# Understanding Biotechnology: A Necessity for Science Literacy

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# Understanding Biotechnology:

# A Necessity for Science Literacy in the Twenty-first Century

## Abstract

A hands-on semester-long course in biotechnology for middle school students, high school students, or college students provides a way to learn about new technologies and can be coupled with assignments that provoke their thinking about the ethical and social ramifications of the field's advances.

Recent news reports claim that a human has been cloned, advertise that companies will collect your pet's DNA for future cloning, state that genetically modified "Frankenfoods" have unknowingly entered consumer food products, and assert that stem cell transplants can cure diabetes as well as other diseases. The list of controversial topics and issues presented to the general population continues to grow. Unfortunately, many of these reports are designed to grab attention and sell advertisements, but they do little to inform. Responsible citizens in the twenty-first century need to distinguish between hype and scientific progress. With advances in sequencing of the human genome and DNA cloning, students need a solid grounding in biotechnology that gives them the ability to think critically about this new information. Only then can they make wise, informed, and ethically sound decisions about technology that will affect their lives and our global community at ever increasing rates.

**The History of Biotechnology**

Biotechnology is a term used to encompass the use of living things to better our lives. This occurs in industry, medicine, in the environment, and through agriculture. But biotechnology really began when humans first gathered seeds, domesticated livestock, and started breeding animals and plants for desired characteristics and properties over 10,000 years ago. Early uses included fermentation of alcoholic beverages, cheese making, and leavening bread. Ancient China used molds as the first natural antibiotic and plant products as the first natural insecticide.

It has only been in the past one hundred years, however, that humans have gained an understanding of genes and their role in heredity. A working draft of the sequence of the human genome was completed in 2001 (International Human Genome Sequencing Consortium, 2001; Venter, 2001) and in 2003 researchers announced that the Human Genome project was completed. The year 2003 also heralded the fiftieth anniversary of Watson and Crick's Nature paper elucidating the structure of DNA (Watson and Crick, 1953). This work, along with many other advances, have led to the ability to deliberately and routinely modify the genomes of organisms so that today we are even able to treat a few human genetic diseases using gene transfer technology (Simon, 2002).

**Some Current Advances *or Why Study Biotechnology?***

Replacing dysfunctional genes with healthy copies has been explored as a way of curing some genetic diseases. The first human experiment attempting to replace a defective gene occurred in 1990 when Ashanti De Silva was treated for severe combined immunodeficiency caused by a mutation in the gene for adenosine deaminase (Anderson, 1995; Simon, 2002). Lack of stability and proper expression of the inserted genes, disruption of normal cell function, limitation in cell availability, and the difficulty in returning genes to the body have been cited as stumbling blocks to realizing the promise of *gene therapy* (Verma, 1990). As trials for gene therapy are developed and studied, a better understanding of the risks of the technology have become apparent and questioned (Marshall, 2000).

*Genetic vaccines* are at various stages of clinical trials. A genetic vaccine is created by introducing the genes for viral, parasitic, or cancer specific proteins into the cells of healthy organisms so that they produce these foreign molecules, which enhances the body's own immune response (Weiner and Kennedy, 1999).

While there has been minimal response in the United States markets to the presence of *genetically modified foods*, the markets in the European Union and elsewhere have strongly resisted their introduction. Introducing new genes into the plant creates genetically modified crops. Goals for this technology include the diminished use of pesticides by making the plant more resistant to insect pests (*Bacillus thuringiensis* toxin gene for Bt corn), increased crop yield by selectively

inhibiting competitive weeds (glyphosate herbicide resistance gene for Roundup® Ready soybeans), and enhanced nutritional quality (vitamin A synthesis gene producing golden rice) (Brandner, 2002).

