Exploring Environmental Issues:

FOCUS ON RISK

BIOTECHNOLOGY SUPPLEMENT
Activity 1: Biotechnology and You

In this activity, students will explore artificial selection, as well as learn how advances in science are allowing increasingly specific methods of genetic manipulation in organisms (genetic engineering). Students will explore the risks and benefits of genetic engineering and concerns that affect what we eat and wear.

Objectives:
Students will (a) model artificial selection through a simulation; (b) simulate genetic engineering through insertion of novel genes into a model of a plasmid; (c) recognize and detect bias in writing; and (d) explore the benefits, risks, and risk management strategies for genetically engineered products.

Assessment Opportunities:

- To evaluate the students’ knowledge of artificial selection:
  - Ask your students to identify the selective force in the bean activity. The selective force is your students; they are choosing which beans “survive” and will be allowed to “reproduce.”

- To evaluate students’ knowledge of genetic engineering:
  - Have students compare and contrast artificial selection and genetic engineering. Students should realize that both are forms of genetic modification. Selection can modify traits that are controlled by many genes, while genetic engineering works best on traits controlled by a single gene. This factor is one that limits the genetic engineering of crops and forest trees for improved productivity and stress resistance. Such complex traits are affected by many genes; in field testing, it has not proven easy to use single genes to make improvements that show increased value.

- To evaluate students’ understanding of the use of plasmids in transformation:
  - Ask your students to explain what a plasmid is, where it is naturally found, and why it is useful for this type of activity. Plasmids are small, circular, extra-chromosomal pieces of DNA that are typically double-stranded and are found in bacteria. Because plasmids replicate autonomously and do not undergo recombination, they can pass on the inserted gene without interruption.

- To evaluate students’ understanding of the use of enzymes in the transformation process:
  - Ask your students to identify which enzymes are represented by the scissors and tape in the activity that uses Student Page: Paper Plasmid Construction and to explain their respective functions. Scissors represent restriction enzymes (used to cut DNA at specific sites), and the tape represents ligase (used to join strands of DNA that have double-stranded breaks).

- To evaluate students’ understanding of risks vs. benefits associated with genetically engineered organisms:
  - Ask your students to write a list that contains at least three risks and three benefits of genetically engineered organisms. Next, have the students write a brief report (one page) on whether they would purchase clothing that has been produced from genetically modified cotton. Ask them to address at least two of the risks or benefits that they listed. Remind them that although there is no right or wrong answer, they should be able to articulate why they have taken a specific stance.

- To evaluate students’ understanding of containment and escape issues of genetically modified organisms:
  - Ask your students to choose a genetically modified plant that is currently grown and to discuss the specific ways in which potential escape of that organism or gene has been addressed.

Subjects: Biology, AP Biology, Environmental Science, AP Environmental Science

Concepts: 1.4, 1.6, 2.2, 2.8, 2.10, 3.5, 3.11, 4.1, 4.7, 5.4, 5.6

Skills: Classifying and Categorizing, Compare and Contrast, Decision Making, Determining Cause and Effect, Discussing, Inferring, Interpreting, Organizing Information, Problem Solving, Reasoning, Representing, Researching

Materials: pinto beans, rulers, calculators (optional), bags or bowls (for pinto beans), scissors, clear tape, copies of student pages, transparency, overhead projector

Time Considerations:
Preparing the Activity
Part A: 30 minutes
Part B: 60 minutes
Part C: 30 minutes
Part D: 30 minutes
Part E: 30 minutes
Part F: 15 minutes

Doing the Activity
Part A: One 50-minute period
Part B: Two 50-minute periods
Part C: Two 50-minute periods
Part D: One 50-minute period
Part E: One or Two 50-minute periods
Part F: Two 50-minute periods
Humans have been genetically modifying organisms for thousands of years. So why does there seem to be such a controversy over genetically engineered organisms (GEOs) in today's world? The answers to that question are varied and complex. In this activity, students will explore (a) the distinction between artificial selection and genetic engineering; (b) the ways some scientists use genetic engineering to modify agricultural crops; and (c) several of the scientific, economic, environmental, and ethical considerations that must be addressed when assessing GEOs.

What does it mean to genetically modify an organism? Artificial selection is one example of how an organism can be genetically modified. When people choose to breed only dogs that have a specific phenotypic trait, those people are ultimately creating a group of organisms that possess a specific trait, and the results are often called a breed. Labradors make great retrievers, collies make great herders, and Dobermans are good guard dogs.

There are also many different examples of artificial selection when it comes to food. A classic example is corn. The corn that we eat today (Zea mays ssp. mays) was developed from a wild grass, teosinte (Zea mays ssp. parviglumis). The ancestor to today's variety was much smaller in size, with hard, indigestible kernels. Today's corn has bigger, more easily digested kernels.

When the modification involves altering DNA, it is referred to as genetic engineering, which is a form of genetic modification that is a more precise process than traditional artificial selection and is based on phenotypes because it deals directly with DNA. Genetic engineering involves recombinant DNA (rDNA)—DNA that has been altered, usually using gene splicing. Genetic engineering became possible in the middle of the 20th century when advanced technology allowed researchers to learn much more about the genetic code and how it worked.

In 1953, James Watson and Francis Crick published their findings in the journal *Nature* about the double helix structure of DNA. In 1983, Kary Mullis

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**Box 1.1 Did You Know?**

The first commercially available and genetically engineered pet is the GloFish®. This fish has been genetically engineered with a protein that causes it to fluoresce, or glow, all the time! By inserting a gene normally found in marine organisms (such as jellyfish and sea anemones) into a zebra fish, scientists were able to create a fish that glows all the time.

Although the fish was originally developed for use in genetic studies in the laboratory, researchers are now looking to use these fish as bio-monitors to detect environmental pollutants. Along the way, someone realized there was a demand in the pet market for this novel aquarium critter.

Even though the GloFish can be legally sold in the United States (the Food and Drug Administration deemed there were no significant differences with respect to safety between the glowing fish and its traditional counterpart), some countries, including Australia, Canada, and most of those in Europe, have banned the sale of this genetically engineered organism.

revolutionized the field of genetics by creating a process known as the **polymerase chain reaction**, or PCR, (eventually winning the Nobel Prize for his discovery).\(^3\) PCR enables scientists to make millions of copies of a single region (a specific gene, for example) of a **genome**. This copying, or amplification technique, enables researchers to study a specific region of a genome in detail. By 2001, a group of more than 200 researchers published a paper announcing that they had sequenced (that is, determined the order of nucleotides or base pairs, or ACGT) the entire human genome (more than 2.9 billion base pairs).\(^4\)

So why are GEOs so controversial? The answer is complex and has its roots in two very different areas: science and ethics. **Bioethics** is a subset of ethics that deals with issues that arise out of advances in biology, medicine, and technology. There is no comprehensive list of the ethical concerns, but some of the ethical issues that are often discussed revolve around religion (genetic engineering is viewed by some as akin to “playing God”), concern for animal welfare (some people view genetic engineering techniques as painful invasions), concern for human health (how well scientists understand the long-term implications of consuming genetically engineered food), and concern for the environment (whether or not a GEO might transfer its genes to the wild).\(^5,6\)

Scientific controversy over GEOs centers around human health concerns, as well as environmental concerns.\(^7\) For example, inserting genes for pest resistance into plants raises questions about how the products of those genes might affect humans and other nontarget organisms, such as butterflies, when and if they are consumed. Environmentally, there is concern about the escape of **transgenes** into plant populations that have not been genetically engineered (see the case study of StarLink™ corn in part E). Those concerns need to be evaluated against the potential benefits of transgenic organisms, such as reduced pesticide use, higher yield, more nutritious food, bioremediation, and production of pharmaceuticals.

Many people are concerned that the scientific technology that allows us to modify and change living organisms is increasing so fast that society is unable to stay on top of such issues with respect to debating and developing ethical and moral guidelines for using the techniques. Another concern is that although there are formal agencies that regulate the use of GEOs in our society (Food and Drug Administration, U.S. Department of Agriculture, Environmental Protection Agency),\(^8\) no agency is specifically set up to evaluate the ethical implications.

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**Box 1.2 Policies Governing Labeling of Genetically Engineered Organisms**

Genetically engineered organisms are becoming increasingly prevalent in today’s society, especially in agriculture. With the use of genetic engineering comes an entirely new set of rules and regulations, not only in the United States but also in countries throughout the world.

In our increasingly globalized society, the economic, social, and environmental implications of how individual countries choose to regulate such crops can be far-reaching. Consider the United States and the European Union (EU). The EU has stringent rules when it comes to labeling food originating from organisms that have been genetically engineered, whereas the U.S. rules are much less stringent.\(^1\)

To learn more about how decisions governing food labeling are made, check out the World Health Organization’s website at [www.who.int/foodsafety/biotech/en/](http://www.who.int/foodsafety/biotech/en/).

