# Genetically Modified Crops

## Resources for Environmental Literacy

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Environmental Literacy Council
National Science Teachers Association

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# Contents

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# Competing Images of Biotechnology

Boy eating orange-fleshed sweet potato rich in beta-carotene. Scientists are using genetic modification to enhance the drought and disease tolerance of the orange-fleshed potato in order to enable the more nutrient-rich variety to grow in the arid lands of developing countries.

Source: Image © International Potato Center (CIP) 2006; *(www.ifpri.org/media/HPNairobi/BoyEating_OFSP.jpg).*


Greenpeace climbers hang a banner on the front of the Hotel Cavalieri Hilton in Rome, where food industry executives were meeting for the World Food Business Summit in June 2004.

Source: Image © Greenpeace / Alessandro Vasari

# Preface

The primary responsibility of teachers of science is to teach science, not to inform their students on environmental issues—and certainly not to influence the stand students may take on those issues. Fostering student understanding of the scientific view of the natural world and how science goes about its work is the first order of business in the teaching of science.

Nevertheless, experienced science teachers—backed by research on learning—know that most students do better when they see how the science they are studying helps them to understand “practical” things that matter to them. Thus, it makes sense to organize science teaching contextually from time to time, that is, to treat the science content from a “real-world” perspective. Many such contexts exist, including inquiry, mathematics, health, sports, technology, history, biography, art, and other cross-cutting themes, such as scale, systems, constancy and change, and models. It is the contention of this project that the environment is another such context, and a particularly important one at that.

Environmental issues and concerns provide a particularly attractive context for teaching various scientific concepts and skills. That belief is what motivated the Environmental Literacy Council (ELC) and the National Science Teachers Association (NSTA) to join forces in developing this set of science/environment modules for teachers. From an educational perspective, science learning and environmental understanding effectively complement each other in two ways:

- The environmental context can improve science learning.
- Learning science can improve the ability of students to deal with environmental issues.

Another way of putting this is that studying science in the context of the environment is doubly productive. It shows how scientific knowledge and ways of thinking, coupled with the process of making decisions about our collective interaction with nature, can illuminate each other to the advantage of both.

—F. James Rutherford
Environmental Literacy Council

# Introduction

Genetic engineering involves the manipulation of genes within a species, and may also involve the transfer of genes—and thus the characteristics governed by those genes—from one species to another. Genetic engineering goals in plants include flower color and in agriculture include improving crop production and introducing new traits, such as enhanced nutrients, temperature resistance, or the ability to grow in saltier soils. Certain characteristics may allow a genetically modified (GM) crop to be grown, harvested, or shipped at lower cost or with less damage and may allow the crop to be grown using less pesticide. In some cases, GM crops may yield entirely new products that are not normally derived from traditional crops—such as medicines.

Source: Rebecca Hulse and R. Rajagopal, U.S. Geological Survey.

Supporters of this technology point to the potential of GM crops to improve human health and increase environmental protection. However, some concerned groups and individuals have argued that the risks of GM crops may outweigh their benefits. These groups urge avoiding GM crops or, at the very least, subjecting them to more rigorous scrutiny by government regulators.

The issues surrounding the genetic engineering of crops can be a powerful learning context for teaching ideas about the nature of science, genetics, and the use of technology, allowing students to connect and apply what they are learning to real-world issues that affect their lives. Students can also develop an awareness of an important environmental issue while seeing how science and technology interact and influence one another and how they relate to social issues and decision making.

The purpose of this module is not to assess whether GM crops are good or bad—or whether they require additional regulation—but rather to provide a useful resource for promoting student understanding of specific scientific ideas and the value of science in thinking through environmental issues. To help teachers tap the potential of using GM crops as a learning context and access the resources they need more readily, this module addresses five essential questions:

1. What is the science involved in the genetic engineering of crops?
2. How is genetic engineering different from more traditional genetic manipulations, such as hybridization?
3. What steps are usually involved in genetically modifying a crop?
4. What are the known or projected risks and benefits of genetically modifying crops?
5. Under what conditions, if any, should crop biotechnology be pursued?

The sequence of the essential questions is intentional and important to preserve. It moves from the science and technology that underlie genetic engineering to a consideration of the possible risks and benefits associated with GM crops. This is intended to foster a more thoughtful way of approaching complex environmental issues without leading students to particular decisions regarding the issue. It is, after all, very important that students learn to draw their own conclusions with regard to the desirability of genetically engineered crops, doing so based on an understanding of the relevant science and technology, in addition to their own social, economic, and personal considerations.

The next section of this module presents "Student Learning Goals". Good instruction usually begins with a clear picture of what "take-away" learning we want students to acquire—the understandings and ways of thinking that will remain with them long after the details of instruction have been forgotten. The learning goals for this module, which are selected from *Benchmarks for Science Literacy* (American Association for the Advancement of Science 1993) and *National Science Education Standards* (National Research Council 1996), assume student familiarity with the molecular basis of heredity. You may want to administer a pretest to assess the readiness of your students to undertake this module.

The learning goals are followed by the "Background Content for Teachers" section, which summarizes useful scientific and environmental information and is organized with reference to the essential questions. The "Teaching Approach" section includes an overview of possible student activities, suggestions regarding potential student misconceptions, commentary on assessing student learning, and some recommended resources.

The module concludes with four student activities. These activities are presented as examples and therefore may be replaced with other activities, as appropriate. Some of the activities involve student handouts (instructions or readings), which are found in the "Student Materials" section.

# About the Authors

The **Environmental Literacy Council** is a nonprofit organization dedicated to improving the knowledge base of K–12 teachers in environment-related sciences. Its membership—drawn from the life, physical, Earth, mathematical, and social sciences of prestigious institutions—reflects the cross-disciplinary nature of environmental concerns.

The **National Science Teachers Association** is the oldest national association of science educators in America and the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all.

This material is based upon work supported by the National Science Foundation under Grant No. ESI-0243521. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Responsibility for the content and design rests with the Environmental Literacy Council and the National Science Teachers Association.

*Disclaimer:* The opinions, findings, conclusions, and recommendations expressed in *Resources for Environmental Literacy* are those of the Environmental Literacy Council and the National Science Teachers Association and may or may not conform to the individual viewpoints of each organization's members or staff on either current or historical events, or their impacts on the environment.

# Dedication

This publication is dedicated to the memory of **Kathleen B. deBettencourt**. She was known for her dedication to the preservation of our environment through a better understanding of science, for being extraordinarily informed on the connections between science and responsible environmental stewardship, and as a leader in environmental education with a keen ability to collaborate effectively with others. As the founding executive director of the Environmental Literacy Council, Kathleen was innovative and tireless in advancing the Council's goals. To those of us fortunate to have worked with her, she was both an admired colleague and dear friend.

# Student Learning Goals

*Benchmarks for Science Literacy* and *National Science Education Standards* describe core biology content appropriate for all students. They do not dictate instruction, but rather articulate some key ideas and skills students should be left with after their learning experiences are complete. There is considerable overlap between science learning goals as expressed in the two documents; however, since some teachers choose to use one over the other, both are presented here.

Although these documents do not list specific risks and benefits of GM crops, they do suggest that students understand some general ideas about benefits, risks, and trade-offs in the use of technology—especially as they relate to ecosystems. Although both documents contain a variety of learning goals on aspects of science, technology, and society, they are not all listed here. Only those that relate best to the expected learning outcomes of this module are included.

## From *Benchmarks for Science Literacy*

- New varieties of farm plants and animals have been engineered by manipulating their genetic instructions to produce new characteristics. (p.186)
- Agricultural technology requires trade-offs between increased production and environmental harm and between efficient production and social values. In the past century, agricultural technology led to a huge shift of population from farms to cities and a great change in how people live and work. (p. 186)
- In deciding on proposals to introduce new technologies or to curtail existing ones, some key questions arise concerning alternatives, risks, costs, and benefits. What alternative ways are there to achieve the same ends, and how do the alternatives compare to the plan being put forward? Who benefits and who suffers? What are the financial and social costs, do they change over time, and who bears them? What are the risks associated with using (or not using) the new technology, how serious are they, and who is in jeopardy? What human, material, and energy resources will be needed to build, install, operate, maintain, and replace the new technology, and where will they come from? How will the new technology and its waste products be disposed of and at what costs? (p. 57)
- Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological factors as well as scientific ones. (p. 52)
- Benefits and costs of proposed choices include consequences that are long-term as well as short-term, indirect as well as direct. The more remote the consequences of a per-

sonal or social decision, the harder it usually is to take them into account in considering alternatives. Benefits and costs may be difficult to estimate. (p. 166)

## From *National Science Education Standards*

- Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations. (p. 199)
- Understanding basic concepts and principles of science and technology should precede active debate about economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges. (p. 199)
- Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of the basic questions: "What can happen?" "What are the odds?" and "How do scientists and engineers know what will happen?" (p. 199)

### References

American Association for the Advancement of Science. 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

National Research Council. 1996. *National science education standards.* Washington, DC: National Academy Press.

# Background Content for Teachers

Ideas and issues that can serve as background knowledge are summarized in this section for teachers. It is not intended to be comprehensive, but can easily be supplemented by reference books and websites listed under "Recommended Resources" in the "Teaching Approach" section of the module. Although this material is intended for teachers, some of the ideas presented might also be useful in the course of instruction for the students. However, it is highly recommended that the student learning goals be emphasized when thinking about the core content that is most important for students to understand.

## Essential Question 1:

### *What Is the Science Involved in the Genetic Engineering of Crops?*

*Deoxyribonucleic acid (DNA)* is found in all living things (see Figure 1). It is a complex self-replicating molecule used by cells to pass hereditary characteristics, or traits, from generation to generation. It carries information that an organism needs to make protein molecules—the structural and functional constituents of the cell. *Proteins* are long chains composed of smaller molecules called amino acids. The type and order of the amino acids—there are 20 different kinds—determine how the protein will work in the cell, the structure it will take, or the job it will do. DNA is the blueprint that determines the order of amino acids for any given protein. DNA differs with each species.