The *Human Genome Project* has provided insight into the individuality of genetic expression. With segments of single-stranded DNA from known genes affixed to chips and placed into an array, it is possible for researchers to quickly determine which genes are specifically expressed in any tissue sample (Friend and Stoughton, 2002). Moreover, there is growing evidence to indicate that the extent to which certain genes are expressed is correlated with disease and suggestive of the course of treatment (Friend and Stoughton, 2002; Kolata, 2003). Controlling the expression of genes is also being explored as treatment for viral infections and cancers (Cohen and Hogan, 1994). Treatment with short synthetic segments of DNA can decrease the transcription or translation of certain genes by interfering with regulatory functions. In so doing, viral replication and cancer cell proliferation may be slowed or halted.

The medical research community is optimistic about the use of *embryonic stem cells* for treatment of Type-1 diabetes, burns, heart disease, and neurological disorders such as Alzheimer's and Parkinson's diseases. Derived from the inner cell mass of blastocysts (pre-implantation embryos), embryonic stem cells have the ability to grow in culture almost indefinitely and can differentiate into almost

any kind of cell, opening the possibilities of using them to replace damaged cells, tissues, and perhaps whole organs (Stolberg, 2001; Trefil, 2001; www.nih.gov).

These advances are only a few that our society is currently grappling with. Our students, no matter where their career path takes them, will need to understand these plus many more.

**Biotechnology in the Classroom**

Teaching biotechnology, at both the middle school and high school levels provides an engaging and interdisciplinary topic for students. Using the print and television media provides a way to intrigue students and to promote critical thinking. Depending on the exact source, these reports may have more or less credibility. All, however, can be used because they gain students' attention and interest. The information provided should be examined critically in the context of what students know and understand. Other reports and credible web sites may be consulted to confirm or refute specific findings.

Students are excited and intrigued by science fiction turned into science fact and practice. Using this technology in simple experiments provides better understanding and a springboard to other topics such as ethics and the societal implications of biotechnology. This interdisciplinary approach encompasses doing basic techniques with writing a paper, reading and discussing literature, and engaging in an independent laboratory investigation. In this way, biotechnology can address the National Science Education Standards, especially those

concerning heredity, technology, and social perspectives, although others can be covered as well (National Research Council, 1996).

Another reason to include biotechnology education is that biotechnology and the related field of genetics receive significant emphasis in the advanced placement biology curriculum. The molecular biology portion includes bacterial transformation and restriction enzyme analysis of DNA, two biotechnology techniques. The genetics section, consisting of fruit fly genetics (chi-square analysis of genetic crosses) and population genetics (Hardy-Weinberg), can be enhanced by a polymerase chain reaction (PCR) laboratory in which students amplify a polymorphic region of their own DNA and compare the data generated across the class.

Bacterial transformation consists of transferring plasmid DNA into bacteria, which confers upon it a new characteristic such as resistance to an antibiotic or the ability to glow in the dark or fluoresce. Restriction enzymes cut DNA into smaller pieces, a key component to the more complex technique of DNA cloning. PCR is a method of copying and amplifying small, specific segments of DNA. This technique is commonly used in forensics to identify individuals, but has also been used for a number of applications in biotechnology (Scheppler et al, 2000). These three techniques can serve as the core hands-on portion of a class and used to provide fundamental information about the more complex technologies (figure 1).

Cancer can be used as a platform from which to examine the tools of biotechnology as they are employed by a society entering into the molecular biology age. Early in the course, students are assigned a group final project (figure 2) in which they must write and present a story of a fictitious relative who died from cancer, *A Day in the Life*. The twist is that the relative lived in our present time, but the students are to write from a perspective of looking back from the year 2061. Students create three days in the life of this cancer patient: the day of diagnosis, the last birthday, and the day before dying. From this future perspective, they are then to discuss how the cancer of their fictitious relative can be cured. This assignment gives a context for learning normal cell physiology, the genetic changes that result in tumorigenesis, as well as DNA manipulation. It also addresses the social impact of technology on individuals in society. Students are thus able to relate a rich story built with support from their accumulated knowledge of biotechnology from an historical perspective of technology, and begin to find their own place in our technological society.