With all this controversy over genetic engineering, one might automatically assume that there are uniform guidelines that regulate GEO production. But that is not the case and, again, the reasons are complex. Because much of the science is so new, there are few long term studies that have specifically addressed many of the concerns surrounding GEOs, such as their effect on human health and the environment. In addition, different countries have adopted different laws and regulations to deal with GEOs. In a world where commerce is becoming increasingly globalized, those differences can have enormous economic, political, and environmental effects.9

As with many issues, the controversy surrounding biotechnology is complex. Learning more about the science, including the different reasons and ways that organisms are genetically engineered, will allow you and others to make more informed decisions. Critically evaluating all information is important when examining issues. Part C of this activity allows students to critically evaluate information from several sources with differing points of view (bias). Part D of this activity introduces students to different reasons for genetically modifying crops and allows them to explore both the risks and benefits of genetic engineering. Part F of this activity encourages students to investigate the use of genetically modified cotton for clothing.

Biotechnology is a global issue—with global implications. For example, 75 percent of processed food in America contains ingredients derived from a genetically engineered organism, and those foods are often sold in the world market.10 Additionally, more than 20 different countries worldwide are growing genetically engineered crops.11 Learning about the scientific, environmental, and ethical issues surrounding GEOs will help students make informed decisions in this area of biotechnology.

ENDNOTES

10. Ibid.
Part A: Artificial Selection

Students will explore the differences between artificial selection and genetic engineering. They will then model the process of artificial selection using a simulation involving pinto beans of varying sizes.

GETTING READY

1. Make enough copies of Student Page: Bean Activity for each student.
2. Prepare one bag of 200 beans for each pair of students. Label it “New Beans” (pinto beans work well because they can be quite variable in size [a 1-pound bag is enough for about six groups], but other beans (e.g., lima beans) may work if their sizes vary).
3. Each student should have a ruler to record his or her results.
4. A calculator for each group is optional.
5. Students should sit facing each other with a flat desk or table in between them.
6. Supply each student group with one extra bag or bowl (labeled “Discarded Beans”) for the discarded beans.

DOING THE ACTIVITY

1. Begin this activity by asking students to list organisms that have been genetically modified by humans. They will likely come up with a list that includes examples of organisms that have been modified through both artificial selection and genetic engineering. If they do not, shape the discussion by suggesting some examples of both types.

Genetically modified organisms include various crops (corn from teosinte is an excellent example), dogs, ornamental plants, and trees. GEOS include crops (Bt-resistant corn and cotton), Flavr-Savr tomato, animals (GloFish®), and bacteria (used to produce insulin and many other proteins).

2. Explain to the students that in this activity they will be exploring a specific type of genetic modification called artificial selection. Ask them to come up with a definition of artificial selection. If they are having trouble, remind them of the examples they have just listed in step 1. They should end up with an understanding that artificial selection involves breeding organisms according to their desired phenotypic traits.

3. Go back to the list of organisms the students came up with in step 1, and ask them to identify and circle those that were modified using artificial selection. They should realize that not all the organisms on their list have been circled. Explain to them that genetic modification can be accomplished through different methods and that artificial selection is only one of the methods. At this point, you can introduce the term genetic engineering and explain that the remaining items on their list fall under that category.

4. Tell the students that you are going to have them perform a simulation that models artificial selection, and explain that this activity is an analogy. After briefly outlining the simulation, ask the students to think throughout the simulation how the different parts relate to the concept of artificial selection. Explain that each bean represents an allele for bean size. In this simulation, big beans represent alleles for big bean plants, and small beans represent alleles for small bean plants. Remind students that each organism has two alleles and contributes one of the alleles to the next generation. It is also important to note that many genes affect a single trait and that this example of a single allele representing plant size is greatly simplified.

5. Have the class break up into pairs. For each pair of students, pass out a bag of beans (each bag should contain at least 200 beans), and one “Discarded Beans” bag or bowl. Each student should have a ruler and a copy of Student Page: Bean Activity.
6. Have each student pick 10 beans out of the bag labeled “New Beans.” Using the ruler, have each player measure the length of each of his or her beans in millimeters and record that information on the student page in the column labeled “Length at Beginning of Simulation (mm).” After they have measured all 10 of their beans, ask the players to each calculate the average size of his or her 10 beans and to record that information in the last row of the column.

7. Next, have the players lay out their beans in front of them, in a line, in a random order about 1 inch apart. The line of beans from player 1 should line up with the beans from player 2 (see Figure 1.1). The line of beans represents 10 organisms with two alleles each. Explain to the class that the goal is to use artificial selection to increase the average size of the beans in their possession. Each pair of beans represents a single breeding organism, with each bean representing an allele.

8. Round 1: Taking turns, have each player select a pair of beans. Remind students that their goal is to end up with larger beans. They cannot mix and match between pairs; they must select two beans that are across from each other (see Figure 1.1; selection may result in their choosing a really big bean that is paired with a really small bean). After each player has selected three pairs, have them put the remaining unselected beans in the “Discarded Beans” bag (those beans will no longer be used). The pairs of beans that each student has selected (representing six alleles) are going to be used in the next round. Explain that this round of the activity represents the **generation time** for beans. Generation time is the time it takes an organism to grow and reproduce, and the time varies for different organisms. The generation time for a pinto bean is 2.5 months.

9. Have each student randomly select four new beans from the “New Beans” bag (not the “Discarded Beans”). Ask them to mix those beans in with the selected beans from the previous round. Each student should now have 10 beans (6 from the previous round and 4 new beans), which they should place in a line, in random order. They should then repeat the selection activity, where each student takes a turn at selecting pairs of beans (representing an organism with two alleles). Remind students that after each round of choosing three pairs each, they should put the beans they did not choose in the “Discarded Bean” bag and should keep their selected beans for the next round.

10. Students should repeat step 9 until they have completed 10 rounds. After rounds 5 and 10, students should measure each of their six remaining beans, calculate the average bean size, and record their data on their papers (add the length of the six remaining beans and divide by six). This result is an indication of the average bean size in the population that they have created through their selection process.

11. Have each student subtract the initial average bean size from the final average bean size. The result represents the net increase (or decrease) in bean size for each person. Have each person record this value on a chart on the board.

12. Once all the students have recorded their values, ask them to contemplate causes for the variation. They should come up with reasons, such as different sizes of beans in their bags (representing different genetic material), dif-

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*Figure 1.1. Pair of Beans, Each Representing Two Alleles of a Single Organism.*
ferences among students in their ability to discriminate among beans of different sizes (representing differences among people in characterizing phenotypic traits), and differences as a result of random chance (a big bean randomly paired with a small bean). You can use corn as an example of a genetically modified crop to relate this activity to the real world.

13. As a follow-up to the activity, use the following set of questions to generate discussion among the students. The questions will allow them to solidify their understanding of the analogy of the bean selection simulation to the process of artificial selection.

- This activity is intended to model a real-world process. In this analogy, what are the beans meant to represent in real life?
  
The beans are meant to represent alleles for bean size. Each bean represents a single allele donated by either the male or the female.

- What is the addition of new beans to your line supposed to represent?
  
  It is meant to represent the addition of new alleles into the population. In artificial selection, this determination is done by bringing new plants or animals into your breeding population.

- Why must you choose a pair of beans rather than just one?
  
  One of the beans represents an allele from the mother, and the other bean represents an allele from the father. The pair of beans that is chosen, therefore, reflects a new individual, which has two alleles: one from each parent.

- Although analogies help us understand new ideas, they are often imperfect. What are some ways in which the bean analogy does not accurately reflect reality?
  
  In reality, no single allele codes for size. It is a complex process, influenced by many genes at many loci, as well as by environmental conditions. Also in this analogy, the generation time was very fast, so students were able to see the results of their selections almost immediately. In reality, the generation time for bean plants would be several months.

- Describe the trend in the class data of average bean size.
  
  Students should notice that in general the average bean size has increased. There may be some students whose average bean size stayed the same or even decreased. This is to the result of random chance and reflects the importance of collecting more than one set of data.

- Ask the students how they think the results would differ at 100 rounds? 1,000 rounds?
  
  The more rounds they play, on average, the more dramatic the difference between the beginning average bean size and the final average bean size. Eventually, however, the difference in size will stop changing as they reach the size limit of the population (i.e., their maximum average bean size can never exceed the largest bean in the population).

ENDNOTES

Bean Activity

In this activity, you will be using beans to model the process of artificial selection.

1. Pick 10 beans from your bag labeled “New Beans.” Measure the length of each bean using your ruler and then calculate the average size of all 10 beans. Hint: You calculate the average by adding up all the lengths and dividing by the total number of beans. Remember that in this simulation, the first round has 10 beans; however, after the 5th and the 10th rounds, you are measuring only 6 beans.