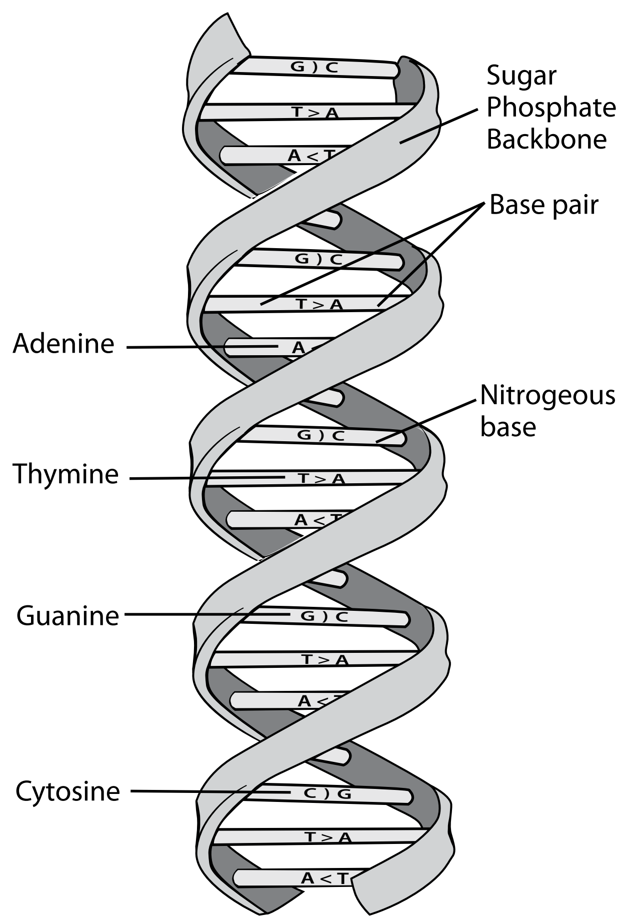


**Figure 1. The Structure of DNA**

Source: National Institutes of Health.

While some protein molecules make up the physical structure of the cell, others—called *enzymes*—do the physical, chemical, and electrical work of the cell. Under proper conditions, enzymes can change their physical shape—they are able to bend, stretch, open, and close—carrying out essential jobs around the cell and even outside of the cell, such as creating and secreting proteins that defend the cells from attack or letting cells communicate with each other. Proteins are also important in the creation of nucleic acids, carbohydrates, and lipids (fats), with which they sometimes work jointly. Therefore, proteins are the key component in determining the characteristics, or traits, of cells and of living things that are made up of many cells. The shape of a leaf formed by a plant is, for instance, determined by the proteins produced by the plant's cells.

The section of DNA that codes for a particular kind of protein is called a *gene.* When a gene is used to actively create proteins, the gene is said to be *expressed*. Some regions of DNA control the genes by either encouraging or preventing their expression. *Promoters,* for example, are regions of DNA that produce the molecules needed for the expression of genes. The promoters control gene expression through complex feedback systems evolved over millions of years.

In a population of any given species, there may be variant copies of a particular gene—called *alleles*—that differ in their expression but produce proteins for the same purpose. New alleles arise when the DNA that codes for a certain protein changes for some reason, such as when an error occurs as the DNA replicates itself in the cell. Alleles may be helpful, harmful, or neutral; what is important to understand is that without alleles—different forms of the same genes—all individuals of the same type (e.g., humans) would look exactly the same. Therefore, alleles introduce diversity into a population.

In plant and animal cells, most DNA is kept inside the nucleus with individual genes arranged on a number of different DNA strands. Each strand, which contains many genes, is called a *chromosome*. Species often differ in the number of chromosomes they carry. Plants, for instance, may have more than two copies of the same chromosome. Humans have 23 pairs of chromosomes, with one half of each pair contributed by each parent, thereby contributing a gene of every type (there are two genes in every cell for each type of protein). The exceptions are the X and Y chromosomes, whose genes determine a child's sex and some other traits.

In bacteria, the primary DNA is a single, long circular strand of genetic material that floats in the cell's cytoplasm. Bacterial cells may also contain working genes on smaller circular or linear strands of DNA called *plasmids*. Although most plasmids are dispensable—meaning the bacterium could survive without them—plasmid genes may code for certain important characteristics from time to time, such as antibiotic resistance, toxin production, or the breaking down of hydrocarbons. In large populations, plasmids may be transferred among bacteria, and hence they have proved to be valuable carriers of DNA in genetic engineering.

## Essential Question 2:

### *How Is Genetic Engineering Different From More Traditional Genetic Manipulations, Such as Hybridization?*

Genes that are moved from one species to another are called *transgenes*. Crop varieties created by *transgenic engineering*—that is, the deliberate human introduction of a gene from one species to another—are often referred to as genetically modified crops, or GM crops (see Figure 2). Although this module focuses on modifying agriculturally important plants, the principles are the same in relation to both animal husbandry and medicine.

Humans have always genetically manipulated crops. This was initially done through *crop selection,* where farmers or other agriculturalists systematically select the seeds of the best crops to sow each year, thus eventually developing strains with alleles that are relatively uniform in producing the desirable traits for which they were selected. Over the past century, as the science of genetics has evolved, crops have been manipulated through *systematic hybridization*. Hybridization developed from the discovery that it was possible to control the heredity of the offspring by controlling the genetic lineage of the parents. Through careful selection—and knowledge of the effects of different kinds of alleles—it has become common to cross male and female plants in order to produce offspring with the desirable characteristics from both parents. Hybridization usually involves the controlled transfer of genes within a species; it normally does not involve the transfer of genes between different species. However intergeneric crosses are sometimes possible and a technique of embryo rescue can provide living progeny that can be propagated. The plant triticale (a cross between rye and wheat) is the most notable crop example.

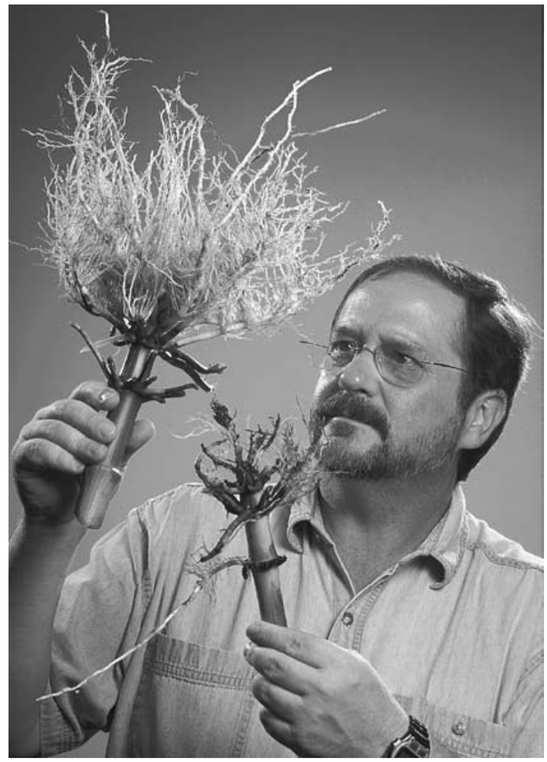

**Figure 2. Entomologist Wade French examines corn roots from plots that have been artificially infested with western corn rootworm. The transgenic root is at left.**

Source: Image by Scott Bauer, U.S. Department of Agriculture.

As with any biotechnology, hybridization is limited in its effects. It can take as long as 15 years to bring a new variety of crop to market using hybridization. In addition, linkages among genes may require trade-offs that can compromise the crop; for example, breeding for traits that result in better appearance or transportability may compromise taste or nutritional value.

In contrast to hybridization, transgenic engineering involves the deliberate transfer of genes between species (although it is possible, and may sometimes be desirable, to transfer genes within a species by using the same techniques). Genes can be transferred from any cells or from any virus; the species do not need to be closely related. The goal is to induce the new host (the cell to which the gene is transferred) to create one or more proteins that it does not naturally produce.

## Essential Question 3:

### *What Steps Are Usually Involved in Genetically Modifying a Crop?*

How do we transfer genes among species? One way that scientists genetically engineer crops is with the use of bacterial plasmids discussed earlier. In 1907, scientists found that a common plant tumor called crown gall (see Figure 3) was caused by the invasion of a bacterium called *Agrobacterium tumefaciens* (Smith and Townsend 1907). In 1977, scientists discovered that the crown gall tumor was caused when plasmids from the bacteria were taken into the DNA of the host plant's cells and expressed (Drummond 1979). By 1983, researchers had modified the plasmids to remove their ability to induce tumors but left them with the ability to incorporate themselves into plant cell DNA, thereby creating a strand of DNA that could be used as a transfer plasmid (Barton and Brill 1983).

**Figure 3. Crown Gall on a Pecan Tree**

Source: Image © Christine L. Case; *(http://smccd.net/accounts/case/biol230/plantge1.html).*

To transfer genes between species, biotechnologists can attach the transgene—along with other necessary genes, including a promoter that induces gene expression in plant cells—to a transfer plasmid. The most common promoter used today is from the cauliflower mosaic virus. *Marker genes*, such as those for antibiotic resistance, are then used to enable direct selection of the transferred genetic material. Despite its original popularity, use of antibiotic resistance as a marker is now being phased out. Europe has outlawed the use of such marker genes in commercial crops, so now it is more common that, even with antibiotic resistance genes, several techniques are subsequently used to eliminate marker genes before commercialization.

Transfer plasmid is constructed in a test tube and then reinserted into the *A. tumefaciens* bacteria, which are then inserted by syringe or enabled to invade the wounded host cells. Once inside their host, they release plasmids which the host cell's DNA takes in to be expressed as if it were part of the host's normal genetic makeup. In fact, it is at this point that they become a part of the plant's genetic makeup. The new DNA cannot be extracted independently of the host DNA and will be passed from generation to generation. This method is currently considered preferable to the gene gun method (see next paragraph) because fewer copies of the gene are inserted into a single cell and more cells survive.

Another bioengineering technique does not make use of plasmids. Instead, the transgene copies and associated genes are painted onto microscopic metal particles and shot into the nucleus of the host cell with a "gene gun." Once the metal particles enter the plant cell nucleus, the transgenic DNA washes off and inserts itself into the host DNA. The host plant cells in these transformation methods are grown as tissue cultures on petri dishes. Since only some of the host cells are actually transformed by the transgene and marker gene, all of the target cells are grown on a medium that contains an antibiotic chemical. The transformed cells resist the antibiotic while the other cells die. They can then be harvested and grown into a tissue mass from which normal plants with the new desired trait can be grown.

