Students, teachers and the impact of biotechnology on the community

Renato A Schibeci
School of Education
Murdoch University
Murdoch Western Australia

Associate Professor Renato Scibeci’s main research interest is in the public understanding of science and technology, including biotechnology. He is on the staff of the School of Education at Murdoch University, WA. He taught science and mathematics in NSW schools before moving to his present position, where he teaches units in science education and educational technology.

Abstract

Who could have foreseen the revolution in molecular biology? This article reviews some ways in which developments in biotechnology can be used to explore both the biology and the social impact of this science on the wider community. A specific example is included to help students explore the ramifications of biotechnology applied to human medicine, specifically, gene therapy in cystic fibrosis.

‘We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A). This structure has novel features which are of considerable biological interest.’

Thus began what must surely be one of the most important scientific papers of this century, in which Watson and Crick (1953) proposed a structure for DNA. Who could have foreseen the revolution in molecular biology which followed this elucidation of the structure of DNA? A recent editorial in the *Journal of Biological Education* described biology as ‘the science of the millennium’ (Phoenix, 2000); others (eg Rifkin, 1998) have been more specific: they say we are entering the ‘age of biotechnology’.

The development of biotechnology highlights the impact of science and technology on the community. This impact of science is, of course, not new, but it has been brought into sharp focus by many recent developments in this burgeoning science.

The purpose of this paper is to review approaches which can help teachers help their students deal with social, ethical and political issues related to developments in biotechnology. These approaches can help students appreciate the impact of science and technology on the community in one specific and important context.

Introduction

Biotechnology has become a vital factor in national strategies for economic development into the twenty-first century: many nations have declared it to be an essential technology area in achieving international competitiveness and sustained economic growth (Australian Science and Technology Council, 1993). Biotechnology Australia, a Commonwealth government agency established in 1999, provided a more recent view:

Biotechnology is a rapidly developing technology, with diverse applications and with the potential to generate major economic, health and environmental benefits. It is likely to play a key role in Australia’s future prosperity. (Biotechnology Australia, 2000a, p3)

Biotechnology Australia (2000b) quotes the Commonwealth government’s vision for biotechnology as follows:

Consistent with safeguarding human health and ensuring environmental protection, that Australia captures the benefits of biotechnology for the Australian community, industry and the environment. (p7)

Given its importance, biotechnology provides a powerful vehicle for analysing the impact of science and technology on the community in the context of an important scientific development. In particular, there are obvious links between biotechnology and the *Working Scientifically* strand of the national science statement (Curriculum Corporation, 1994), especially in the substrands using science and acting responsibly. There are also links to the *Life and Living* strand, especially ‘biodiversity, change and continuity’.
What is biotechnology?

Before you read any further, jot down your own view of what biotechnology is....

Developing a view of what constitutes biotechnology is an important activity for both teachers and students. There are at least two hotly contested views. One is that biotechnology is an extension of technology which has been used by humans for millennia; that is it is an extension of bread- and wine-making, both regarded as 'biotechnology' activities. The other view is that the modern developments involving the direct manipulation of genes are quite different from earlier applications of biotechnology.

Students can engage with this issue by undertaking an activity such as:
Using a dictionary, science textbook, science dictionary and the Web to answer the following questions and find examples of each.

- What is biotechnology?
- What is genetic engineering?
- What is gene technology?

The first use of the word biotechnology may have been in 1919, when an agricultural economist used the word to mean the interaction of biology with technology, connoting all production using biological transformations [Kennedy, 1991].

Lucassen (1995) noted that biotechnology refers to a wide variety of activities. Sometimes it is used to indicate activities involving any practical use of living organisms, and at other times it is used to refer to activities involving the use of genetic methods to modify inherited characteristics. This hints at the reality that biotechnology is a complex and contested term. It is not surprising that public surveys reveal that there is considerable confusion and uncertainty about the terms biotechnology and genetic engineering. A survey of over 2,000 adults in New Zealand, for example, revealed that while 57 per cent of respondents had heard of the term biotechnology, only nine per cent could explain what it meant (Couchman and Fink-Jensen, 1990). Replacing the term biotechnology with genetic engineering in some surveys of community perceptions resulted in significantly lower levels of support (Davison, Barns and Schibeci, 1997).