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Average length

2. Lay your beans out in front of you. Line them up randomly. In other words, you do not want to try to line them up according to their color or their length. You partner will do the same so that you each have a line of beans in front of you. Your beans and your partner’s beans should be parallel (in line with) each other.

![Figure 1.1a. Pairs of Beans, Each Representing Two Alleles of a Single Organism](image)

3. Players take turns picking the pairs of beans from the lines in front of them until each player has chosen three pairs. The goal is to pick the biggest pair. But you cannot mix and match among pairs! For example, if the biggest bean is paired with the smallest bean, you have to choose both. It is up to you to decide the best strategy. For example you could pick a pair with the biggest bean, even if it is paired with the smallest bean. Or you could pick a pair that has two medium beans.

After each player has chosen three pairs, have one player take the remaining unselected pairs and put them in the bag labeled “Discarded Beans.” Those beans will no longer be used in the simulation.
Bean Activity (continued)

This circle represents a pair of beans. In this simulation, a pair represents one bean from your line and one bean from your partner’s line.

Figure 1.1b. Pairs of Beans, Each Representing Two Alleles of a Single Organism

4. Round 2: Each player should pick four new beans from the bag labeled “New Beans.” Again, each player should randomly line up his or her 10 beans, parallel to the partner’s beans.

   Repeat the instructions in step 3. Do this until you have completed five rounds (a new round begins every time you select new beans).

5. After five rounds, each player needs to measure the six remaining beans in his or her row and to record the information on his or her data table (remember to do this BEFORE you pick the new beans for the next round). Calculate the average bean size.
Part B. Genetic Engineering

Students will identify the variety of organisms that have been genetically engineering by humans. They will then mimic the process of genetic engineering by transforming a plasmid with two novel genes: one for pest resistance and one for fluorescence.

GETTING READY

- Make enough copies of Student Page: Transformation for each student.
- Make enough copies of the following student pages for each group (three to four students per group). Making each of the following student pages a different color will facilitate the activity:
  - Student Page: Paper Plasmid Construction
  - Student Page: Genes for Insertion into Plasmid
  - Student Page: Restriction Enzymes
  - Student Page: Instructions
- Obtain one pair of scissors and clear tape for each group.

DOING THE ACTIVITY

In this activity, students will simulate the insertion of a reporter gene (GFP) and a pest-resistance gene (Bt gene) into a tobacco plant.

1. Begin this activity by reminding students of the list of organisms they developed in the beginning of part A. Explain that in this activity they are still focusing on genetically modified organisms but will explore those GEOs that have been modified using genetic engineering instead of artificial selection and that will go directly to step 2. If you have not already completed part A with your students, you can guide the discussion using the following:

   - Ask your students to come up with a list of organisms that have been modified by humans. Write their examples on the board as they come up with them. They will likely come up with a list that includes examples of organisms that have been modified through artificial selection and genetic engineering. If they do not, shape the discussion by suggesting some examples of both types.

   Examples of organisms modified through artificial selection may include various crops (corn from teosinte is an excellent example), dogs, ornamental plants, and trees. Organisms modified through genetic engineering may include crops (Bt-resistant corn and cotton), Flavr-Savr tomato, animals (Dolly, the cloned sheep), and bacteria (used to produce insulin and many other proteins).

   - At this point, introduce the terms artificial selection and genetic engineering. Artificial selection is based on phenotypic selection of organisms, whereas genetic engineering is more specific than artificial selection in that it usually deals directly with DNA.

   - Go back to the list of organisms that the students came up with in step 1, and ask them to identify those that were modified using artificial selection (by circling them) and those that were modified using genetic engineering (by underlining them). They should realize that genetic modification can be accomplished through several different routes, namely, artificial selection and genetic engineering. At this point, introduce the term transgenic, and explain that it refers to organisms that have been genetically modified through the process of genetic engineering. The class should now be familiar with the definition of genetic engineering and can go directly to step 3.

2. As a class, have the students develop a definition for genetic engineering. Their definition should touch on the fact that genetic engineering involves inserting or deleting DNA. At this point, you can introduce the term transgenic and let them know it refers to organisms that have been genetically modified through the process of genetic engineering.

3. Ask students what they know about transgenic crops. The following questions can be used to lead the discussion so that students mention
some of the costs and benefits associated with transgenic crops.

- What are some examples of transgenic crops?
- Why are the specific advantages of the crops mentioned?
- What are the risks of transgenic crops?

4. Once the students have an understanding of the costs and benefits of transgenic crops, pass out Student Page: Transformation to each student. Have each student read the background information to himself or herself. Initiate a discussion in which students can ask questions about the information they have just read. Note: The use of GFP to monitor an accidental release of a transgenic organism is technically possible and has been used in research settings. It has not, however, been used as yet by farmers for this purpose in a nonresearch setting.1

5. Have one student volunteer to read the scenario from Student Page: Transformation. This information will set the stage for the paper plasmid activity that follows.

6. After the students have read the Student Page: Transformation for the activity, you should initiate a discussion. You will want to give the students an opportunity to discuss why some farmers would choose to use transgenic crops and why some would choose to grow organic crops. Divide the class into two groups, and ask one group to represent the farmer who is growing transgenic crops and one group to represent the organic farmer. Have each group come up with the list of the costs and benefits of each type of crop. Bring the class back together, and then have the groups share their lists with each other.

7. Explain to the students that they will now investigate in more detail how scientists have created the transgenic plant by modeling the steps used to create the plasmid that contains the genes that will be inserted into the crops.

8. Divide the students into small groups (two to four students each). Each group should receive a copy of the following student pages:

- Student Page: Paper Plasmid Construction
- Student Page: Genes for Insertion into Plasmid
- Student Page: Restriction Enzymes
- Student Page: Instructions

In the following steps, students will assemble their circular plasmid and will cut out the genes they will insert. After identifying the correct restriction enzyme, they will use scissors to mimic the actions of the restriction enzyme, cutting both the plasmid and the genes to be inserted. They will then insert the genes into the plasmid. The final product will be a genetically modified plasmid that now contains two novel genes: one for pest resistance (Bt gene) and one for green fluorescence (GFP gene).

**HELPFUL HINTS**

Explain that the DNA fragments are copies of the two genes (Bt resistance and GFP) that were generated by scientists through the use of the **polymerase chain reaction** with a special protocol that generates “sticky ends” (overhanging base pairs at each end of the DNA fragment). The sticky ends are necessary because they allow the two genes to be connected (or ligated) to form a single piece of DNA. This piece of DNA will eventually be inserted into the plasmid and, after the transformation process, will allow the plants to resist certain pests (caused by the Bt gene) as well as to fluoresce (caused by the presence of the GFP gene).

Student Page: Restriction Enzymes lists the three restriction enzymes from which students must choose, as well as details the specific sequences where each one cuts the DNA. Tell students that they need to identify where to cut the plasmid so they can insert the Bt and GFP genes. There are several different cutting sites, so remind the students of what they need to consider, including the following:

- The restriction enzyme should cut the plasmid only once, but it should cut the genes of interest twice.
Students should have identified HindIII as the best choice. It cuts the plasmid only once and cuts the genes on both ends. EcoRI also cuts the plasmid only once, but the sequence does not appear on the genes. PstI does not have a restriction site on either the plasmid or the genes.

- The restriction enzyme should produce the appropriate sticky ends that will allow it to incorporate the DNA fragment containing the genes of interest. Ask the students if they can explain why many restriction enzyme cutting sites are **palindromes**. A palindrome is a word or phrase that reads the same in either direction (e.g., the words “civic,” “level,” “radar,” and “testset” or the phrase “a man, a plan, a canal: Panama”).

- Students should understand that the sequence will be read the same when the two strands of DNA are separated and will be read from the 5-foot end to the 3-foot end.

- Explain the origin of restriction enzymes.

  *Restriction enzymes are naturally produced in bacteria as a defense mechanism. Restriction enzymes chop up DNA that can invade bacteria, thus serving a protective role.*

- Remind the students that they are using scissors to mimic the action of the restriction enzyme they have chosen and are using tape to mimic the action of the enzyme DNA ligase.

9. The students have now created a plasmid that contains the genes for Bt resistance and fluorescence. The next step in this process would be to insert the plasmid into the crops. This step will allow the crops to be both pest resistant and identifiable as transgenic. Use the following questions to assess the student’s understanding of the paper plasmid activity:

- In this activity, you used scissors and tape to represent the tools used in genetic engineering. What tools are those items supposed to represent?