One of the first—and still the most widespread—uses of GM crop technology was the development of crops resistant to common insect pests (see Figure 4). *Bacillus thuringiensis* (abbreviated Bt) is a common soil bacterium, and it has been known since 1911 that it can kill flour moths (see *www.bt.ucsd.edu/index.html*). In the 1950s, scientists found the protein that caused this lethal effect and, by the 1980s, a number of different Bt proteins that were capable of killing a variety of insect pests were discovered. Scientists first used modified *A. tumefaciens* plasmids to carry Bt genes, which are lethal to the boll weevil and budworms—common and serious pests for cotton farmers—into cotton plant cells. This effort was an apparent success: after some adjustments, cotton varieties that produced these proteins were producing 10% more cotton, with decreasing use of pesticides, than unaltered cotton varieties (Patlak 2003). Since then, squash, cantaloupe, papaya, and tomato varieties resistant to debilitating plant viruses have been produced by using transgenes from a milder form of the viruses, a process akin to vaccination.

A more recent but also widely used application of transgenic engineering has been herbicide resistance. *Glyphosate* is one of the most common herbicides currently used on crops by farmers in the United States, killing plants by interfering with an essential enzyme in their cells called EPSP synthase (Funke et al. 2006).

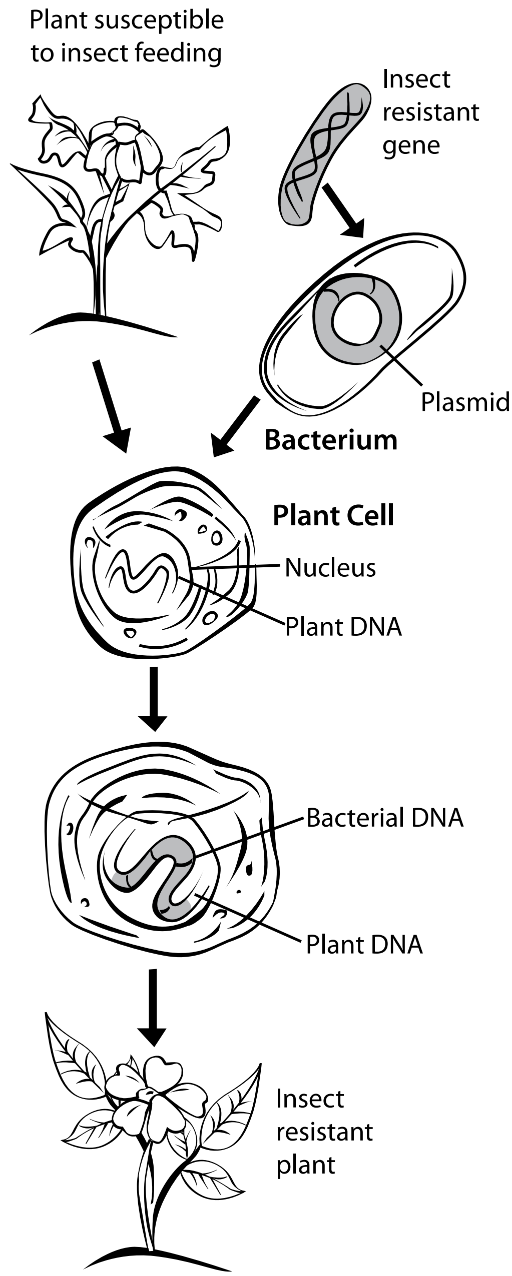


**Figure 4. Process for Creating an Insect-Resistant Plant**

Source: This image is from National 4-H Council's curriculum Field of Genes: Making Sense of Biotechnology in Agriculture and is used with National 4-H Council's permission. It is available on the web at *www.fog.n4h.org*.

Biotechnologists were able to create a modified gene for EPSP synthase that works in the presence of glyphosate. They were able to insert this gene into crops, such as soybeans, creating a variety of plant that could safely be sprayed with glyphosate. This allowed for the spraying of crops and weeds in a more effective manner, using less herbicide to control the weeds. Varieties of cotton, canola, corn, and tomatoes have since been given similar herbicide resistance.

Increased pest and herbicide resistance are but two of the many potential applications of crop bioengineering. Proponents of transgene technology envision a day when plants may produce medicines, industrial oils, plastics, enzymes, drugs, and vaccines. The use of the technology for novelty effects is already occurring—it has produced aquarium fish that glow in the dark (using a gene from a jellyfish) and hairy cacti. Ornamental plants, such as glowing trees—produced by introducing luminescence genes into ornamental plant cells—are feasible and may one day be on the market.

Those wary of GM technology are primarily concerned that the transgenes, once inserted into the DNA of the host plant, cannot be removed. The gene and trait can then be transferred to any plant capable of receiving the pollen of the new crop. Any undesirable effects—especially if discovered well after the new varieties are widely disseminated—could be difficult or even impossible to stop. This is also true for conventionally bred crops.

To prevent GM crop genes from going where they are not wanted, as well as to prevent the unauthorized use and spread of patented GM crops, transgenic engineers can include a *Technology Protection System (TPS)* (see *www.ars.usda.gov/is/br/tps*) in the crops. A TPS is made up of genes that may be mixed and matched from a number of unrelated species that are expressed in series to kill the embryo in the seed of the GM crop. The TPS is inactive during the initial growth of the seeds for the GM crop. However, before the seeds are sold, they are

**Table 1.**

*GM Crops in 2003 in Six Leading Countries*

| Country | Acreage (in millions) |
|---|---|
| United States | 105.7 |
| Argentina | 34.3 |
| Canada | 10.9 |
| Brazil | 7.4 |
| China | 6.9 |
| South Africa | 1.0 |

Source: Agrifood Awareness Australia, Ltd. Biotech Bulletin 5: Global Uptake of GM Crops in 2003. *(www.afaa.com.au/biotechpdf/05_2004_World_GM_Crop_Statistics.pdf)*. Conversion from hectares to acres by author.

soaked in a chemical activator that starts the TPS. Crops from these seeds will express the desired GM trait, but they will not produce seeds that grow if replanted.

The T-GURT (Trait-specific Genetic Use Restriction Technology) system is similar to the TPS except that it shows the desired genetic modification only in the first generation, unless the seeds from the first generation are chemically activated (Eaton and van Tongeren 2002). If the seeds are not activated, the seed will grow but will not express the GM trait. If these seeds accidentally spread or are deliberately harvested and replanted, they will still grow—unlike the TPS seeds—but the GM trait will not show up.

## Essential Question 4:

### *What Are the Known or Projected Risks and Benefits of Genetically Modifying Crops?*

Despite worldwide concerns about the safety and utility of GM crops, the acreage planted worldwide has grown from 4.3 million acres in 1996 to 166.2 million acres in 2003. The six nations with the greatest acreage of GM crops are shown in Table 1. In the United States, nearly half of the soybeans grown in 1999 had a Bt gene conferring resistance to insect pests, and about one-quarter of the corn crop had a Bt gene making it resistant to corn-boring caterpillars (James 2000).

The following subsections list some of the real or potential benefits and risks of GM technology and crops.

### *Potential Benefits*

Many benefits claimed for the growth of GM crops have significant environmental impacts, including reducing the use of pesticides, herbicides, and fertilizers; improving the use of available land, and increasing the recovery and better use of marginal land. Advocates also believe that genetic engineering can produce future specialty crops that are not possible through traditional means.

#### Reduced Pesticide and Herbicide Use

Herbicides and insecticides are expensive, can pollute both the air and water, and may also have negative health effects on those who apply them or work around them. In many less developed countries the lack of safe equipment and training often results in serious health injuries and environmental degradation linked to the use of agricultural chemicals. It is a benefit to all to reduce pesticide and herbicide use.

According to a 2002 report by the National Center for Food and Agricultural Policy (Gianessi et al. 2002), crops developed through biotechnology—variants of soybeans, corn, cotton, papaya, squash, and canola—produced an additional 4 billion pounds of food and fiber on the same acreage, improved farm income by $1.5 billion, and reduced pesticide volume used by 46 million pounds in 2001. According to a report from the Canola Council of Canada, farmers in Canada who used the engineered variety of canola increased their yields by 10% and spent 40% less on herbicides, using less fuel and increasing their incomes by C$5.80 (approximately US$4.98) per acre compared with conventional growers (Canola Council of Canada 2001). Additional studies have verified both gains in production and reductions in pesticide and herbicide use, including reports from less developed countries.

### Reduced Fertilizer Use

Farmers often rotate crops in fields, periodically sowing plants such as alfalfa that are associated with nitrogen-fixing bacteria in their roots. These bacteria are able to capture and fix nitrogen from the atmosphere into a chemical form that plants can use. The nitrogen is released when the alfalfa dies and their roots are plowed under and decay. Over the course of several years, other crop plants use the nitrogen. Absent the use of crop rotation, farmers may spread nitrogen fertilizers, which can pollute local waterways from runoff. Developing GM crops with the capability to live with nitrogen-fixing bacteria or to fix nitrogen themselves could eliminate or lessen the need for fertilizers, thus decreasing pollution.

### Use of Land and Recovery

Since GM crops are usually more productive, producing more food on less land, more marginal lands can be removed from agricultural use, thus reducing erosion and environmental degradation. GM crops can also be developed that would allow for the recovery of land that has already been degraded by overuse, depletion, salinization, or misuse in marginal climates. Desertification could be reduced or even halted by planting with drought-tolerant plants engineered to withstand extreme conditions, providing a "pioneer" stage that would allow less-tolerant native plants to regain a foothold. Land polluted by industrial chemicals or heavy metals could also be recovered by using plants (or bacteria) engineered to take up or break down these chemicals.

### Development of Specialty Crops

Biotechnologists foresee the development of food crops and other agricultural products unlike those we are familiar with today. In the future, crops could be developed that would produce more product with less impact on the environment or would require less space per pound of product. They foresee a kind of "green revolution" that would increase human nutrition and welfare with relatively few health and environmental costs. GM plants might also be developed to yield new medications or even to serve such novel purposes as detecting buried landmines.

## *Potential Risks*

Arguments against GM crops are complex because ecological interactions are themselves complex and because we do not know enough about the interactions of genetic and ecological systems and the potential impact of engineered gene combinations on health. Opposition ranges in intensity from those who want a ban on all activity to those who merely urge greater caution.

Opponents argue that any gains may be offset by eventual losses and that current gains may not be sustainable. Increased resistance, environmental and genetic risks, and threats to human health may result in long-term costs that are unacceptable in relation to the benefits. Social, economic, moral, and ethical concerns must also be considered, and although they are not discussed in detail here, they will be apparent in any web search conducted on this issue.