As part of an investigation of perceptions of biotechnology (Schibeci and Barns, 1999) university students were asked the meaning of biotechnology. Among the sample were nineteen first and third year biotechnology students and eighteen students involved in various science and society programs. Despite the reasonable science background of most of the students in the sample, seven had little idea about the meaning of biotechnology. When asked to nominate examples of products which have been the subject of biotechnological research, a range of responses was given. Ten were unable to cite an example, or were very vague. The remainder were able to cite examples such as disease-resistant crops and vaccines produced by genetic engineering. One applied science student responded:

"Well, I guess it is all the antibiotics. I mean that is with biotechnology. Pesticides. Probably the wine, or the fermentation industry, could be where you have got biotechnology. Germ warfare. Warfare is another one. I mean, there is some discussion about that and cattle breeding - biotechnology breeding. Or any sort of animal breeding. Artificial insemination. Those areas."

Definitions of biotechnology given by students in this group include:

- Well Technology is, you know, instruments and stuff like that, and bio is sort of like, biology, so I suppose it is something to do with technology concerning biology. Or you know, developments in that respect.
- It is sort of the scientific manipulation of genes to learn about technology, that we see is useful to us.
- You do genetic engineering, you do the molecular side of things, you do processes, such as a product. Products such as antibiotics and pharmaceuticals as well as bio processes like vinegar production and beer and stuff like that.

There appears to be two broadly distinct uses of the term biotechnology. One refers to a long tradition of modifying the characteristics of various life-forms to make them more useful to humans: in this view, modern biotechnologies are a continuation of practices going back to the Babylonians, and do not represent a radical break with the past. The food industry is the oldest and largest user of these biotechnological processes, which include traditional areas such as cheesemaking, fermenting and brewing to produce alcoholic drinks, and breadmaking. The other view, represented particularly by anti-biotechnology activists such as Rifkin (1991), is that biotechnology is a radically new field in which molecular biology has given humans unprecedented powers of genetic manipulation. Biotechnology allows us to modify nature; this capacity needs to be exercised cautiously.
It is useful for students to distinguish between uses which involve direct gene manipulation and other forms of biotechnology. The Australian Science and Technology Council (1993) has used the term gene technology which avoids negative connotations associated in the minds of many with genetic engineering. The specific term gene technology can be used to refer to modern technologies that involve the direct modification of genetic material.

The social impact of biotechnology: some approaches

Lucassen (1995) outlined one approach to help undergraduate students discuss ethical issues by providing a set of statements to groups of three or four students and invited them to rank the statements 'in order of acceptability'. The statements, under four headings, related to genetic engineering of microorganisms, animals, plants and human disease. Lucassen reported that 'students had differing opinions' which resulted from the relative weighting they gave to four aspects of genetic engineering: its purpose, its safety, its impact on animal suffering, its impact on the 'sanctity' of human life, and, 'the principle that we should not tamper with nature at all' (p137).

Clark (1997) advocated a discussion, in the context of a genetics course, of genetic testing and its implications. This research outlines the context of this debate: a discussion of a 'smoking gene' which was reported in the media, but not in a scientific journal. Six different viewpoints are suggested for students to consider: the genetic expert, the former smoker expecting a child, the president of a tobacco company, the president of an insurance company, the civil rights lawyer and the newspaper columnist. Further reading is provided for students to consult.

Herreid (1996) suggests the use of a 'structured controversy' to highlight some of the issues in the use of DNA fingerprinting in forensic science. There is less emphasis here on the wider social issues. Rubenstein, Anderson and Hall (1996) suggest a somewhat more dramatic way to highlight some of the difficulties through a murder-mystery play.

In addition to these sources, studies of attitudes to biotechnology have also been undertaken. The research program on public perceptions of biotechnology undertaken by the author (Schipeci, 1999) has used various approaches to help adults articulate their views (see, for example, Schipeci, Barns, Kennealy and Davison, 1997; Davison et al., 1997). Most recently this involved a scenario as a way to contextualise the issue of biotechnology. In the scenarios, participants imagine they are one of a couple contemplating having a child, given the possibility of the child being born with cystic fibrosis, a genetic disorder.

This study is one of the few reported investigations in Australia. Science teachers from 15 primary schools and 57 high schools participated in the workshops. They were all asked, individually, to respond to the question, "Do you think that human gene technology is generally a positive or negative development?" The overwhelming majority (93%) of high school teachers regarded this as a generally positive development. Fewer primary school teachers were positive (73%). These studies begin to build up a picture of what students and teachers think about biotechnology.