  *Scissors represent restriction enzyme, and the tape is supposed to represent the enzyme ligase.*

- In this activity, we inserted two new genes into the plants: one for fluorescence and one for a pest resistance. What was the purpose of the gene for fluorescence?

  *The fluorescence is a “reporter” gene and allows us to see if a particular plant has been genetically engineered. In this scenario, fluorescence was desired because the organic farmer wanted a way to be able to see if any of the genetically engineered seeds ended up in her fields. Although the average farmer does not currently use fluorescence for this purpose, the technique is routinely used in this way on a smaller scale in the lab or in experimental plots.*

- Would it have been possible for a plant to have been transformed by the Bt gene and not by the GFP gene? Why or why not?

  *Because you inserted both genes into a plasmid, the genes would be transformed together. This transformation is because plasmids are circular pieces of DNA that are taken up by plant cells in their entirety. It is not possible for only part of a plasmid to enter a cell and still be functional.*

- What are some other types of genes that are being inserted into plants?

  *In addition to genes for pest resistance, genes for herbicide tolerance are transformed into crops. This process allows farmers to spray herbicides onto the crops to kill weeds, leaving the crops unaffected. Genes for increased nutrition are also used to transform crops, such as in the case of Golden Rice (genes that increase the amount of vitamin A are inserted).*
ENDNOTES

ENRICHMENTS
- Ask the students to research and write (or draw) an outline that details the next steps necessary to complete the transformation process (transformation of plants using the plasmids). A useful resource that gives an overview of this process can be found at [http://ppge.ucdavis.edu/Transformation/transform1.cfm](http://ppge.ucdavis.edu/Transformation/transform1.cfm).
- Classroom kits are available that contain all the necessary materials to conduct a transformation activity in your classroom. Refer to the “Ordering Supplies” appendix for ordering information.
- Have students check Career Connection: Bioinformatics. The field of bioinformatics centers on the vast amounts of data that are being produced in scientific labs today. For example, determining the genetic sequence of the genomes of organisms (from flies to dogs and humans) is made possible by the use of computer programs that generate, store, and manage extremely large amounts of nucleotide data (the human genome, for instance, is made up of more than three billion base pairs). Computer programs that can simulate complex molecular reactions (such as the folding of proteins) allow scientists to model interactions and reactions that could not otherwise be visualized.

Bioinformaticists can also specialize in conducting the complex statistical analyses required by scientists to interpret the data they generate. In addition to understanding the science behind the data, biostatisticians have a strong background and interest in computer programming, software analysis, and database management. Additional information about the field of bioinformatics can be found at [www.ncbi.nlm.nih.gov/About/primer/bioinformatics.html](http://www.ncbi.nlm.nih.gov/About/primer/bioinformatics.html).
Transformation

**Transgenic** plants (plants that have had genes from another type of organism inserted into them) are commonplace in agriculture today. More than 75 percent of the processed food in the United States is derived from genetically engineered organisms. Pest resistance is one of the most common traits introduced into plants through genetic engineering. Other examples of transgenes include genes for increased growth, longer shelf life, and increased flavor.

Although there are benefits to transgenic plants such as increased crop yield or increased pest resistance, which were just mentioned, there are also concerns about the safety of those plants. One concern is the possibility that genetically engineered plants may breed with their traditional counterparts. Although it is possible to genetically test individual plants to determine if they have been genetically engineered, it is not economically feasible to test every plant from an entire field of crops.

How would farmers know for sure that the plants they grow each year were, or were not, genetically engineered? Scientists have come up with a possible solution to this problem. Insertion of a **reporter gene** along with the gene that contains the desired transgenic trait (such as the ability to resist a certain pest species) would ensure that all plants that were genetically engineered would also produce a discernable phenotypic trait. A reporter gene is a gene that produces some sort of phenotypic signal.

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**Scenario:** Scientists are inserting a gene for pest resistance (**Bt gene**) into soybeans. The Bt gene naturally occurs in a species of bacteria. It codes for a protein that is toxic to certain insects. By inserting this gene into a crop, a farmer can make that crop resistant to insects.

This transgenic plant containing the Bt gene will be sold to a group of farmers whose fields are next door to a farmer who grows only organic crops. The organic farmer has expressed concern that some of the transgenic soybeans from his neighbor will accidentally be sown in his organic fields. To mitigate this problem, the farmer planting the transgenic crop has agreed to use a species that contains a reporter gene in addition to the Bt pest resistance gene.

In this activity, you will help the scientists design a **plasmid** that will contain the gene for pest resistance (Bt gene), as well as a reporter gene (green fluorescent protein gene). Once you have inserted the genes of interest in your plasmid, your research and development team will take over and continue the transformation process that will insert the plasmids into bacteria known as **Agrobacterium tumefaciens**. Plants will then be infected with the transformed bacteria, thus delivering the genes for pest resistance and green fluorescent protein into the soybeans.
Transformation (continued)

Often, reporter genes involve a trait such as antibiotic resistance that allows scientists in the lab to select successful transformants by growing them in the presence of antibiotics that will kill any plants that did not successfully incorporate the desired trait. But another type of reporter gene can cause an organism to glow in the presence of ultraviolet light. This type of trait is visible to the naked eye and would allow farmers to know, simply by looking at a plant at night using an ultraviolet light, whether or not it has been genetically engineered.

The type of gene that researchers use for this detection is one that codes for (that is, has a DNA sequence that directs the production of a specific protein) a green fluorescent protein and is referred to as a GFP gene. The most common source of this gene is marine organisms such as jellyfish that produce the protein naturally. 2

Endnotes:

Paper Plasmid Construction

1. Cut out each strip of DNA on the dotted lines.

2. Tape the strips together in any order (but make sure the letters are facing the same way).

3. This is your paper representation of a plasmid. A plasmid is a circular piece of DNA that is extrachromosomal (that is, is not part of the DNA found in an organism’s nuclear DNA).

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This strip of DNA contains copies of both the GFP gene (bold and on dark gray) and the Bt resistance gene (bold and in light gray). The two genes were generated using polymerase chain reaction and pieced together using an enzyme known as ligase. Cut out the strip of DNA along the dotted line. This fragment of DNA will be the one you will insert into the plasmid.

Note that the sequences have been greatly reduced in length for this simulation. The true gene sequences would be hundreds of base pairs in length.
Restriction Enzymes

The following diagram (Figure 1) illustrates the specific sequences recognized by three different restriction enzymes: EcoR1 (pronounced “eco ar one”), HindIII (pronounced “hin dee three”), and Pst1 (pronounced “pee ess tee one”). The cutting site is indicated with scissors. Each of these sequences is a palindrome. (Hint: The words “civic,” “level,” and “radar” and the phrase “a man, a plan, a canal: Panama” are palindromes.) Why do you think this sequence occurs?

EcoR1 recognizes and cuts at the sequence “G A A T T C”

HindIII recognizes and cuts at the sequence “A A G C T T”

Pst1 recognizes and cuts the sequence “C T G C A G”

Because each of the three restriction enzymes cuts within the recognition sequence, “sticky ends” are produced. A sticky end is a single strand of overhanging base pairs that allow two sequences to be aligned and joined by the enzyme ligase (see Figure 2).

Your job is to decide which restriction enzyme you would use to cut out the genes that will be inserted into your plasmid and to cut your plasmid to allow the insertion. You will use the same restriction enzyme for both. Keep the following in mind when choosing your restriction enzyme:

- You want to cut the plasmid in only ONE location.
- You will need the restriction enzyme to cut both ends of the genes you will insert. This change will create sticky ends that will allow the insert to be ligated into the plasmid.
Instructions

1. Cut out the strips of DNA from the page labeled “Paper Plasmid Construction.” Tape them together (in any order, as long as the letters face the same way) to form a circle. This circle represents your plasmid DNA.

2. Now, cut out the piece of paper that represents the genes you are going to insert from the page labeled “Genes for Insertion into Plasmid.” This paper represents the two genes that you are going to insert into your plasmid.

3. Next, you need to identify which restriction enzyme to use that will produce the correct cutting pattern. You want the restriction enzyme to cut the plasmid only once, but it needs to cut the piece of DNA that contains the genes you want to insert twice. Below, circle the restriction enzyme that is the best choice, and circle the cutting site on both the plasmid and gene. Use Student Page: Restriction Enzymes to learn more about how restriction enzymes work.

4. Once you have identified the appropriate restriction enzyme, use your scissors to cut both your plasmid and your gene at the restriction enzyme cutting sites (follow the dotted lines on the restriction enzyme you circled above). Your results should look like the pictures below.

5. Once you have made the appropriate cuts with scissors, you are ready to insert the genes into the plasmid. Tape the genes into the plasmid, making sure to match up the corresponding base pairs (remember, A pairs with T, G pairs with C). Your final product should be a complete plasmid with two novel genes inserted.
Part C: Risks and Benefits of Genetically Engineered Organisms

Students will evaluate the risks and benefits associated with genetic engineering. They will evaluate information from different sources and will learn to perceive, identify, and evaluate bias in information sources.