Some of the more common concerns associated with transgene technology that have been expressed in the scientific literature are identified here. Again, while this discussion focuses on crops, the concerns have broader application to the practice of genetic modification in both medicine and animal husbandry.

## Allergies

One potentially serious concern about transgenic food products is that the modified proteins they contain may cause allergic reactions in susceptible people. For example, a gene from a Brazil nut inserted into soybean or corn could trigger a potentially fatal reaction in someone with severe nut allergies. In principle, all food crops must be shown to be nonallergenic in order to gain regulatory approval; however, regulations—and the ability to enforce them—vary across nations. Under the rules currently operating in the United States, a GM product with a gene from one of the allergy-producing foods must be clearly labeled, unless it can be shown that the protein definitively does not cause an allergic reaction.

There is also the possibility that an allergy-causing protein could show up where it is unexpected due to crop-to-crop genetic drift and mishandling of crops. Allergens may also occur with conventionally bred crops. The StarLink (SL) case provides an example of how this can happen. The SL variety of Bt corn was marketed in the 1990s with a modified protein that was suspected by regulators of being potentially allergenic. Under regulations enforced at the time, the SL variety was approved for commercial sale as animal feed, with the provision that it could not be sold for human consumption. However, in 1999, a survey of 230 farmers who had planted SL corn revealed that 29 had no idea what happened to their corn after its sale and 2 knew the corn had been sold for human consumption (Taylor and Tick 2001). In 2000, DNA from SL corn was detected in taco shells and was later found in a variety of corn products—all of which were removed from supermarket shelves. In addition, although the acreage of SL corn was never large, its DNA was detected in other varieties of non-GM corn, indicating contamination, most likely by windblown pollen.


**Figure 5. Farmers in Spain burn their harvest after it was revealed that their organically grown plants had cross pollinated with nearby fields of genetically engineered maize.**

Source: Image © Greenpeace International; *www.greenpeace.org.*

The political and economic impacts of this case were significant, leading regulators to require that all crops that may potentially be used for human foods be nonallergenic. Although no case of human allergy to SL corn was ever confirmed, it illustrates that gene drift through the food chain can occur.

## Gene Flow

When crops can distribute their pollen easily to other plants, it is more difficult to limit the flow of their transgenes. Broad barriers such as fields planted with other crops or tree belts may help to lessen, but not necessarily eliminate, the gene exchange between plants. Threats to genetic diversity may arise when GM varieties are introduced into geographical areas populated by ancestral types—plants that are genetic forebearers of the domesticated crop (see Figure 5).

This occurred in 2001 when transgenic sequences were reported in native maize in southern Mexico, a major ancestral repository of genetic diversity from which modern corn originated (Quist 2004). Since Mexican law forbids the cultivation of GM corn within its borders in order to protect the ancestral gene pool, any transgenes in the ancestral maize likely originated either from spilled seeds imported for food and feed or from illegally grown GM corn. The impact on the genetic diversity of these land races is not yet known.

Experience shows that when a given crop is a domesticated version of a wild species that grows in the area, its traits may escape into the wild populations. A trait that is desirable in the crop—such as pest resistance—may be undesirable in the ancestral species. Incidents like this have the ability to occur worldwide: with tomatoes in South America, wheat in the Middle East, and soybeans in China.

It also appears that plants may exchange genetic material across some species more often than was previously suspected. In the United States, goat grass is a weed problem in wheat-growing areas. Goat grass is a different species than wheat but it is a distant relative, and a low rate of genetic transfer has already been documented—indicating the possibility that transgenes could have undesirable effects on nontarget species.

## Damage to Animals From Pollen

In 1999, three scientists reported the results of laboratory experiments in which monarch butterfly larvae fed on milkweed leaves dusted with pollen from a Bt corn variety were killed or incurred slow growth (Losey, Rayor, and Carter 1999). Subsequent research demonstrated that the doses of pollen commonly encountered by monarch butterfly larvae in the field were far below those used in this lab study, and field studies did not show similar effects on wild populations from the commonly planted Bt varieties. However, the report did raise the possibility that a lethal protein could affect a nontarget species in undesirable ways through pollen. Because pollen-related allergies are common, the possibility that serious allergens could be transmitted to humans through pollen must also be considered.

## Transfer of Antibiotic Resistance

Marker genes conferring antibiotic resistance on the modified crop are transferred to its DNA along with the genes conferring the desired trait. Cells that successfully take in the desired gene also become permanently resistant to the antibiotic used to select the altered plant cells. If bacteria in the human digestive system take up the genes for antibiotic resistance, then antibiotic resistance would be conferred on them, leading to the unintentional development of strains of bacteria that we might not be able to combat if the need arose. However, there is no confirmed evidence of gene transfer from a plant to bacteria, that is, when a gene becomes incorporated into the genome of a plant. If such transfer were common, humans would be full of plant genes, which we consume daily. Transfer from bacteria to plants is also very rare, such as with the crown gall bacterium.

## Alteration of Soil Ecology

When crops die in the field, their cells eventually release their contents into the soil. Soil bacteria and fungi are also involved in the decomposition of plant tissue. Some scientists are concerned that these decomposers and other plants may take in and use the antibiotic or other genes, which could alter the "balance of power" that currently exists in the soil.

If plants were engineered to produce antibiotics, plant residue could release antibiotic into the soil, perhaps dramatically affecting the soil ecology. Interactions in the soil community are not well known, so it is difficult to assess the likelihood of negative effects. Many soil organisms do produce antibiotics or have antibiotic resistance, and bacteria can exchange DNA among themselves comparatively easily. Although most plant DNA released into the soil will probably be degraded rather than absorbed by microorganisms, some such transfer may be possible. In addition, potential GM plant products such as industrial-grade oils or plastics could pollute agricultural soils through their release when the plant dies or even as a result of normal metabolic loss. The potential for transfer of transgenes to soil organisms during plant decomposition is the subject of a significant amount of research.

### Dangers of Eating Foreign DNA

Critics have raised concern about the unknown effects of eating genetically altered DNA on human health. However, it is generally assumed that DNA in foods is broken down during normal digestion. Biotechnologists point out that we consume a variety of microorganisms and their promoters on the foods we normally eat and our bodies have developed defenses to deal with them before they cause any harm. Virtually all conventionally bred foods in developed countries are significantly different genetically from their original counterparts.

### Lowered Nutritional Value of GM Foods

It is questionable as to whether modified foods have a significantly different nutritional value than unmodified foods. For GM products to be approved by regulatory agencies, they must show that they are substantially equivalent to their non-GM counterparts. Therefore, the major nutritional components of the seed—such as oils and proteins—should not change much due to the integration of a transgene unless the GM crop contains deliberately altered seed components designed to meet a consumer need. This could potentially cause nutritional changes, especially where yield and the ability to harvest are given priority. However, this issue is not exclusively related to GM crops; it has also been a problem in conventional plant breeding.

### Crop Diversity

The temptation to plant vast acres with one modified variety of crop could reduce crop diversity. Areas planted in this way may become "biological deserts" that separate natural environment areas and make it difficult for wild populations to move between them. Monocultures may also be highly susceptible to unsuspected diseases. In 1970, southern corn leaf blight (SCLB) devastated the American corn crop. As it turned out, 85% of that corn crop had Texas cytoplasm—a gene in the mitochondria that causes male sterility, allowing corn varieties to be crossed without having to remove the tassels (Tatum 1971). Unknown to breeders, the mitochondria in this cytoplasm also had a gene that made it susceptible to the SCLB fungus. This example is often cited as a lesson on the dangers of the genetic uniformity of a monoculture. As with the reduction in nutrition, this is not a problem exclusively linked to GM technology.

**Member of the Philippine Biosafety Regulatory Team inspecting Bt corn cobs during the harvesting of one of the open field trials of Bt corn in the Philippines.**

Source: Image © International Service for the Acquisition of Agri-biotech Applications, 2002, Ithaca, NY; (*www.isaaa.org*).

### Evolution of Resistance

Just as disease organisms have developed increasing resistance to antibiotics in medicine, there is the possibility that pest populations—weeds or insects—will evolve resistance to the lethal proteins in GM crops. Bt genes act as selective agents because they do not kill all of the target insects that feed on the crop. The insects that survive may carry genes for some degree of Bt resistance, and their offspring will inherit these genes, which—over many generations—could allow the population as a whole to become resistant.

Similarly, weed populations may evolve in response to repeated use of an herbicide. This is the current trend with the increased acres of Roundup Ready crops (Pollack 2003). Eventually, farmers may be forced to use more or different herbicides, thus defeating the purpose of sowing that crop. Crop varieties may then be needed that have greater resistance, with ever-increasing environmental risks. The large number of Bt genes could ease this problem in the case of pesticides, but it cannot prevent it from occurring. Weed populations can become resistant to pesticides without any Bt genes.

## Essential Question 5:

### *Under What Conditions, if Any, Should Crop Biotechnology Be Pursued?*

The debate over GM crops worldwide focuses to a great extent on issues of regulation. In the United States, three government agencies regulate various aspects of transgenic crop engineering. The Environmental Protection Agency regulates the environmental impact of pesticides—primarily with Bt crops. The Food and Drug Administration is responsible for the safety and labeling of foods and animal feeds derived from all crops, including GM crops and all products derived from plants. Finally, the Department of Agriculture's Animal and Plant Health Inspection Service oversees safety related to both field testing and planting of genetically engineered crops.

Decisions on new technologies always involve questions of costs and benefits that are quite difficult to assess. Regulatory agencies worldwide apply different standards and sets of criteria when it comes to assessing the biological safety of genetically engineered organisms, which makes any final decisions that much more controversial.

In the *decision threshold* approach, a new GM crop is considered to be substantially equivalent to other varieties of the same species if it can be shown that no changes have been introduced other than those that are directly linked to the newly introduced gene. This is the same reasoning that is applied

**Table 2.**

*Range of Standards for Evidence of Safety Required*

| | | Potential Environmental Risk | |
|---|---|---|---|
| | | **Minor or Reversible** | **Major or Irreversible** |
| **Potential Value of Benefits Lost by Delaying Implementation** | **Small** | Intermediate standard | Highest standard |
| | **Large** | Lowest standard | Highest standard |

to the evaluation of hybridized crops. If the transgene itself is shown to be harmless, then it is assumed that the GM crop is no different from its non-GM counterparts. Currently, the possibility of unintended genetic interactions and products is not heavily weighed. As of this writing, the regulatory agencies in the United States use this standard.