Understanding the molecular processes that result in cancer can be central to the science of the biotechnology course. Students study the cell as it properly functions and as it changes through tumorigenesis. Simultaneously, students encounter the tools of biotechnology, such as manipulations of DNA, molecular cloning, and PCR. By understanding the applications of biotechnology, students will be better able to answer questions about cancer and to understand the

processes that are used to gather information relevant to cancer causes and treatments.

Genetically modified organisms (GMO) provide a different aspect for written work. The bacterial transformation laboratory serves as a basis for understanding gene transfer. Students are given the assignment to choose a GMO and provide a written response to the following questions:

1. Describe in what way the genetic material of the organism is modified. This means writing more than " a gene was cut out of one organism and placed in another." Provide some scientific explanation.
2. Describe the new characteristic that the organism has as a result of modification, including how the organism may be used in a new way.
3. Given our limited understanding of the effects that GMOs have on the environment, how can we make decisions about their use? What are the criteria that should be applied and who is responsible for the decision?

Another way in which students can come to understand the social implications of biotechnology is by reading imaginative literature that offers commentary on our cultural values system. For example, Edward Bellamy's technological utopia described in *Looking Backward, 2000-1887* (1881) and Kurt Vonnegut, Jr.'s technological dystopia set in *Piano Player* (1952) establish two very different sociological poles for our consideration. Bellamy portrays a society where technology is the solution to all problems from inequality to urban blight.

Vonnegut, on the other hand, devises a foreboding, mechanized human society where only those intellectually worthy of engineering or mechanics have any freedom to make decisions that we would consider to be inalienable rights. Examining the poles of society's technological values system offered by these authors aids students in understanding the individual and cultural values systems operational in the application of technology in western culture and the place of the individual in a technological society.

We have used a biotechnology course to introduce students to scientific inquiry by incorporating an investigation into the course. At the beginning of the semester, students are informed that they will have the last quarter to pursue a laboratory project. While they are learning some of the basics, they begin to formulate a research plan. They are expected to submit a proposal detailing what they plan on accomplishing. This helps them focus as well as providing the instructor with a list of reagents and supplies to be ordered. Some students will devise very imaginative and original projects, while others will struggle with the freedom of owning and directing their own learning. Some students use the Internet as a source of ideas and protocols while others will stick to conducting a more advanced laboratory from the text. All students have enormous goals. The instructor's role is partly that of expert colleague, but also that of a cheerleader, rewarding what the students perceive as small achievements, promoting student confidence in the laboratory and with their own analytical abilities.

**Biotechnology for Middle School**

Middle school students are very capable of conducting the same basic laboratories, bacterial transformation, restriction enzyme analysis of DNA, and PCR, as high school students. The content material provided is just not as complex and additional background material will need to be covered, such as the basics of DNA. But making bacteria glow in the dark or seeing their own DNA on a gel is a sure way of gaining students interest and attention. They are also capable of writing assignments and reading such books as *Eva* and *The Giver*.

**Biotechnology Resources**

Biotechnology can be a very challenging topic to teach. Teachers with many years of experience may not have encountered the discipline simply because it was not part of their science education. Newer teachers may have had the opportunity to perform one or two standard hands-on laboratories in undergraduate or graduate courses, but they may not have been exposed to these laboratories in a way that helped them understand how to teach them.

The past ten years has seen the advent of an increasing number of resources for teaching biotechnology ranging from texts (Alcamo, 2000; Glick and Pasternak, 2003; Kreuzer and Massey, 2001; NABT, 2002) and laboratory manuals (Bloom et al, 1996; Scheppler et al, 2000) to centers devoted to biotechnology education and scientific companies that are supportive with useful kits and affordable equipment (figure 3). Some of these companies, as well as

other educators, offer workshops at the National Association of Biology Teachers (NABT) and National Science Teachers' Association (NSTA) national meetings and other places.