GETTING READY

- Make enough copies of the following student pages for each student (each student page should be on uniquely colored paper if possible). If you have multiple classes, you can laminate the copies (or put them in clear plastic paper protectors). Then you can use them repeatedly so that you need to make only as many as you would need to accommodate your largest class. Students can even write on them with markers, and you can clean them with ethanol (or water if the marker is water soluble).
  - Student Page: Genetically Engineered Organisms – Perspective A (industry perspective: pro-biotechnology)
  - Student Page: Genetically Engineered Organisms – Perspective B (environmental group perspective: anti-biotechnology)
  - Student Page: Genetically Engineered Organisms – Perspective C (third-party perspective: independent, verifiable information)
  - Student Page: Detecting Bias

DOING THE ACTIVITY

1. Ask students if they have taken any risks today? To initiate the discussion, you might ask how they traveled to school, what they have eaten, if they drank water from a tap, and so forth. Then ask them to define a risk.

2. Next, divide the class into groups. We suggest keeping group sizes to four or below to encourage participation from all group members. Give everyone in one group copies of Student Page: Perspective A, everyone in the second group copies of Student Page: Perspective B, and everyone in the third group copies of Student Page: Perspective C. If you have more than 12 students, some topics can be covered by multiple groups. Have each group assign the role of reporter and recorder to members of the group.

3. Ask each group to read through the information on its student page and to make a list of the risks and benefits of the genetically engineered organisms that are presented in the information. Make sure to remind the students who have been assigned the role of recorder to write down the information.

4. Have the reporter from each group write its list on the board. Have each group make a separate list so that you end up with three lists.

5. Ask all the students to take a moment and to read through the lists on the board. Ask them if they notice any differences or similarities among the lists.

   They should notice that some of the lists contain mainly risks, one contains both risks and benefits, and one contains mainly benefits.

6. Ask the students why they think their lists were so different. During this discussion, they should determine that the lists they received contained different information.

7. Pass out the remaining student pages so that each group has access to all three. Give students time to read through the two new student pages. Ask each student to mark which student page he or she finds the most persuasive and why.

8. Challenge the students to come up with suggestions of how to detect and evaluate bias in articles. Write their suggestions on the board. Discuss any apparent bias found in each student page.

9. Pass out Student Page: Detecting Bias. Ask the students to identify any methods for detecting bias that are not represented on the list they made in step 8.
10. Ask the students if they have changed their opinion about which article was most persuasive. Why or why not?

11. Ask the students which student page seems the least biased and to explain why.

12. Ask each group to identify the potential sources of each student page. Have the reporter from each group verbally share the group’s thoughts with the class. Reveal the actual sources of the data to the students.

*Student Page: Perspective A was developed by a group composed of professionals from leading biotechnology companies; Student Page: Perspective B was written by the environmental advocacy group Green Peace; and Student Page: Perspective C was written by a group consisting of scientists, religious leaders, and academics who had no personal financial stake in the agriculture biotechnology industry.*

13. Ask students whether they think all industry groups or environmental advocacy groups would hold the same perspective as these respective groups. What might be similar? What might be different?

14. To reinforce students’ ability to detect bias, assign the following activity for homework. Ask each student to find two articles (using newspapers, magazines, and Internet) that represent opposing views on a particular genetically engineered crop. They should summarize the main points of each article and list the type of source and any types of bias that may be evident. Alternatively, they can bring in a single article from a recent newspaper that discusses some type of biotechnology. Ask them to read the article and to summarize the viewpoint of the author. Ask them to consider whether the way the information was presented led to bias (e.g., were only positive consequences discussed? What were the sources of information presented in the article?).

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**ENDNOTES**


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**ENRICHMENT**

Ask the students to consider the risks and benefits of genetically engineered organisms from a global perspective. For example, the need for drought-resistant species in a developing country might be more compelling than the need for the same type of crops in the United States. How might different cultures and different political systems affect how one might perceive risks and benefits?
Genetically Engineered Organisms – Perspective A

**General Information** – Genetically engineered (GE) plants and animals have the potential to be one of the greatest discoveries in the history of farming. Improvements in crops so far relate to improved insect and disease resistance and weed control. Those improvements using bioengineering or GE technology lead to reduced cost of food production. Future GE food products may have health benefits.

**Scientific Impact** – Genetic engineering is a technique that has been used to produce food products that are approved by the Food and Drug Administration (FDA). Genetic engineering has brought new opportunities to farmers for pest control and in the future will provide consumers with nutrient-enhanced foods. GE plants and animals have the potential to be the single greatest discovery in the history of agriculture. We have just seen the tip of the iceberg of future potential.

**Human Impact** – The health benefits from genetic engineering can be enormous. A special type of rice called Golden Rice has already been created and has higher levels of vitamin A. This rice could be very helpful because vitamin A deficiency (VAD) is devastating in third-world countries. VAD causes irreversible blindness in more than 500,000 children and is also responsible for more than one million deaths annually. Because rice is the staple food in the diets of millions of people in the third world, Golden Rice has the potential for improving millions of lives a year by reducing the cases of VAD. The FDA has approved GE food for human consumption, and Americans have been consuming GE foods for years. Although every food product may pose risks, there has never been a documented case of a person getting sick from GE food.

**Financial Impact** – Genetically engineered plants have reduced the cost of food production, which means lower food prices, and that result can help feed the world. In America, lower food prices help decrease the number of hungry people and also let consumers save a little more money on food. Worldwide, the number of hungry people has been declining, but increased crop production using GE technology can also help further reduce world hunger.

**Environmental Impact** – GE technology has produced new methods of insect control that can reduce chemical insecticide application by 50 percent or more. This change means less environmental damage. GE weed control is providing new methods to control weeds, which are a special problem in no-till farming. Genetic engineering of plants has the potential to be one of the most environmentally helpful discoveries ever.

Genetically Engineered Organisms – Perspective B

General Information – Genetic engineering is one of the most dangerous things being done to your food sources today. There are many reasons that genetically engineered (GE) foods should be banned, mainly because unknown adverse effects could be catastrophic! Inadequate safety testing of GE plants, animals, and food products has occurred, so humans are the ones testing whether or not GE foods are safe. Consumers should not have to test new food products to ensure that they are safe.

Scientific Impact – The process of genetic engineering takes genes from one organism and puts them into another. This process is very risky. The biggest potential hazard of genetically engineered foods is the unknown. This process is a relatively new technique, and no one can guarantee that consumers will not be harmed. Recently, many governments in Europe assured consumers that there would be no harm to consumers over mad cow disease, but, unfortunately, their claims were wrong. We do not want consumers to be harmed by GE food.

Human Impact – Genetically engineered foods could pose major health problems. The potential exists for allergens to be transferred to a GE food product that no one would suspect. For example, if genes from a peanut were transferred into a tomato, and someone who is allergic to peanuts eats this new tomato, that individual could display a peanut allergy.

Another problem with genetically engineered foods is a moral issue. The foods are taking genes from one living organism and transplanting them into another. Many people think it is morally wrong to mess around with life forms on such a fundamental level.

Financial Impact – GE foods are being pushed onto consumers by big businesses, which care only about their own profits and ignore possible negative side effects. Those groups are actually patenting different life forms that they genetically engineer and have plans to sell them in the future. Studies have also shown that GE crops may get lower yields than conventional crops.

Environmental Impact – Genetically engineered foods could pose major environmental hazards. Sparse testing of GE plants for environmental effects has occurred. One potential hazard could be the effect of GE crops on wildlife. One study showed that one type of GE plant killed monarch butterflies. Another potential environmental hazard could come from pests that begin to resist GE plants that were engineered to reduce chemical pesticide application. The harmful insects and other pests that get exposed to such crops could quickly develop tolerance and wipe out many of the potential advantages of GE pest resistance.

Genetically Engineered Organisms – Perspective C

**General Information** – Bioengineering is a type of genetic engineering where genes are transferred across plants or animals, a process that would not otherwise occur (in common usage, genetic engineering means bio-engineering). With bioengineered pest resistance in plants, the process is somewhat similar to the process of how a flu shot works in the human body. Flu shots work by injecting a virus into the body to help make a human body more resistant to the flu. Bioengineered plant-pest resistance causes a plant to enhance its own pest resistance.

**Scientific Impact** – The Food and Drug Administration [FDA] standards for genetically engineered (GE) food products (chips, cereals, potatoes, etc.) are based on the principle that they have essentially the same ingredients, although they have been modified slightly from the original plant materials. Oils made from bioengineered oil crops have been refined, and this process removed essentially all the GE proteins, making them like non-GE oils. So even if GE crops were deemed to be harmful for human consumption, it is doubtful that vegetable oils derived from GE crops would cause harm.