The *safety standard* approach considers a GM crop to be equivalent to its non-GM counterparts only if rigorous scientific testing demonstrates that the introduction of the new genes has not caused changes that might result in additional risks not found in the non-GM counterparts. This takes into consideration the unexpected interaction between the transgene and other genes in the organism. Canada and various European countries—as well as many environmental groups—favor this approach.

The decision threshold approach has the advantage of speeding up the development of new GM crops, but it also increases the chances of missing a latently harmful side effect, and it places more of the burden of proof on those who allege possible harm. The safety standard approach is more likely to identify hidden problems, but it can greatly delay benefits from the development of a harmless crop, and it puts the responsibility on biotechnologists to demonstrate the safety of the products. The decision about which approach to use is driven less by science and more by economic, political, and social considerations.

The safety standard approach allows for different degrees of proof. Depending on the estimated environmental risk and the cost of delaying the potential benefits, the standard can be relatively low, intermediate, or high (see Table 2).

Golden Rice, engineered to manufacture vitamin A in the portion of grain that is eaten, provides a good example. Vitamin A is a nutrient naturally found in the discarded hull of rice. Golden Rice was created to provide vitamin A to populations that have difficulty obtaining sufficient quantities of the nutrient (see *www.goldenrice.org*). Therefore, the cost of not introducing Golden Rice would lead to more vitamin A deficiency, which according to the World Health Organization is the leading cause of preventable blindness in children and can raise the risk of disease and death from severe infections. It also causes night blindness and may increase the risk of maternal mortality in pregnant women.

The Golden Rice crop might appear to be less potentially harmful to the environment than a rice crop engineered to contain the powerful Bt gene. Testing would still be required on both varieties, but less stringent tests might be required for the Golden Rice. However, it is not clear that yellow rice will be accepted by consumers.

As more GM crops are created, the pressure on regulatory agencies may continue to increase and the potential for errors in judgment may also increase; however, as familiarity with GM crops increases, this pressure could decrease. In analyzing any new GM crop, we must ask ourselves whether the health, economic, and environmental benefits outweigh the potential health and environmental costs, and if there are sustainable alternatives that could achieve the same goals with less risk.

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# Teaching Approach

In order to place GM crops in an environmental context, this section provides an overview of the four student activities available for use, a list of possible student misconceptions, ideas for assessing student learning, and some recommended resources.

## Activities Overview

This module provides four student activities. How many and which of the activities to use will depend on several factors—how much class time can be devoted to the topic; prior student knowledge (if they have not yet learned about DNA structure and function, protein synthesis, and how genes work on an introductory high school level, then time will have to be taken to bring them up to speed); and the availability of resources. Where possible, each activity identifies required resources and includes an estimate of the time needed to carry out the activity.

The initial activity is of a general nature and may not be needed. Activities 2 and 3 contribute to an increased understanding of both the science and technology involved in the bioengineering of crops—not whether to support or oppose biotechnology in agriculture. The final activity engages students in taking a position on the issue, but even here emphasis must be on marshaling scientific evidence.

## Activity 1

### *Building Proteins*

This activity responds to the essential question "What is the science involved in the genetic engineering of crops?" Many students may need a refresher activity on the related biology, depending on whether this module is used in a high school biology course (after DNA and genetics) or in a second-year course such as Environmental Science or Biology 2. A list of prior knowledge students should have (selected from *Benchmarks for Science Literacy* and *National Science Education Standards*) is included as a guide.

## Activity 2:

### *Genetic Engineering*

This activity focuses on the essential questions "How is genetic engineering different from more traditional genetic manipulations, such as hybridization?" and "What steps are usually involved in genetically modifying a crop?" Students review the five major steps involved in genetic engineering of crops and are then asked to outline the steps they would take to engineer a crop with a trait of their own choosing. Teacher registration on the High School Crop Genetic Engineering website—with a password—allows students to take related quizzes accompanying the activities. If internet access is limited, the activity can be carried out using downloaded pages.

The learning goals in *Benchmarks* and *National Science Education Standards* do not directly address the specific steps involved in the genetic modification of a crop. That does not, however, imply that students should ignore these steps. Understanding such specifics can assist them in developing their own ideas about genetic engineering and can give them a chance to apply and reinforce ideas they have already learned about genetics and heredity.

## Activity 3:

### *Are Monarch Butterflies Threatened by Bt Corn?*

This activity provides an opportunity for students to discuss an actual case study. Students review a paper by two scientists that criticizes a research paper of other scientists and—in the process—focus on the importance of good science in assessing potential threats from biotechnology. The essential question addressed here is "What are the known or projected risks and benefits of genetically modifying crops?"

## Activity 4:

### *Spectrum of Opinion*

Drawing on what was learned previously, this activity focuses on the essential question "Under what conditions, if any, should crop biotechnology be pursued?"

## Misconceptions

Many students approach the study of science with preconceived ideas or misconceptions about science terms and ideas. The following are some of the misconceptions that students may have about the ideas in this module:

- Agricultural biotech is inherently different and more hazardous than plant breeding.
- Transgenic plants are not "natural."
- Modern agriculture doesn't need biotech because the problem of hunger in the world can be solved solely by redistributing food production.

## Assessing Student Learning

Each of the student activities presents opportunities for assessing student learning. By using embedded assessment, it is possible to follow student growth of understanding and to detect when student misunderstanding persists. The closing exercise in Activity 4, in which students re-evaluate their initial understanding of genetic engineering, can also serve as an overall assessment of the module.

## Recommended Resources

### *Books*

Bains, W. 1998. *Biotechnology from A to Z.* New York: Oxford University Press.

A detailed overview of biotechnology in the format of a glossary of terms.

DeGregori, T. R. 2002. *Bountiful harvest: Technology, food safety, and the environment.* Washington, DC: Cato Institute.

A succinct overview of genetic modifications of plants and other products, comparisons with mitogenesis and chemical modifications, and analysis of international perceptions and emerging regulations.

Grace, E. 2005. *Biotechnology unzipped.* Washington, DC: John Henry Press.

An updated version of his 1997 first edition, offering an in-depth review of the basics of biotechnology and the implications it holds.

National Academy Press. 2000. *Transgenic plants and world agriculture.* Washington, DC: National Academy Press. *http://newton.nap.edu/html/transgenic*

A short, downloadable report prepared under the auspices of the Royal Society of London, the U.S. National Academy of Sciences, the Brazilian Academy of Sciences, the Chinese Academy of Sciences, the Indian National Science Academy, the Mexican Academy of Sciences, and the Third World Academy of Sciences. It contains a series of short chapters summarizing the impact of transgenic crops on world agriculture, potential uses of transgenic crops, and safety and health issues.

Rainis, K. G., and G. Nassis. 1998. *Biotechnology projects for young scientists.* New York: Franklin Watts.

A good introduction to biotechnology through a variety of lab activities, which include extracting DNA, cloning a carrot, and using an oil-degrading microbe to clean up a (small) oil spill.

Ropeik, D., and G. Gray. 2002. *RISK: A practical guide to deciding what's really safe and what's really dangerous in the world around you.* Boston: Houghton Mifflin.

Written for the general public, this book explains common public health concerns, the consequences from exposures to those hazards, and how people can reduce their risk. Topics range from cellular telephones, transportation, and obesity to GM foods, biological weapons, and water pollution.

## *Websites*

Access Excellence: Issues and Bioethics (*www.accessexcellence.org/RC/AB/IE*)

An excellent source for information on scientific breakthroughs propelling biotechnology and related bioethics.

The Dolan DNA Learning Center (*www.dnalc.org/home.html*)

The mission of the Dolan DNA Learning Center is to prepare students and families to thrive in the "gene age." The center works to expose students to the principles of genetics and risk, provides hands-on experiments, and provides access to genetic information needed to make informed choices.

GM Food: Controversies Surrounding the Risks and Benefits of Genetically Modified Food (*http://scope.educ.washington.edu/gmfood*)

Presented by the University of California, Berkeley, the University of Washington, and the American Association for the Advancement of Science, SCOPE is an online intellectual community that focuses on current controversies in science that concern leading research scientists and also connects to the interests of the general public.

Harvest of Fear (*www.pbs.org/wgbh/harvest*)

Despite its fear-inducing title, this PBS NOVA/Frontline special report presents a balanced look at the pros and cons of developing GM foods from the viewpoint of consumers, scientists, and the industry. An interactive website supplements the video, which can be ordered directly from PBS.

The National Center for Case Study Teaching in Science Case Collection (*http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm*)

This site, hosted by the State University of New York at Buffalo, contains numerous case studies on a wide variety of science-related issues in various disciplines, including those involving biotechnology.

Transgenic Crops: An Introduction and Resource Guide (*http://cls.casa.colostate.edu/TransgenicCrops*)

This guide, hosted by Colorado State University, contains a rich set of resources including readings, labs resources, references, slides and other materials for teachers.

# Student Activities

## Activity 1:
### *Building Proteins*

This activity may be used if students need a refresher activity on protein synthesis and gene expression. One or two class days should be sufficient time for this review.

As a result of this review, students should achieve the follow learning goals:

#### From *Benchmarks for Science Literacy*

- New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells. Changes in other cells of an organism cannot be passed on to the next generation. (p.125)
- The information passed from parents to offspring is coded in DNA molecules. (p.108)
- Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment. (p.109)
- The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. The code used is virtually the same for all life forms. Before a cell divides, the instructions are duplicated so that each of the two new cells gets all the necessary information for carrying on. (p.114)
- The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins. Protein molecules are long, usually folded chains made from 20 different kinds of amino acid molecules. The function of each protein molecule depends on its specific sequence of amino acids and the shape the chain takes is a consequence of attractions between the chain's parts. (p.114)

#### From *National Science Education Standards*

- In all organisms, the instructions for specifying the characteristics of the organisms are carried in DNA, a large polymer formed from subunits of four kinds (A,G,T,C). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes and replicated. Each DNA molecule in a cell forms a single chromosome. (p. 185)
- Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms.

> Only mutations in germ cells can create the variation that changes an organism's offspring. (p. 185)

A straightforward way to assess the readiness of the students is to have them identify the relationships among amino acids, cells, chromosomes, DNA, genes, inheritance, mutations, and proteins. Many textbooks have sufficient information for review purposes, but they can be supplemented by the following resources:

- Dolan DNA Learning Center (*www.dnalc.org/home.html*)
- Kreuzer, H., and A. Massey. 1996. *Recombinant DNA and biotechnology: A guide for students*. Washington, DC: ASM Press.
- National Association of Biology Teachers and North Carolina Biotechnology Center (NABT). 1990. *A sourcebook of biotechnology activities*. Reston, VA: NABT.