Biotechnology and human medicine: the case of cystic fibrosis

To make the issues related to biotechnology and human medicine more 'real', the research used a range of case studies such as cystic fibrosis. Initially a brief overview of cystic fibrosis is provided and then suggestions are provided about classroom exercises based on this specific example.

An overview of cystic fibrosis

Cystic fibrosis is a chronic disease of varying severity. It mainly affects the lungs and digestive system. People with cystic fibrosis experience, in varying degrees, impaired function of their lungs, digestive system, pancreas and perspiration.

Sufferers of cystic fibrosis have large amounts of thick, sticky mucus in their lungs, which makes breathing difficult. The mucus clogs their airways and traps bacteria. They have chronic lung infections, and their natural defences not only destroy the invading organism but their lung tissue as well. Permanent lung damage occurs with repeated infections and blockages, and lung function deteriorates progressively. The symptoms were described last century, and affected newborn babies did not survive long. Few children survived to school age. The symptoms include persistent coughing, particularly after physical effort, wheezing or difficulty in breathing, chest pain, tiredness, lethargy or an impaired exercise ability, frequent visits to the toilet, salt loss in hot weather which may produce weakness, abdominal pain, poor appetite or weight loss despite a hearty appetite.
New approaches to treatment have improved prospects for sufferers. Early diagnosis, testing for symptoms and aggressive treatment have helped delay the progression of the disease. There is no cure. Sufferers born today have a life expectancy of about 30 years. To fight lung infections, people with cystic fibrosis are prescribed aggressive courses of antibiotics. Therapy also includes the use of bronchodilators such as ventolin ‘puffers’ and oxygen, as well as at least daily chest physiotherapy regimes and exercise. (Cystic Fibrosis and Cystic Fibrosis Carrier Testing pamphlet from Genetic Services of Western Australia)

High nutrition levels must be maintained and some children with poor pancreas function may need fifty per cent more calories than the average child of their age and also may require daily enzyme supplements for the digestion of food. Many heart and lung transplants are given to people with severe cases of the disease.

Cystic fibrosis is an inherited genetic disorder. Genetic mutations can cause severe or mild forms of the disease. People with cystic fibrosis have inherited two mutated copies of the gene which controls the production of a protein which in turn controls the removal of salt from cells. This protein is called the cystic fibrosis transmembrane regulating protein (CFTR).

CFTR protein has been found in the pancreas, sweat glands, lungs, intestines and reproductive tract. This protein is known to regulate the flow of salt and fluid across cell membranes. Without normal CFTR protein, the functions of specific organs are disrupted. For example, the transport of water and salt across cell membranes in the lung wall is blocked. The result is a build-up of thick, sticky mucus.

Possible classroom exercises

Predicting offspring
Knowledge of inheritance can be reviewed by predicting the occurrence of cystic fibrosis in children of parents with different genotypes. Those with CF have inherited two alleles for the CF gene, one from each parent, who, although not showing any symptoms of cystic fibrosis, are both carriers of the disease. In Australia one in every 25 people is a carrier of the allele for the CF gene. There are 20,000 people with cystic fibrosis in the United States, 7,000 in Britain, and some 2,300 sufferers in Australia.

Humans can have two alleles: a ‘normal’ allele, and an allele for CF. A person with CF will have two copies of the CF gene (homozygous): a ‘carrier’ will have the ‘normal’ allele, as well as the CF allele (heterozygous). A ‘normal’ person has a double dose of the ‘normal’ allele (homozygous). A revision of the genetics of CF can be undertaken by using examples, such as:

- If both mother and father are ‘carriers’, what percentage of children will be healthy and not carriers? healthy and carriers? ‘normal’?
- If one of the parents is a carrier and the other ‘normal’, what percentage of children will be healthy and not carriers? healthy and carriers? ‘normal’?

Exploring options
Once the genetics of CF have been established, it may be appropriate to explore some of the social and ethical implications, for example:

1) A test is available to see if the developing foetus has the CF phenotype.
   - Should parents with a history of CF in their families have the foetus tested?
   - Why or why not?
   - Should this be a decision for individual parents? Should society decide?

2) If a child were born with cystic fibrosis, would you agree to use a new therapy consisting of a monthly inhalation of a genetically modified virus to help clear the child’s lungs? Why or why not?

The issues here are clearly sensitive and discretion needs to be exercised before in engaging in a discussion of these issues.

The scenarios above were used with three different groups of science teachers in professional development workshops. It is important to allow individuals to write down their own views before any group discussions, to avoid individuals being ‘swept up’ by the views of those who may be more articulate.