**Human Impact** – Although many genetically engineered foods are in the process of being put on your grocer’s shelf, there are currently no foods available in the United States where genetic engineering has increased nutrient content. All foods present a small risk of an allergic reaction to some people. No FDA-approved GE food poses any known unique human health risks.

**Financial Impact** – Genetically engineered seeds and other organisms are produced by businesses that seek profits. For farmers to switch to GE crops, they must see benefits from the switch. However, genetic engineering technology may lead to changes in the organization of the agribusiness industry and farming. The introduction of GE foods has the potential to decrease the prices to consumers for groceries.

**Environmental Impact** – The effects of genetic engineering on the environment are largely unknown. Bioengineered insect resistance has reduced farmers’ applications of environmentally hazardous insecticides. More studies are occurring to help assess the effect of bioengineered plants and organisms on the environment. A couple of studies reported harm to monarch butterflies from GE crops, but other scientists were not able to recreate the results. The possibility of insects growing resistant to GE crops is a legitimate concern.

Detecting Bias

**Tips for Effectively Evaluating Information**

- Question each argument. Imagine you are involved in a debate, and think about how you would present the story from a different side.
- If the sources of facts are listed, go back to the original source and interpret it for yourself. Does your interpretation agree with that of the author?
- Read other articles on the same topic. Seek out sources that disagree, and evaluate their arguments.
- Realize that authors often unintentionally produce biased material. Critically evaluate everything you read, regardless of the source. Even scientists, doctors, teachers, and politicians can produce biased material.

**Questions that Can Help You Detect Bias**

**Where is the source from?** The location of the source can often give you information about its potential for bias. It is important to remember that even sources that claim to be neutral (such as newspapers or news programs) can often be biased in the way they choose to present information.

Types of sources include the following:

- Newspaper—In theory, the news articles are supposed to be neutral and to present both sides of the story. But factors such as choice of language, headline, and placement can all influence a reader.
- Magazine—Magazines often depend on selling ads for revenue, so their articles can be influenced by companies that choose to advertise in their pages.
- Peer-reviewed journal—Peer-reviewed journals contain articles that have been assessed and accepted by other experts in the field. Although those types of articles are generally thought to be factual and neutral, they can still contain forms of bias.
- Internet—All the types of sources listed earlier, in addition to others (blogs, websites, etc.), can be found on the Internet. Although the Internet can be an excellent source of information, it is extremely important that you evaluate the information for yourself because anybody can post information, whether or not it is factual.

**Who is the author?** If you know who the author is, you can potentially assess his or her level of expertise or knowledge. You don’t have to know authors personally; you can “know” them through their job title, by becoming familiar with other examples of their work, or through their public reputation. Consider the following:

- Does the article you are using list the author, or is it anonymous?
- Which would you trust more: an article with an author’s name associated with it or one that lists the author as “anonymous”?
- Under what circumstances would you accept information from an anonymous source?
- What about information from encyclopedias?
- Is there a group or society that is linked to the article?
- Is there an author for each entry?
- Would you accept an argument or a conclusion from an author simply because of his or her qualifications?

**Are facts or opinions being stated?** Facts can be proved true or false with data, whereas opinions cannot. Consider the following:

- Does the author attempt to use opinions as facts?
- Are opinions backed up with facts that can be independently evaluated?
Detecting Bias (continued)

Are all sides being addressed? Ask yourself if the story being presented is balanced. Consider the following:

- Are all sides of the story being presented? Note that there can be more than two sides to an issue (not everything is black or white; there are often various shades of gray).
- Why would only some sides be presented?
- Is there evidence that the author is slanting the article (picking and choosing certain facts that support his or her argument)?

Use of language. Evaluate the author’s choice of language. Choice of words can influence how we feel about an event. Consider the following:

- Does the author use words that are charged with emotion?
- Ask yourself how the author’s choice of words has influenced how you feel about the story.

Are the arguments logical? Break down each argument presented, and ensure that the logic makes sense.

- Is the author using circular reasoning (supporting a premise with another premise)?
- Are there facts and, importantly, sources for those facts presented?
- Authors use citations as a way of sharing with you where they learned the information they are presenting. Although citations are not necessarily appropriate in every type of writing, most academics will use them. Newspapers generally cite their sources of information; ideally, reporters will check out the validity of information gained through their sources.

Should all writing and reporting be free of bias? Can you think of situations where presenting a biased argument is appropriate? Do you think it is possible to be completely free of bias, either as an author or as a reader?
Part D. Case Studies of Genetically Engineered Crops

Students will analyze the risks and benefits of a crop that has been developed in one of three focus areas of agricultural engineering, including nutritional enhancement, pesticide resistance, and resistance to environmental stressors.

GETTING READY

- Make enough copies of the following student pages (one for each group):
  - Student Page: Types of Agricultural Engineering
  - Student Page: Genetically Engineered Plants
- Make a copy of Student Page: Risks, Benefits, and Management Strategies of Genetically Engineered Plants for each student.

DOING THE ACTIVITY

1. Initiate a discussion with the class by asking students if any of them have ever eaten a genetically engineered organism. Record the percentage of those who say yes and the percentage of those who say no (you may have a group of students who say they don’t know; if so, record that information). Compare this statistic with the national average that 75 percent of crops have been genetically engineered. Ask the students whether they are surprised by such numbers.

2. Ask the students how they would know whether the food they are eating has been genetically engineered. This question should lead into a discussion of food labeling, ways to test for genetically engineered foods, and the definition of organic. Current U.S. regulations require labeling only if a GEO is found to be significantly different from its traditional counterpart. Currently in the United States, no foods have been genetically altered that require special labeling. There are relatively simple genetic tests (such as polymerase chain reaction and gel electrophoresis) that can test whether a food product was derived from a genetically engineered source. Genetically engineered foods cannot be sold under the organic label; however, just because a food has not been genetically engineered does not mean it is necessarily organic. In addition to not including genetically engineered organisms, organic foods are grown without the use of pesticides, antibiotics, synthetic hormones, or irradiation. Policies governing the labeling of genetically engineered organism vary among countries. More information on this can be found in Box 1.2 in the Introduction.

3. Break the students into small groups, and ask each group to research and to create a list of plants that have been genetically engineered, along with a list of the trait or traits introduced to each plant. They can use a variety of resources, including the Internet. Ask them to arrange the list into similar categories according to the type of modification. Have each group assign both a recorder and a reporter.

4. After giving the students time to conduct their research, have the reporter from each group write its categories on the board. Discuss the similarities and differences among the groups.

5. Pass out Student Page: Types of Agricultural Engineering. Have the students compare their categories with the ones listed, as well as the specific types of genetically engineered plants. Discuss any discrepancies among the lists.

6. Pass out the Student Page: Genetically Engineered Plants. Ask the students how their lists of specific plants that have been genetically engineered compare with those listed on the student page.

7. Break the class into three groups (or more if the students have decided there are more categories than those represented on Student Page: Types of Agricultural Engineering). Have each group make a list of what it thinks are the benefits and risks associated with each category of genetically engineered crops.
8. Bring the class back together as a group, and have each group take turns listing one of the benefits by writing it on the board—until all potential benefits have been listed. Repeat this activity with the risks.

9. Once the class has listed the risks associated with genetically engineered plants, begin a discussion of risk management. Explain that risk management is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and to ecosystems.2 (See PLT’s Focus on Risk secondary module for more information.)

10. Divide students into small groups again, and have them come up with a risk management strategy for the risks associated with each category of genetically engineered crops. Again, have each group read out each of its answers until all responses are represented on the chalkboard.

11. Pass out Student Page: Risks, Benefits, and Management Strategies of Genetically Engineered Plants. Ask the students to read it and compare it with the list that the class came up with. Discuss any discrepancies.

12. As they use the information and ideas learned in class, have each group come up with a position statement on whether it supports the genetically engineered organisms in its category. Not all members of the group necessarily have to agree with the position statement, but everyone should participate in its presentation.

13. You can end this activity by asking the students to consider if the reasons for genetically modifying an organism affect whether or not they support the use of transgenics. For example, in this activity they were considering different ways to modify agricultural plants. But what about using genetic engineering to produce pharmaceuticals (such as insulin and vaccines)? Ask them to consider the case of the GloFish mentioned in the introduction (use of genetic engineering for “re-creation” (i.e., the creation of pets).