# Activity 2:
## *Genetic Engineering*

While genetic engineering is a rather complex process in practice, it typically involves the same general steps: (1) remove the desired gene from a species; (2) clone the gene; (3) modify the gene so it works as desired in the plant; (4) insert the modified gene into the nucleus of the new host and grow the affected cells into new plants; and (5) cross the new trait into plants with other desired traits. This is the level of understanding that students should attain.

This activity is organized into two parts. Part I: Genetic Modification focuses on learning the basic steps needed to develop a GM organism and then applies that knowledge to the design of two GM crops. Part II: Designing Transgenes is more technical and can be either used as an elective or assigned to the entire class.

Highly motivated students may wish to proceed independently through more—or even all—of the biotechnology lessons found on the High School Crop Genetic Engineering website (*http://citnews.unl.edu/hscroptechnology/html/firstPage.html*) an instruction site developed by educators at several land grant universities with leadership and hosting provided by the University of Nebraska Institute of Agriculture and Natural Resources. After their teacher registers on the site and sets a password, students may take online quizzes on each lesson.

## *Part I:*
### Genetic Modification

1. Make a transparency of the Greenpeace "GM Food Is Bad Business" photo from the front of this module and use it to open the discussion. Have the students write down (1) whether they agree or disagree with Greenpeace, or if they are undecided; and (2) what they think genetic engineering is. Collect the papers and save them.
2. Hand out copies of "Genetic Modification" from the "Student Materials" section and set a deadline for its completion.
3. Following completion, conduct a brief class discussion around such questions as
    - What do the two genetic engineering projects—Bt Corn and Cinna-Apples—in the animation have in common?
    - What are the key differences?
    - Assume that insect larvae that damage cotton plants are also killed by the same Bt protein that kills the European corn borer. If we were to create Bt Cotton, what animation steps would be the same? What steps would be different?

## *Part II:*

### Designing Transgenes

If *individual students* elect to undertake Part II, they should be provided with a copy of the "Designing Transgenes" handout. Some may wish to supplement their online study with the "How Do You Make a Transgenic Plant?" handout.

If the *entire class* undertakes Part II, each student should receive a copy of "Designing Transgenes." The activity should culminate with a class discussion around one or more of the following questions:

- There are about 300 different types of cells in a human body, and every gene a person inherited is found in each of these cells. This fact is critical in matching crime scene DNA to a suspect. Why is it critical that each gene has a promoter?
- After working on the "Transgene Design" animation, can you explain why each transgene is the best choice given the options provided?
- One environmental issue with transgenic corn is that the Bt proteins that kill corn pest larvae can also be toxic to nontargeted insects, such as butterfly larvae. This can happen even when the nontargeted insect larvae are not living on the corn plant. How is this possible?
- A second environmental issue with transgenic corn is that some of the insecticidal proteins have the potential to be allergens if people consume these proteins when eating food products made from this type of corn. Compare transgenic corn with corn conventionally bred to be insect resistant. Is it possible to design a transgene that will protect a corn plant from an insect pest but not threaten some people who are allergic to corn?

# Activity 3:

## *Are Monarchs Threatened by Bt Corn?*

This activity is intended to reinforce student understanding of genetic engineering by having them apply their knowledge of genetics, genetic engineering, and decision making to a real case study.

## *Background*

Many people became concerned about accidental and unintended effects of genetically engineered plants when, in 1999, scientists reported that monarch butterflies were susceptible to lethal effects of Bt corn pollen. Researchers had spread the pollen on milkweed plants in a greenhouse and allowed monarch larvae to feed on the plants. The caterpillars displayed considerable susceptibility and, when these results were made known, an outcry by the public was inevitable.

Further research and inquiry determined that the type of corn from which the pollen was taken contained a particularly strong type of Bt protein. The variety was not widely used and was in the process of being phased out. The effects in the field were also much different than in the greenhouse—where the pollen was more concentrated. In fact, some studies found that the monarch caterpillars did better in the United States, where they displayed a preference for feeding on milkweed in the field, than they did in Canada, where they displayed a preference for milkweed away from the field. The differences could be explained by differences in the prevalence of predators.

While concerns about the monarch turned out to be less serious that originally thought, the report did raise public awareness about the potential for harm to unintended species by genetically engineered crops.

### *Instructions*

To make the most of this activity, you may want to have students read the article "The Monarch Butterfly Controversy: Scientific Interpretations of a Phenomenon" by A. M. Shelton and M. K. Sears 27(6):483–488. The authors review the weaknesses in the original research and open the way for a discussion of scientific procedures and standards of evidence. The article makes a provocative introduction to a science-based classroom discussion of the potential effects of genetically engineered crops.

Next, direct your students to the internet exploration activity Agricultural Biotechnology and the Monarch Butterfly: Are Monarchs Threatened by Bt Corn? (*http://cls.casa.colostate.edu/TransgenicCrops/CTmonarch.html*) offered by Colorado State University. The online activity takes students through a series of pages about the monarch situation and allows them to interact by answering questions and making decisions. Have them answer the questions that appear as they go along and submit their answers to the follow-up questions at the end of the activity.

## Activity 4:

### *Spectrum of Opinion*

In this activity, students will draw on and apply what they have learned in the earlier activities in order to take a position on genetic engineering. Students will read a brief overview of cost-benefit analysis, risk analysis, and trade-offs and will then search for arguments both for and against GM crops. They will delineate the role of science as a factor separate from the roles of economics, politics, social philosophy, and other influential factors in genetic engineering.

This activity will take three to four days of class time, depending on the number and length of presentations, and can be used as a final assessment exercise.

1. Provide each student with a copy of "The Nature of Risk" essay to be read as homework. Use part of the next day for class discussion of the concepts.
2. Form the class into groups of three or four and instruct each group to prepare a report presenting the arguments for and against the development of a particular GM crop. (It works best if each group is assigned a different crop and a different position.) Students should visit a variety of websites of both proponents and opponents of genetic engineering. The handout "Bounty or Bane—Taking a Position" can get them started.
3. Groups submit their reports and make presentations to the class. Arguments should be backed up with scientific evidence and defensible logic as much as possible.
4. Show the transparency of the Greenpeace photo to the class again, and return the papers they wrote at the beginning of the module. Ask them to answer these questions, which are similar to the questions asked at the beginning of the module: (1) what is genetic engineering, and how is it carried out? and (2) do you now agree or disagree with the Greenpeace position, and why? Collect their answers and use them to assess student understanding.

**Note:** *Benchmarks* and *National Science Education Standards* do not take a stand on the question of whether the genetic engineering of crops should be pursued, nor does this activity. It is important for students to make their own decisions but to do so based on a sound understanding of science and the analysis of risks and benefits.

# Student Materials

*Genetic Modification*

*Designing Transgenes*

*How Do You Make a Transgenic Plant?*

*Bounty or Bane—Taking a Position*

*The Nature of Risk*

# Genetic Modification

In this activity, you will learn about the overall process of genetic engineering. The High School Crop Genetic Engineering website provides the following explanation of the five steps for genetically engineering a crop:

1. Locating an organism with a specific trait and extracting its DNA.
2. Cloning a gene that controls the trait.
3. Designing a gene to express in a specific way.
4. Transformation, inserting the gene into the cells of a crop plant.
5. Plant breeding to get the transgene into an elite background.

At the completion of this lesson, you should be able to

- define genetic engineering;
- list and briefly explain the five basic steps in genetic engineering, and describe why each is necessary;
- identify the fundamental differences between genetically engineered crops and non–genetically engineered crops;
- explain the limitations to traditional breeding that are overcome by genetic engineering; and
- identify the approximate length of time required to obtain a marketable transgenic crop line (complete the entire crop genetic engineering process).

Begin the activity by going online to the High School Crop Genetic Engineering website (*http://citnews.unl.edu/hscroptechnology/html/htmlPages.html*).

1. Complete the Overview lesson, which is accessible by clicking the menu title in the left margin of the screen. Be sure to respond to the questions at the bottom of each page.
2. Next click on the Animations button on the left menu, then click on "Who wants to be a genetic engineer?" and select the Cinna-Apples genetic engineering project. Use the click-and-drag process in the animation to review the five major steps in crop engineering. End by clicking on the Create Plant button for a summary animation of these five steps.
3. Click on the Bt Corn activity and complete the animation.
4. When you feel you understand the basics of genetic engineering, sign in to take the genetic engineering quiz.

# Designing Transgenes

This activity explores the use of gene cloning to isolate and copy a specific gene of interest. Gene cloning involves the transformation of bacteria with plasmids containing antibiotic resistance genes to make gene libraries. Gene libraries are then used to allow scientists to select bacterial colonies that contain the specific gene of interest. How regions of a gene can be altered to obtain desired trait expression is also discussed. At the completion of this lesson, you should be able to

- explain why gene design is an important step in the crop genetic engineering process;
- list the three regions of a gene and explain their roles in gene expression;
- describe the two promoters discussed (35S and PEP carboxylase) and how their expression differs;
- describe the three Bt coding regions discussed (Cry1A(b), Cry1A(c), and Cry 9c) and how their expression differs; and
- explain how gene design could be used to deal with pest resistance to the Bt toxin.
- Begin the activity by going online to the High School Crop Genetic Engineering website (*http://citnews.unl.edu/hscroptechnology/html/htmlPages.html*).

1. Click on Gene Design 1 on the left menu and work your way through the lesson, making sure to answer the questions at the end of each page and check your answers.
2. Next click on Gene Design 2 on the left menu, then click the Animations button; select Transgene Design and complete the animations.
3. When you feel you understand the basics of designing transgenes, sign in to take the genetic engineering quiz. If the results are not satisfactory, review the activity and the reading "How Do You Make a Transgenic Plant?" (available from your teacher).

