 50%), we had attendance rates of 85-90%.

COURSE EVALUATION

We were interested in formally evaluating student attitudes toward science, engineering, technology, and knowledge of terms and concepts relevant to scientific inquiry. Perhaps the most difficult aspect of introducing novel course material and a nontraditional teaching format (whether it be group learning or computers) is to evaluate the impact of the approach on student learning. We conducted extensive surveys during the first and last week of the course to ascertain these variables. This was carried out as a part of a larger university-wide evaluation of science education at The State University of New York at Buffalo, funded by a grant from the Fund for the Improvement of Post-Secondary Education (FIPSE). The survey battery administered to the students included

- ***Scientific Process Survey*** *developed at the State University of New York at Buffalo under a FIPSE grant (C. Herreid, 1992, pers. comm.)*
- ***World View Survey*** *(Organicism-Mechanism Paradigm Inventory by Germer, Efran, and Overton[19])*
- ***Scientific Attitude Survey*** *developed at the University of Oregon under FIPSE and NSF grants (Morris, 1992, pers. comm.)*
- ***Scientific Literacy Survey*** *(A. Kozak, J. Meacham, and C. Herreid, in preparation, as modified from A.B. Champagne[20])*

The most marked changes were found in content-based knowledge (see Table 2). The **Scientific Process Survey** contained fifty terms and phrases that fall into three categories: experimental design, statistics, and the process of science. Students were asked to assess their knowledge of each term on a scale from 1 to 5, with 5 being the most familiar with the term. The mean for all items at the beginning of the course was 3.02—this corresponds to a level of understanding where students understand the idea vaguely. At the end of the term the mean for all the items was 3.83, corresponding to a level of understanding where students feel they have a pretty good understanding about the idea. Twenty-three of the fifty items had changed significantly over the course of the term ($p < 0.05$). Analyzing the items in the three categories also revealed significant differences (see Table 2).

TABLE 2
Scientific Process Survey
Comparison: First and Last Week of Class

	First Week*	Last Week*	p value
Experimental Design	3.15	4.12	0.0001
Statistics	2.95	3.60	0.0380
Scientific Process	2.99	3.87	0.0001

**Scale of 1 - 5*
1 = I have never heard of the idea before.
2 = I have heard of the idea, but I don't understand it.
3 = I understand the idea vaguely.
4 = I have a pretty good understanding about the idea.
5 = I could explain the idea to an intelligent friend.

The **World View Survey** was a measure of the student's world view that is polarized between a holistic (context-based) and a mechanistic way of looking at the world. We found that, on average, the class had a slightly holistic world view at the first week of the course which did not change significantly over the term of the course. These results were consistent with other university groups at The State University of New York.

The **Scientific Attitudes Survey** had forty-eight items organized into the following six categories: science as a theory-building vs. data-gathering activity; basic vs. applied research; scientists as moral/amoral beings; usefulness of science in everyday life; abilities needed for success in science classes; personal ability to succeed in science class. We found that class averages in each of the six categories were very similar to other university student populations. These averages did not change during the course.

The **Scientific Literacy Survey** contained forty items relating to behaviors relevant to a scientifically literate adult. Students were asked to rate how valuable each of these items are. The scientific literacy items that students most valued were interpreting graphs, defining terms, applying scientific information in personal decision making, being able to evaluate medical claims, engaging in a scientifically informed discussion, and locating scientific or technological information. These were still their priorities at the end of the semester.

Overall, we believe that students' perceptions toward science and science education change as they become more familiar with the basic terms, ideas, and processes of science. One way to promote positive attitudes of non-majors toward science and engineering is to teach these topics more effectively. The case-study/group-learning approach used in this course may be a suitable method to achieve that goal.

SUMMARY

By the end of the course, students had a general understanding of the breadth of the biotechnology industry, from pharmaceuticals to agriculture. They had a basic familiarity with recombinant DNA techniques, large-scale expression and purification of proteins, and product testing. By discussing how biotechnology companies operate in a scientific, legal, and economic environment, students became interested in material not normally accessible to them. The use of case studies made the material approachable and more easily comprehended, organized, and remembered. The group work allowed for much of the scientific learning to occur beyond the borders of the classroom. By the end of the semester, biotechnology no longer seemed like a brave new world to these students—they occasionally brought in their own newspaper clippings and provided insightful commentary on the technology or criticisms of the reporting.

This type of course is especially important in the context of the lack of scientific literacy among college students.[21-23] The students not only learned important aspects of biotechnology, but also learned to appreciate and understand the process of science and engineering, especially as it affects their lives. We consider this an improvement over the "list of facts" approach[24-26] of defining scientific literacy (*e.g.*, references 21, 27, 28) Also, it would be difficult for a university faculty to decide exactly what list to use.[29] Indeed, our students indicated that those aspects of science with personal relevance and application were the most valuable to them. Designing courses for general education students with engineering content will be best achieved if the course design integrates both a content and a process focus.

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