ENDNOTES


Types of Agricultural Engineering

**Nutritional Enhancement:** Genetic engineering can increase the nutritional qualities of plants. Nutritional enhancements can include modifying plants to produce higher yields, to contain novel nutrients such as vitamins, or to decrease the prevalence of nonnutritious components such as trans fats. Genetic engineering introduces novel genes that were not originally present in an organism.¹

**Herbicide Resistance:** Weeds can have significant adverse effects on crop production. Methods of weed control generally fall into three categories: (a) mechanical (tilling or hoeing), (b) cultural (rotating which crops are grown in certain fields), and (c) chemical (through the application of herbicides). Farmers often rely on a combination of all three types of control. Plants that are genetically engineered to be resistant to common herbicides can survive the application of herbicides that are used to control weeds.¹

**Resistance to Environmental Stressors:** A variety of environmental conditions can stress plants and adversely affect plant growth and crop yield. Potential stressors include pests, salinity, and drought. Various plants have been genetically engineered to be immune to or more tolerant of such types of stresses. The genetic modifications can either increase tolerance for varying environmental conditions (allowing plants to survive higher or lower temperatures than usual) or allow plants to visually indicate potential stressors that farmers can then act on (e.g., producing a color change when water availability is critically low).¹²³

**Endnotes:**

Genetically Engineered Plants

(Examples of genetically engineered plants that have been marketed or are in late-stage development)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>Delayed softening, increased salt tolerance, disease resistance</td>
</tr>
<tr>
<td>Rice</td>
<td>Contains vitamin A</td>
</tr>
<tr>
<td>Canola</td>
<td>Herbicide resistance, contains no trans fats</td>
</tr>
<tr>
<td>Turfgrass</td>
<td>Herbicide resistance</td>
</tr>
<tr>
<td>Banana</td>
<td>Vaccine delivery (cholera, hepatitis B, and diarrhea), increased shelf life, pest resistance</td>
</tr>
<tr>
<td>Sunflower</td>
<td>Herbicide resistance, mold resistance</td>
</tr>
<tr>
<td>Potato</td>
<td>Pest resistance</td>
</tr>
<tr>
<td>Flax</td>
<td>Herbicide resistance</td>
</tr>
<tr>
<td>Corn</td>
<td>Pest resistance, drought resistance, increased energy availability, increased nutrients, amylase production (assists in production of ethanol)</td>
</tr>
<tr>
<td>Carnation</td>
<td>Produces a purple carnation</td>
</tr>
<tr>
<td>Cotton</td>
<td>Pest resistance, herbicide resistance</td>
</tr>
<tr>
<td>Dairy</td>
<td>Enzyme that curdles milk to make cheese, protein that increase milk production</td>
</tr>
<tr>
<td>Papaya</td>
<td>Virus resistance</td>
</tr>
<tr>
<td>Peanut</td>
<td>Increased oleic acid content</td>
</tr>
<tr>
<td>Soybean</td>
<td>Herbicide resistance, increased oleic acid content</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>Herbicide resistance</td>
</tr>
<tr>
<td>Apple</td>
<td>Pest resistance</td>
</tr>
</tbody>
</table>

Endnotes:

Benefits of Genetically Engineered Plants

- Increased yield: Genetic engineering can make plants grow faster or produce bigger fruit.
- Decreased use of pesticides: Genetically engineering plants to resist certain pests can eliminate the need to use toxic pesticides to protect the crop.
- Decrease in energy needed to produce crops: Genetic engineering that results in fewer pesticide applications will result in less energy use by farmers (fewer trips with the tractors, thereby saving fuel).
- Increased nutritional quality: Genetic engineering can introduce vitamins and increase protein levels.
- Ability to grow in severe or extreme environmental conditions: Genetic engineering can enable some crops to grow in areas that otherwise may not be able to support a crop; extreme conditions can involve high or low temperatures, flooding, or drought.
- Increased shelf life: Genetic engineering may result in crops that are easier to store and ship.
- Use for human health: Genetically engineered organisms can be used to improve human health such as in the case of edible vaccines.

Risks of Genetically Engineered Plants

- Introduction of allergenic or harmful proteins into food: Concerns have arisen about increasing the presence of known allergens in novel plant species (such as nut allergies) and about the possible toxicity of transgenic proteins not normally consumed by humans.
- Detrimental effect on nontarget species and the environment: Transgenic crops that have insecticidal properties may affect nontarget organisms (e.g., butterflies that naturally feed on the plants).
- Potential for increased invasiveness and weediness of genetically engineered crop plants: Genetic engineering of an organism that already possesses invasive traits could exaggerate such traits, potentially causing widespread environmental damage.
- Pest resistance: The possibility of pests’ developing resistance to transgenic proteins has generated concern.
- Effect on biodiversity: Transgenic crops could hybridize with native plant species, thus decreasing overall biodiversity; cross fertilization through wind-borne pollen or seeds could allow transgenic plants to grow in fields considered free of genetically engineered organisms.

Risk Management Strategies

- Using male sterile plant lines (no pollen produced) prevents crop cross-contamination.
- Making seed viability dependent on the application of a chemical that is not normally found in the environment can prevent seed dispersal.
- Using nonfood crops such as tobacco can limit the possibility of genes entering the food chain.
- Using greenhouses can contain transgenic crops and their pollen and seeds.
- Using phenotypic markers (such as fluorescence) could allow for visual monitoring of transgenes.
- Labeling genetically engineered foods will enable consumer choice.
- Instituting regulatory requirements will ensure that certain safety considerations are met.
- Harvesting crops before they are reproductively mature will limit pollen or seed escape.

Endnotes:

Part E: Issues of Containment

The purpose of this activity is to introduce some of the concerns about the regulation and control of transgenic plants. It is a real-life example of how regulation and containment efforts that were put in place to prevent the unintended escape of a transgene failed. By the end of this activity, students will have a greater understanding of the complexities and potential consequences of transgenic organisms. They will understand that although the potential benefits of transgenic organisms can be great, the risks can be difficult to predict and control. For more information on how risk is communicated, please read Activity 5 in PLT’s Focus on Risk module.

GETTING READY

- Duplicate Student Page: Transgenes Escape to Taco Bell for each student.
- Make four copies of Student Page: Timeline of Events Linked to the Escape of the StarLink™ Transgene.
- Make one transparency of the Timeline of Events Linked to the Escape of the StarLink™ Transgene Student Page.

DOING THE ACTIVITY

1. Begin this activity by asking the students to consider the words containment and escape and to come up with definitions for both. Ask them to suggest things or items that need to be contained and that may escape. Ask students to consider the words in a biological sense. Can they suggest examples of plants and animals that humans have tried to contain but failed? Lead the discussion so that the students eventually consider the idea of gene escape. For example, if a transgenic plant is not contained and ends up producing pollen that fertilizes a nontransgenic plant, the transgene is considered to have escaped.

2. Write the following two phrases on the board: Physical Containment and Biological Containment. Lead the group in a discussion of the differences between the two, and ask the students to come with definitions and examples of each. Write each new example on the board. For physical containment, they might suggest growing plants in a greenhouse, separating male and female plants, or growing only plants of a single sex. For examples of biological containment, they might suggest using only sterile plants or using plants that have been genetically altered to reproduce only in the presence of some external mechanism. Wrap up the discussion by asking the class to consider the following questions: Are physical and biological containment methods mutually exclusive? Will one type of method be best for all types of plants? If not, what are some plant characteristics that might influence containment methods?

3. Ask each student to read the story on Student Page: Transgenes Escape to Taco Bell. Once all students have finished reading, initiate a class discussion to answer any questions they may have and to ensure that they understand the following definitions and concepts:

   - Transgenes and transgenic plants
   - Methods of containing transgenic plants
   - Consequences of not containing transgenic plants
   - The role of the Food and Drug Administration in regulating transgenic organisms

4. Divide the class into four groups. Each group will be assigned one of the following four categories: (a) political, (b) economical, (c) ecological, and (d) human health. Assign a recorder and a reporter in each group. Pass out a copy of Student Page: Timeline of Events Linked to the Escape of the StarLink™ Transgene. Ask each group to fill in its category (political, economical, ecological, and human health) at the top of the last column.
5. Ask each group to read over the timeline of events associated with the StarLink incident and indicate with a check in the column labeled “Category” which of the events described fall under the category assigned to their group.

6. Have the recorder from each group fill in the group’s information on the master overhead using a symbol assigned to each particular category. The groups can each choose a symbol, or symbols can be created and assigned by the teacher. Make sure each group writes a key (e.g., $ = economical) at the bottom of the transparency. Display the results to allow the students to see that each event can have consequences in a variety of categories.

7. Have the reporters from each group stand in front of the class and give a brief summary explaining why the events so indicated fall into that group’s category.

8. After all groups have reported on their categories, initiate a discussion with the students about the variety of consequences associated with the StarLink transgene escape. Ask the students to consider how human error and unforeseen consequences should figure into policy decisions. What can be learned from this particular case?