# How Do You Make a Transgenic Plant?

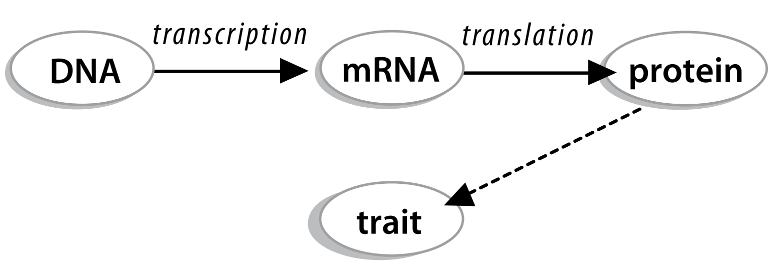
The underlying reason that transgenic plants can be constructed is the universal presence of *DNA* (deoxyribonucleic acid) in the cells of all living organisms. This molecule stores the organism's genetic information and orchestrates the metabolic processes of life. Genetic information is specified by the sequence of four chemical bases (adenine, cytosine, guanine, and thymine) along the length of the DNA molecule. Genes are discrete segments of DNA that encode the information necessary for assembly of a specific protein. The proteins then function as enzymes to catalyze biochemical reactions, or as structural or storage units of a cell, to contribute to expression of a plant trait. The general sequence of events by which the information encoded in DNA is expressed in the form of proteins via an mRNA intermediary is shown in the diagram below.

The transcription and translation processes are controlled by a complex set of regulatory mechanisms, so that a particular protein is produced only when and where it is needed. For more information on molecular genetics, consult any recent genetics text or the Access Excellence Graphics Gallery (*www.accessexcellence.org/RC/VL/GG/index.html*) website. Even species that are very different have similar mechanisms for converting the information in DNA into proteins; thus, a DNA segment from bacteria can be interpreted and translated into a functional protein when inserted into a plant.

Among the most important tools in the genetic engineer's tool kit are enzymes that perform specific functions on DNA. *Restriction enzymes* recognize and cut the DNA at a specific region. Other enzymes known as *ligases* join the ends of the two DNA fragments. These and other enzymes enable the manipulation and amplification of DNA, essential components in joining the DNA of two unrelated organisms.

## *Locating Genes for Plant Traits*

Identifying and locating genes for agriculturally important traits is currently the most limiting step in the transgenic process. We still know relatively little about the specific genes required to enhance yield potential, improve stress tolerance, modify chemical properties of the harvested product, or otherwise affect plant characters. Usually, identifying a single gene involved with a trait is not sufficient; scientists must understand how the gene is regulated, what other effects it might have on the plant, and how it interacts with other genes active in the same biochemical pathway. Public and private research programs are investing heavily into new technologies to rapidly sequence and determine functions of genes for the most important crop species. These efforts should result in identifi-



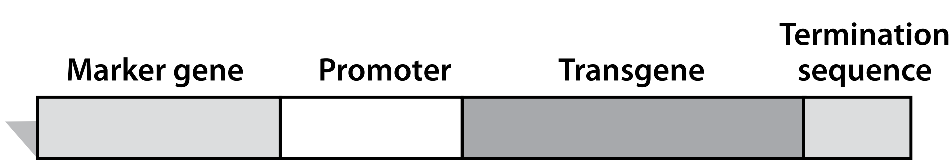
cation of a large number of genes potentially useful for producing transgenic varieties.

The techniques for locating and sequencing stretches of DNA that control specific traits are beyond the scope here. Interested readers are referred to Klug and Cummings 1998; Lewin 1999; Wong 1997; or other recent genetics texts.

## *Designing Genes for Insertion*

Once a gene has been isolated and cloned (amplified in a bacterial vector), it must undergo several modifications before it can be effectively inserted into a plant.

1. A *promoter sequence* must be added for the gene to be correctly expressed (i.e., translated into a protein product). The promoter is the on/off switch that controls when and where in the plant the gene will be expressed. To date, most promoters in transgenic crop varieties have been "constitutive,", i.e., causing gene expression throughout the life cycle of the plant in most tissues. The most commonly used constitutive promoter is CaMV35S, from the cauliflower mosaic virus, which generally results in a high degree of expression in plants. Other promoters are more specific and respond to cues in the plant's internal or external environment. An example of a light-inducible promoter is the promoter from the cab gene, encoding the major chlorophyll a/b binding protein.
2. Sometimes, the *cloned gene is modified* to achieve greater expression in a plant. For example, the Bt gene for insect resistance is of bacterial origin and has a higher percentage of A-T nucleotide pairs compared to plants, which prefer G-C nucleotide pairs. In a clever modification, researchers substituted A-T nucleotides with G-C nucleotides in the Bt gene without significantly changing the amino acid sequence. The result was enhanced production of the gene product in plant cells.
3. The *termination sequence* signals to the cellular machinery that the end of the gene sequence has been reached.
4. A *selectable marker gene* is added to the gene "construct" in order to identify plant cells or tissues that have successfully integrated the transgene. This is necessary because achieving incorporation and expression of transgenes in plant cells is a rare event, occurring in just a few percent of the targeted tissues or cells. Selectable marker genes encode proteins that provide resistance to agents that are normally toxic to plants, such as antibiotics or herbicides. Only plant cells that have integrated the selectable marker gene will survive when grown on a medium containing the appropriate antibiotic or herbicide. As for other inserted genes, marker genes also require promoter and termination sequences for proper function.




**Simplified Representation of a Constructed Transgene, Containing Necessary Components for Successful Integration and Expression**

## *Transforming Plants*

Transformation is the heritable change in a cell or organism brought about by the uptake and establishment of introduced DNA. There are two main methods of transforming plant cells and tissues:

1. The *"Gene Gun" method* (also known as microprojectile bombardment or biolistics). This technique, which is shown and explained in the animated demo section of the website, has been especially useful in transforming monocot species like corn and rice.
2. The *Agrobacterium method* (described below). Transformation via Agrobacterium has been successfully practiced in dicots (broadleaf plants like soybeans and tomatoes) for many years, but only recently has it been effective in monocots (grasses and their relatives). In general, the Agrobacterium method is considered preferable to the "gene gun," because of the greater frequency of single-site insertions of the foreign DNA, making it easier to monitor.

## *Agrobacterium Method of Plant Transformation*

*Agrobacterium tumefaciens* is a remarkable species of soil-dwelling bacteria that has the ability to infect plant cells with a piece of its DNA. When the bacterial DNA is integrated into a plant chromosome, it effectively hijacks the plant's cellular machinery and uses it to ensure the proliferation of the bacterial population. Many gardeners and orchard owners are unfortunately familiar with *A. tumefaciens*, because it causes crown gall diseases in many ornamental and fruit plants.

The DNA in an *A. tumefaciens* cell is contained in the bacterial chromosome as well as in another structure known as a Ti (tumor-inducing) plasmid. The Ti plasmid contains:

- a stretch of DNA termed T-DNA (~20 kb long) that is transferred to the plant cell in the infection process;
- a series of *vir* (virulence) genes that direct the infection process.

*A. tumefaciens* can only infect a plant through wounds. When a plant root or stem is wounded it gives off certain chemical signals. In response to those signals, the *vir* genes of *A. tumefaciens* become activated and direct a series of events necessary for the transfer of the T-DNA from the Ti plasmid to the plant's chromosome. Different *vir* genes:

- copy the T-DNA;
- attach a product to the copied T-DNA strand to act as a leader;
- add proteins along the length of the T-DNA, possibly as a protective mechanism;
- open a channel in the bacterial cell membrane, through which the T-DNA passes.

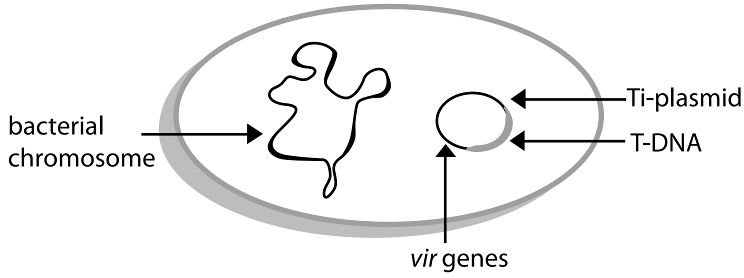
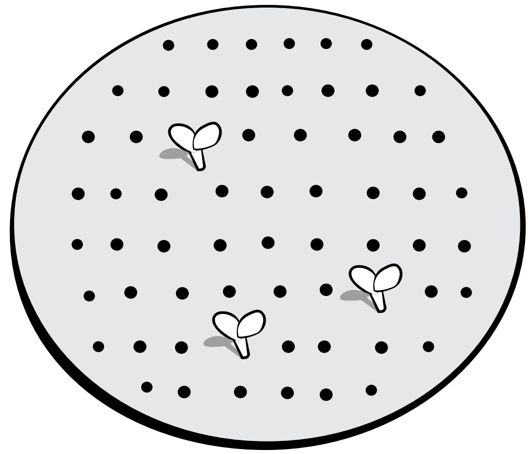



**Diagram of *Agrobacterium tumefaciens* Cell**

The T-DNA then enters the plant cell through the wound. It is not clear how the bacterial DNA moves from the cytoplasm to the nucleus of the plant cell, nor how the T-DNA becomes integrated into the plant chromosome. Remember that most of the time plant DNA does not exist as an exposed strand, but is wrapped with histone proteins and is in a supercoiled state. One speculation is that the T-DNA waits until the plant DNA is being replicated or transcribed, then inserts itself into the exposed plant DNA (Galun and Breiman 1997).

To harness *A. tumefaciens* as a transgene vector, biotechnologists have removed the tumor-inducing section of T-DNA, while retaining the T-DNA border regions and the vir genes. The transgene is inserted between the T-DNA border regions, where it is transferred to the plant cell and becomes integrated into the plant's chromosomes (Wong 1997).



**When grown on selective media, only plant tissues that have successfully integrated the transgene construct will survive.**

## *Selection and Regeneration: Selection of Successfully Transformed Tissues*

Following the gene insertion process, plant tissues are transferred to a selective medium containing an antibiotic or herbicide, depending on which selectable marker was used. As shown below, only plants expressing the selectable marker gene will survive and it is assumed that these plants will also possess the transgene of interest.

Thus, subsequent steps in the process will only use these surviving plants.

## *Regeneration of Whole Plants*

To obtain whole plants from transgenic tissues such as immature embryos, they are grown under controlled environmental conditions in a series of media containing nutrients and hormones, a process known as tissue culture. Once whole plants are generated and produce seed, evaluation of the progeny begins. This regeneration step has been a stumbling block in producing transgenic plants in many species, but specific varieties of most crops can now be transformed and regenerated.