Students and teachers views
Michael, Grinyer and Turner (1997) analysed the views of a sample of sixteen teachers (fifteen of them biology teachers) in Ireland. These views, which resulted from focus group interviews, found that the teachers emphasise the ‘pure’ science of biotechnology. They point out, however, that ‘teachers do engage with ethical and practical uncertainties of science and technology’. Clearly, there is ambivalence at work here.
Lock, Miles and Hughes (1995) in the UK investigated the influence of teaching on the knowledge and attitude of 188 students in six schools. They reported a general approval for genetic engineering involving microbes and plants. In the case of genetic engineering of animals, there was more uncertainty among students. Further, teaching resulted in increased knowledge levels and less student uncertainty about attitudes. Finally, they reported that female students are generally more unsure of their view on genetic engineering than male students.

Gunter, Kinderlerer & Bey leveled (1991) surveyed British teenagers’ views of biotechnology, especially related to food products. They reported that teenagers were not more aware of biotechnology than older age groups. One difference between teenagers and older respondents was that young people were consistently less pessimistic about net risks.

**Biotechnology and Australia**

The Australian Government’s discussion paper, *Developing Australia’s biotechnology future* (http://www.isr.gov.au/ba/) noted:

Advances in biotechnology offer substantial opportunities for social and economic benefits that will improve the quality of life of Australians. Biotechnology is the application of biological processes to make products that are useful to society, some of which include food, medicine and chemical compounds. Biotechnology is providing improvements in health care and the treatment of disease, and offering greater efficiency in agriculture with improved agricultural and food products, new processes and products in industry and more efficient mineral processing. Many of these applications benefit the environment through the reduced use or production of toxic chemicals. The environment may also benefit from applications which have the potential to reduce emissions of greenhouse gases and which enable the removal of such gases from the atmosphere. Biotechnology is expected to become a key driving force in economic growth and employment over the next 30 years, offering broad development opportunities for the nation, based on our considerable strengths in research, particularly in agricultural and medical research. It also has the potential to help enhance and protect the future competitiveness of major sectors of economic and export activity, including agriculture, health care and pharmaceuticals, mining and manufacturing. (p. i)

Commonwealth, State and Territory Governments of Australia are committed to protecting public health and the environment through management of any risks associated with biotechnology. Governments have worked together to ensure that Australia has a rigorous system of regulatory controls for managing these risks, putting health and safety of the public and environmental protection as paramount considerations. One of the ways governments are meeting this objective is by establishing and maintaining the regulatory bodies for food, therapeutic goods, border control, agricultural and veterinary chemicals and other genetically modified organisms] independent of the Government’s industry programs. The regulatory arrangements have been the subject of extensive consultation between the Commonwealth and State and Territory governments and have taken into account the views expressed by interested parties to date. Regulatory systems will not be addressed in detail in the development of the biotechnology strategy and comments are not being sought through this Discussion Paper. However, the effectiveness of regulation and its impact on commercialisation of biotechnology is a long-term issue that needs to be understood by the community and remain under review. (p. ii)

Clearly, an exploration of the impact of biotechnology on the community provides an ideal vehicle for exploring science–community interactions, highlighted in this discussion paper. Biotechnology is one of those areas of science which allow teachers to explore fully this impact of science beyond the laboratory.

**Biotechnology in the classroom**

There are many resources for teachers of high school and university students to access. Russell (1997), describes two investigations which illustrate DNA cloning principles safely, and Bauer (1998), who presents a procedure for studying DNA repair. Classroom exercises outside the laboratory can be found in Burns (1995), which provides an exercise in DNA fingerprinting, while Bohrer (1997) and Britton and Wanderssee (1997) describe classroom aids to help students visualise key processes in DNA technology.

All of these exercises would provide a context for emphasising the social impact of biotechnology. This is preferable to devoting a special unit to ethics or the social implications of science. One of these experiments or classroom exercises could be used as a lead-in to discuss the social impact of the science.
Numerous websites also provide useful information: the Genetics Education Centre at the University of Kansas Medical Center http://www.kumc.edu/gec/#resource; the National Centre for Biotechnology Education at the University of Reading, UK; the Irish Biotechnology Information Centre http://www.ul.ie/~biotech/page3.html; the Consensus Conference on genetically modified foods held in March 1999 at http://www2.abc.net.au/science/slab/conconf/ and the CSIRO’s biotechnology web site at http://genetech.csiro.au/.

References


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