9. As a follow-up activity, ask each student to write a brief essay that addresses what could be done to minimize the chances of this issue occurring in another transgenic organism and whether he or she feels more limitations should be placed on transgenic organisms.

Ask your students to use the Internet to find popular press articles of this incident (they can start by typing the terms “StarLink” and “Taco Bell” into the Internet search engine). Ask them to print an article, read it, and look for signs of bias (they may need to consult Student Page: Detecting Bias). Have them write a one-page paper that summarizes the type of bias (if any) that they find.
In September 2000, a genetically modified variety of corn, known as StarLink™, was detected in Taco Bell® taco shells. StarLink corn contains a gene known as Cry9C, which codes for a protein that makes plants resistant to certain insects. Because of a concern that this particular gene might induce allergic reactions in humans, the corn was approved for use as feed for nonhuman animals only.¹

Once the StarLink variety was detected in the taco shells, a massive recall was launched to ensure that all foods containing traces of the StarLink corn intended for human consumption were destroyed. However, despite massive efforts to destroy food products containing StarLink corn and to destroy StarLink seed stocks, the StarLink transgene was still detectable in U.S. corn supplies up to 3 years later.²

This story illustrates several very important points. First, efforts to ensure that only livestock ate StarLink corn failed. As a result of the StarLink transgene escape, the U.S. Environmental Protection Agency no longer approves transgenic plants unless they are intended for both human and animal consumption. Second, despite the massive effort, complete removal of the escaped transgene once detected was impossible. Although the prevalence of StarLink corn in the U.S. corn market has decreased dramatically as a result of massive containment efforts, it is still detectable years after having been completely banned.

Endnotes:

# Timeline of Events Linked to the Escape of the StarLink™ Transgene

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Sept.</td>
<td>• StarLink™ corn found in taco shells.</td>
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<tr>
<td></td>
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<td>• Kraft Foods announces recall of taco shells that have been found to contain StarLink corn.</td>
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<td>• Aventis (the biotechnology company that produces StarLink corn) announces it will purchase entire crop of StarLink corn from this year to prevent any further use of the corn in food products.</td>
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<td></td>
<td>Oct.</td>
<td>• Aventis chooses to cancel the U.S. registration of StarLink corn. This move means that StarLink corn can no longer be planted for any agricultural purpose.</td>
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<td></td>
<td>• Aventis asks the Environmental Protection Agency (EPA) to temporarily allow the use of StarLink corn for human consumption because it has already appeared in many food products (EPA considered and later rejected this request).</td>
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<td></td>
<td>Nov.</td>
<td>• The U.S. Department of Agriculture (USDA) announces plans to test corn shipments bound for Japan for the presence of StarLink grain. The move was taken to reassure consumers in Japan, the largest importer of U.S. corn, that the StarLink gene had not escaped.</td>
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<td></td>
<td>• Aventis confirms reports that the StarLink protein (Cry9C) was present in corn hybrids having no known connection to StarLink varieties. USDA officials begin working with the companies involved to investigate the mix-up.</td>
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<tr>
<td></td>
<td>Dec.</td>
<td>• An EPA-appointed Scientific Advisory Panel concludes that the Cry9C protein has a medium likelihood of causing allergic reactions in humans.*</td>
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<td></td>
<td></td>
<td>• Because the Cry9C protein has been found in several varieties of non-StarLink hybrid corn, USDA recommends that U.S. seed companies test all their corn seed lots for the presence of the Cry9C protein.</td>
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</tr>
<tr>
<td>2001</td>
<td>Jan.</td>
<td>• Farmers whose nontransgenic crops were found to contain the Cry9C protein will be compensated for losses they may incur, under an agreement signed by Aventis and the attorneys general for 17 corn-producing states.</td>
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<td></td>
<td>Feb.</td>
<td>• The president, general counsel, and vice president for market development of the U.S. crop sciences division of Aventis Crop Science are fired. A spokesperson for Aventis said it was fair to link the firings to the StarLink fiasco.</td>
<td></td>
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<tr>
<td></td>
<td>Mar.</td>
<td>• Tainted seed is found in inventories slated to be sold to corn farmers this spring. There is concern that U.S. corn exports will suffer again this year if the crop contains traces of the Cry9C protein.</td>
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<td></td>
<td></td>
<td>• USDA announces that it will buy Cry9C-tainted corn seed from small seed companies that are not affiliated with Aventis and were not licensed to sell StarLink corn last year. Major seed companies and companies licensed to sell</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• An Aventis executive estimates the amount of corn contaminated with the Cry9C protein to be 430 million bushels, far more than the amount of contaminated corn seed that will be bought by the U.S. government to prevent its being planted this spring.</td>
<td></td>
</tr>
</tbody>
</table>
# Timeline of Events Linked to the Escape of the StarLink™ Transgene

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>June</td>
<td>• The Centers for Disease Control releases its finding that the transgenic protein in StarLink corn was probably not the cause of the apparent allergic reactions that have been attributed to it by people who suffered symptoms shortly after eating corn products.</td>
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<td></td>
<td>July</td>
<td>• Stores remove from their shelves a brand of tortilla chip made from white corn because traces of StarLink corn were found in it. Makers of tortilla chips have been switching to white corn as a precaution because the Bt Cry9c transgene was incorporated only into a yellow corn variety. Avoidance of yellow corn was believed to eliminate the presence of the StarLink protein, which has been found widely—at low levels—in stores of corn destined for human consumption.</td>
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<tr>
<td></td>
<td></td>
<td>• The panel of scientists who have been advising EPA on the safety of StarLink corn declines to recommend lifting the ban on human consumption of the corn, saying it is not yet satisfied that the transgenic product is safe.</td>
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</tr>
<tr>
<td>2002</td>
<td>Dec.</td>
<td>• Japan’s Agriculture Ministry reports that it has found traces of StarLink corn in a shipment of U.S. corn that docked at Nagoya Harbor. USDA officials say they believe the last stocks of StarLink corn were destroyed last year.</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Sept.</td>
<td>• The genetically engineered (GE) gene from StarLink corn, along with the GE genes from other types of GE corn, is reported to have entered the native corn populations of Mexico. The commercial cultivation of any kind of GE corn is prohibited in Mexico because of concerns about gene flow to Mexico’s indigenous corn varieties, but GE corn kernels can be imported for use as food.</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Oct.</td>
<td>• EPA proposes to cease testing yellow corn for the presence of the StarLink variety after concluding that “potential exposure of the U.S. population to the Cry9C protein in StarLink corn in the current U.S. food supply is extremely low, and continued testing of corn grain by grain handlers and millers for the presence of Cry9C provides no additional human health protection.”</td>
<td></td>
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</tbody>
</table>

*There is no evidence that the StarLink variety of corn has caused harm to any individuals.

**Endnotes:**

Part F. Genetically Engineered Organisms and Clothing

In this activity, students will identify the main traits that are genetically engineered in cotton plants. They will learn how non–genetically modified cotton can be identified and will explore the reasons some clothing manufacturers choose to use organic cotton.

1. Your students will explore the use of genetically engineered cotton in today’s society. Begin by challenging them to identify products that they use in their everyday life and that come from cotton or cottonseed oil or both. On a large piece of paper or the chalkboard, list all the products they identify.

2. Ask your students to arrange the items into categories.

*The two main categories likely to appear are food and clothing.*

3. Using the Internet or other resources, have your students determine what the major modifications are in genetically engineered cotton.

*They should come up with herbicide resistance and pest resistance.*

4. Divide the class into small groups. Challenge each group to identify a clothing manufacturer that chooses to use cotton that has not been genetically engineered. Ask the students to make a magazine advertisement that is for the company and that expresses the reasons for the company’s choosing to use this type of cotton in its products.

*If students are having trouble finding a clothing manufacturer that does not use genetically engineered cotton, the following tips may help them:*

- **One way to determine whether cotton is genetically engineered is to determine if it has been certified organic. Certified organic cotton must come from plants that have not been genetically engineered.**

- **Some big-name clothing manufacturers such as Patagonia sell all organic cotton, whereas others such as Nike advertise that they use a certain percentage of organic cotton. Students will generally find that many brands that use organic cotton tend to be smaller, less global names.**

- **The Organic Trade Association’s website (www.ota.com) contains links and information on organic cotton.**

5. Display the advertisements around the classroom, and allow all students to read each one. Initiate a class discussion that touches on the common themes. You may use the following questions to help guide a discussion:

- What is the most common reason companies express for using organic cotton?

- Are the opinions expressed by the companies supported by facts?

- Are there any flaws or gaps in the logic of the companies?

- What would the economic effect be if all cotton sold were produced from non–genetically modified organisms?

- Did the information from your classmate’s advertisement change your view on genetically engineered cotton? Why or why not?