The equipment and materials for basic biotechnology are becoming common in college and university undergraduate courses. Teachers will find local university partners very willing to share resources, knowledge, and perhaps even willing to host a class field trip for a hands-on laboratory. Some university faculty members also offer summer hands-on workshops designed specifically for teachers.

Biotechnology is a field that has been with humankind for a long time and will continue to have a huge impact on our lives and the lives of our future generations. Whether someone is a biologist, physicist, poet, policeman, lawyer, or CEO of a large corporation will not lessen the profound influence that this technology will have on her life. Her education, however, will determine whether it is used wisely and expeditiously and whether she can make informed choices for her own well being.

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**Figure 1 Teachable Moments**

**Bacterial Transformation**

- Eucaryotes versus prokaryotes
- Evolution
- Drug resistance
- Gene therapy
- Genetically modified organisms

**Restriction Enzyme Analysis of DNA**

- DNA structure and function
- Enzyme structure and function
- Gel electrophoresis

**Polymerase Chain Reaction**

- DNA structure and replication
- Genetics and heredity
- Forensics

**Figure 2: A Day in the Life …**

**Scenario**: The year is 2061 and you and the remaining members of your family have just returned from your annual reunion with a surprise discovery, a journal of one of your great-grandparents. Three entries in the journal particularly inspire your passion for the story of this family member who came before you: the day he/she was diagnosed with cancer, his/her last birthday, and the day before he/she died of cancer. The entry on the day of diagnosis tells you the technology applied to him/her as a patient. The birthday entry tells you the everyday events in the life of an individual. The entry on his/her last day tells you about reflections on the valued place of a living, thinking, cancer-stricken individual in society. You realize the truth of these entries is a measure of the society in which your great-grandparent lived.

**Personal data items**

| | **Agnes Li** | **Sunshine Carter** | **Ajay Reddy** | **Stanley Miles** |
|---|---|---|---|---|
| **Born** | **April 7, 1939** | **January 15, 1968** | **April 23, 1942** | **March 27, 1945** |
| **Died** | **December 4, 2003** | **December 5, 2003** | **December 8, 2003** | **December 9, 2003** |
| **Profession** | **Restaurateur** | **Actress/receptionist** | **Doctor** | **Farmer** |
| **Cause of Death** | **Lung cancer and associated complications** | **Breast cancer and associated complications** | **Colorectal cancer and associated complications** | **Malignant melanoma and associated complications** |

**Your assignment:** You have 45 minutes to relate these days in the life of your relative to your colleagues. In particular, pay close attention to the effect of technology on the life of the individual. Remember: your perspective is from the

year 2061, whatever you consider 2061 will become. Also, submit a ten to fifteen page paper supporting and complementing, not reiterating, your presentation. Please provide twenty to thirty references.

**Figure 3: Biotechnology Resources**

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|---|---|---|
| Access Excellence | www.accessexcellence.org | Teacher-developed curriculum ideas and other on-line resources |
| Biotechnology Institute | www.biotechinstitute.org | Publishes *Your World, Our World* magazine for students |
| Biotechnology Industry Organization | www.bio.org | On-line industry information, lists state biotechnology organizations |
| Bio-Rad | www.biorad.com | Scientific company with educational division offering kits, equipment, and workshops |
| Carolina Biologicals | www.carolina.com | Educational company offering kits and equipment |
| DNA Learning Center | www.dnalc.org | Offers workshops for teachers and on-site labs for students |
| Edvotek | www.edvotek.com | Educational company offering kits, equipment, and workshops |
| Foto-Dyne, Inc. | www.fotodyne.com | Scientific company supporting biotechnology education and offering equipment and kits |
| Modern Biology | www.modernbio.com | Educational company offering kits |
| New England Biolabs | www.neb.com | Scientific company supportive of biotechnology education |
| Wards | www.wardsci.com | Educational company offering kits, equipment, and works |