## *Future Developments in Transgenic Technology*

New techniques for producing transgenic plants will improve the efficiency of the process and will help resolve some of the environmental and health concerns. Among the expected changes are the following:

- more efficient transformation, that is, a higher percentage of plant cells will successfully incorporate the transgene;

- better marker genes to replace the use of antibiotic resistance genes;
- better control of gene expression through more specific promoters, so that the inserted gene will be active only when and where needed;
- transfer of multi-gene DNA fragments to modify more complex traits.

## *Plant Breeding and Testing*

Intrinsic to the production of transgenic plants is an extensive evaluation process to verify whether the inserted gene has been stably incorporated without detrimental effects to other plant functions, product quality, or the intended agroecosystem. Initial evaluation includes attention to:

- activity of the introduced gene;
- stable inheritance of the gene;
- unintended effects on plant growth, yield, and quality.

If a plant passes these tests, it will most likely not be used directly for crop production, but will be crossed with improved varieties of the crop. This is because only a few varieties of a given crop can be efficiently transformed, and these generally do not possess all the producer and consumer qualities required of modern cultivars. The initial cross to the improved variety must be followed by several cycles of repeated crosses to the improved parent, a process known as backcrossing. The goal is to recover as much of the improved parent's genome as possible, with the addition of the transgene from the transformed parent.

The next step in the process is multilocation and multiyear evaluation trials in greenhouse and field environments to test the effects of the transgene and overall performance. This phase also includes evaluation of environmental effects and food safety.

## References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Klug, W. S., and M. R. Cummings. 1998. *Essentials of genetics.* 3rd ed. Upper Saddle River, NJ: Prentice Hall.

Lewin, B. 1999. *Genes VII.* New York: Oxford University Press.

Wong, D. W. S. 1997. *The ABCs of gene cloning.* New York: Chapman & Hall.


Source: Excerpted with permission from "Transgenic Crops: An Introduction and Resource Guide," presented by Colorado State University at *http://cls.casa.colostate.edu/TransgenicCrops/how.html.*

**Note:** Ann Fenwick, formerly a research associate in the Department of Soil and Crops Sciences at Colorado State University, contributed to the content. 

# Bounty or Bane—Taking a Position

In this activity, you will work in small groups to fashion a position either in support of or against the development and use of transgenic crops. The teacher will assign each group a particular crop and what position the group will take; thus you may be working to justify a position that you yourself do not support. This is appropriate because the point of the activity is to learn how to use valid evidence and careful logic in reaching decisions with regard to environmental issues.

A sampling of pertinent websites related to genetic engineering is listed below, but there are many others that you might find in defending the position assigned to your group.

## *Opposing Transgenic Crops*

Ag BioTech InfoNet (*www.biotech-info.net*)

Alliance for Bio-Integrity (*www.biointegrity.org*)

Center for Ethics and Toxics (*www.cetos.org*)

Center for Food Safety (*www.foodsafetynow.org*)

Greenpeace Genetic Engineering (*www.greenpeace.org/usa/campaigns/genetic-engineering* )

Union of Concerned Scientists: Genetic Engineering (*www.ucsusa.org/food_and_environment/genetic_engineering*)

## *Supporting Transgenic Crops*

Agbioworld (*www.agbioworld.org*)

AgCare (*www.agcare.org*)

Biotechnology Industry Organization (*www.bio.org*)

CheckBiotech (*www.checkbiotech.org*)

Council for Biotechnology Information (*www.whybiotech.com/main.html*)

CropGen (*www.cropgen.org*)

After you have completed your research, your team will prepare a written report and make a presentation to the class. Remember that your argument should be backed up with scientific evidence and defensible logic as much as possible.

**Note:** The internet is a rich resource for finding data on the impact of transgenic crops. Web pages that both support and oppose GM crops are readily available; you should, however, try to determine how credible a site is by virtue of the logic and evidence it offers to back up its position. The University of California, Berkeley *(www.lib.berkeley.edu/TeachingLib/Guides/Internet/Evaluate.html)* gives excellent guidance in evaluating the credibility of web resources.

## The Nature of Risk

What is risk? How would you define it? Most people think of risk as a number, a statistical probability, the likelihood that something will happen, as in "the risk is one in a million."

But there is more to risk than just probability. Risk means that something bad, harmful, or negative could happen. If you were talking about winning the lottery you'd probably say "The chances of winning the lottery are one in a million." But if you were talking about being hit by lightning you'd say "The risk of being hit by lightning is one in a million." Risk implies a potentially negative outcome.

A hazard is simply some agent or circumstance out there—like a poison or pollution or an earthquake fault running under your house—known to cause an adverse effect under certain circumstances. It is the first factor that risk assessors investigate when studying a risk. Everything can post a hazard under the wrong circumstances.

Assessors of risk don't just study the agent to see what kind of hazard it could pose, they want to know the circumstances under which a hazardous substance poses a risk—i.e. what is the threshold? Does the risk increase at a constant rate? Is the risk big or small? At what levels? Severity of the consequences is also an important consideration. Think about the difference between germs that cause the common cold and being hit by lightning. Both are hazardous, but one has much more serious consequences.

Comparing the common cold to lightning helps to illustrate another factor involved in risk—exposure. If you are not exposed to the hazard, it's not a risk. Think about a poisonous snake in a display at a museum or zoo. It is hazardous, but safely inside its display it is not a risk to you because you are not actually exposed to it. But take the snake out and put it on the floor at your feet, and it is a risk, because now you have both hazard and exposure. You must have both for a risk to exist.

To fully understand exposure, risk assessors need to know not just whether we are exposed, but how much exposure to something (the dose) causes what kind of response and with what degree of likelihood. This is known as the dose-response relationship. Toxicology—the study of poisons—is one way to investigate the dose-response relationship. A toxicological study to see if a hazard (known or suspected) causes some specific negative outcome, like liver cancer, will provide different groups of test animals various doses of the suspected hazard and observe how many in each group get sick and at what doses. If a dose-response study gives a small dose of the hazard to a group of 100 mice and 20 show signs of the disease being investigated, the test indicates that there is a 1 in 5 chance—at that level of exposure—of mice developing that disease. If another group of 100 mice gets a larger dose and 50 get sick, the likelihood of illness at that level of exposure is 50%.

Now there are two ways to think about risk. We have a hazard—an agent known or suspected to cause harm—and a dose-response relationship showing what the likelihood is that the hazard will cause harm depending on the level of exposure. This gives us a richer way to think about risk since we can talk about whether the risk is bigger or smaller in terms of likelihood and based on the hazard and the severity of its consequences.

Going back to cold germs and lightning—in terms of likelihood, cold germs are a bigger risk since, even at modest levels, being exposed to them poses a pretty good likelihood of a negative outcome. The risk is high because the likelihood of it happening is high. However, in terms of hazard, being hit by lightning is a more serious hazard because, even though the likelihood of being exposed to a lethal dose is low, being killed is a more serious consequence than having the sniffles.

Risk is something that can be estimated but not measured. Estimating risk means predicting what we don't know based on what we do know, and we can't know everything about hazards or exposures. We can get a lot of good information from toxicology, but it has limitations. For example, studies often give test animals huge doses of the substance being investigated to make sure that it will trigger even the smallest possible response. Sometimes a huge dose can cause effects that simply wouldn't occur at lower doses. In other words, it is possible that the huge dose triggers some biological response in the animals that wouldn't happen at all if the dose were lower. Another way would be to give animals smaller doses, but if you want to make sure you catch any response that occurs at a likelihood of one in a million, you would need to dose more than a million animals to see if that response happens.

Also, what happens in rats or mice or other test animals may or may not happen in people. Our bodies and biochemical systems are similar, but not identical. So how much of a dose is safe for a rat may not give us a precise idea of how much is safe for humans.

Toxicological tests that use only one species of test animals may show that a substance is safe, but it is possible that the substance might still be dangerous to other species, including us. Tests on rats of a drug called thalidomide found it safe, but when pregnant humans took thalidomide they had babies with serious birth defects. So toxicologists went back and tried it on several other species of test animals until they tried rabbits, which showed the same results as people. This shows that they just hadn't tested thalidomide on the right species.

Still, since we cannot test potentially harmful substances on people—and, for financial and ethical reasons we can't use millions of test animals—toxicology provides important information about the dose-response relationship and the likelihood of a risk.

There is another important science that helps us understand risk—epidemiology, the study of patterns and causes of disease in human, other animal, and plant populations. An early demonstration of the power of epidemiology was by John Snow in England, who noticed in 1854 that an unusually large number of people in one small London neighborhood were getting cholera. He asked them what they ate, what they drank, where they worked, and where they traveled. After all his detective work, he discovered that the one thing they had in common was that they were all drinking from the same well. Officials turned off the well and nobody else got sick.

Epidemiology has helped identify some pretty well-known risks, including the risk of lung cancer from tobacco and the risk of heart disease from high cholesterol levels. But epidemiology also has its limits. Because it is subject to biases and confounding, epidemiologic studies can establish associations but rarely conclusions about causation.

Other sciences can help us understand risk too. For earthquakes, geology can tell what the probability is that we will be exposed to a tremor (within a pretty broad time span), and both engineering and physics can help to predict the various responses we will suffer (just the shaking of shelves or whole buildings collapsing) and from what doses (how severe the earthquake shaking was). Meteorology and hydrology can help us understand the dose-response relationships from floods—and likelihood of various severities of the hazard.

And now, new sciences—like genetics—are helping us understand risks. Tests can identify a mutation on a woman's DNA that may contribute to the likelihood she will develop breast cancer, and some genes may provide an indication of the likelihood of developing Alzheimer's disease. These genetic factors are part of how risk assessors gauge how much exposure to various external hazards will produce what likelihood of those diseases.

In addition to genetics, other powerful scientific procedures help to identify new hazards. Atmospheric chemistry helped recognize that chlorofluorocarbons (CFCs) destroy ozone molecules in the upper atmosphere, exposing us to more harmful ultraviolet radiation. And new techniques allow us to detect materials in our bloodstream at far lower levels that we could ever see before, shedding new light on potentially hazardous things to which we are being exposed.

Humans have faced serious threats for a long time and have conquered a lot of them, in part because of careful risk assessment. Yet, the industrial and technological age we live in creates new substances, products, and processes—like genetically modified food—that yield many benefits but can also introduce new risks. But while that risk race is being run, scientific advances are continually giving risk assessors better tools to figure out some of the most important questions we all face all the time: what are the risks, which ones are bigger or smaller, and how can we keep ourselves safe?