BUILDING FOOD FOR THE FUTURE

Agricultural Biotechnology Activities for Urban Students
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FOR THE FUTURE

AGRICULTURAL BIOTECHNOLOGY ACTIVITIES FOR URBAN STUDENTS

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Acknowledgements
Development of this unit was funded by a grant to
Washington University Science Outreach from the
Monsanto Fund. Additional support was provided
by Howard Hughes Medical Institute.
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Although agricultural biotechnology has now been around for decades, the average urban citizen has little exposure to this field of research and product development. With the recent marketing and common distribution of genetically modified foods, agricultural biotechnology has now entered everyday life. However, for many people a knowledge gap or disconnect exists between agricultural biotechnology and food consumption. The focus of this curriculum project is to raise the scientific literacy of urban students in the application and use of agricultural biotechnology such that they can be educated consumers and understand the challenge of feeding a rapidly growing world population.

This unit is comprised of several activities designed to enhance student understanding of agricultural biotechnology. The target audience level for the activities is advanced high school biology. While the activities are intended for use together as a single agricultural biotechnology unit, they have been designed in a modular format so that they may be used separately as enhancement for other topics in modern biology and genetics.

SECTION A – WHAT IS AGRICULTURE?

The first section is an introduction to the topic of agriculture, specifically for the urban student who has no real connection to farming practices. The first activity uses a classroom survey to generate conversation about the students’ specific experiences with agriculture. The second activity helps students make the connection between the foods they eat and the practice of agriculture as they are asked to research different foods, discovering animal or plant sources and geographical origins. The third activity is a viewing of Mark Lewis’ film *The Natural History of the Chicken* and completion of a worksheet designed to help students think about their relationship to this particular agricultural product. The fourth activity introduces students to the concept of food production and consumption on a global scale and includes a startling visual demonstration of the disparity in food consumption between major geographical regions. The fifth activity is a viewing of the film *History’s Harvest: Where Food Comes From* and completion of a worksheet designed to help students think about the significant association of science with agriculture. The final activity is a competitive card game invented to give students a hands-on demonstration of selective breeding as they try to fix desirable traits in a crop plant over successive generations. Taken together, this series of six activities can help urban students learn some basics of agricultural history and practice and begin to see how their personal food consumption is actually intimately linked to farming.
SECTION B – BIOTECHNOLOGY AND THE EVOLUTION OF AGRICULTURE

The five activities in the second section explore modern agricultural practices and showcase the significance of biotechnology in agriculture. Students may be unfamiliar with the fact that farmers now use biotechnology in selective breeding of plants and animals. The first activity is inquiry-based, as students must piece together a definition of marker-assisted selection while working through a board game that shows the advantages of having genetic information available in selective breeding of cattle. The second activity is a short reading that defines genetic modification and compares and contrasts the different techniques used to produce modern agricultural products. The third activity explores some specific GM products and the problems they are designed to solve. The fourth activity is an inquiry-based lab experiment designed to show specific challenges of crop farming as students grow “mini-fields” of soybeans and weeds. This lab demonstrates how the combined use of a GM crop and an environmentally responsible herbicide has revolutionized agriculture practices. The final activity in this section has students acting as researchers at a biotech company “testing” powdered potato samples from transgenic plants for the presence of the desired transgene product, human insulin. This hands-on activity introduces students to the concept of biopharming, which promises more plentiful and cheaper supplies of pharmaceutical drugs.

SECTION C – ISSUES

This section covers the controversial issues surrounding the use of agricultural biotechnology. Regulation, labeling, ecology, ethics, and economics are all topics to be considered in a study of modern agriculture. The first activity is a case study of a Canadian incidence of transgenic rapeseed spread into non-transgenic rapeseed. The second activity is a viewing of Harvest of Fear, a Frontline/NOVA film investigating genetically modified foods. The third activity asks students to address the question “How can we better feed a growing population?” as they work in pairs to create a fictional GMO designed to meet certain assigned needs. They will present their product to the board of directors of a biotech company, defending their product on issues of regulation, ecology, ethics, and economics.

APPENDIX

The appendix contains activities designed to broaden your students’ agricultural knowledge through the introduction and reinforcement of specific terminology. These activities are well suited to assignment as homework.
SECTION A

WHAT IS AGRICULTURE?

ACTIVITY A 1: Harvest ........................................... 7
ACTIVITY A 3: “The Natural History of the Chicken” .... 17
ACTIVITY A 4: Feeding the World ......................... 19
ACTIVITY A 5: “History’s Harvest” ....................... 33
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LESSON OVERVIEW

This activity is an introductory lesson designed to get your students thinking about both the practice and the products of agriculture. They will complete a short reading and then survey their classmates for agricultural experiences and information.

TIMELINE

The short reading should take less than 5 minutes for students to complete. The classroom survey may take 10-15 minutes, depending on the agricultural expertise of the students and the layout of your classroom.

HINTS AND TROUBLESHOOTING

• You should have a plan for how the students will move about your classroom during the survey.
• Because there are 35 items on the survey, you will most likely need to have a few students complete more than one item for each individual’s survey sheet.
• Depending on the experiences of the students in your class, there may be survey items that cannot be completed. You should have a plan for how to deal with those particular items. You may choose to participate in the survey so that an additional item is completed.

SURVEY ANSWERS

_____ 1. Someone in my family owns a farm.
_____ 2. I have milked a cow.
_____ 3. I have planted a vegetable garden.
_____ 4. One of my ancestors or relatives worked on a farm.
_____ 5. I have cleaned out a horse stall.
_____ 6. I know what a soybean plant looks like.
_____ 7. I know that flour is ground up wheat seeds.
_____ 8. What time of year is winter wheat harvested? __June/July__
_____ 9. Are potatoes part of the root, stem, or leaves of a plant? __stem__
_____ 10. Are peanuts grown above ground or under ground? __underground__
_____ 11. Who invented the steel plow? __John Deere__
_____ 12. What seeds are used to make bio-diesel? __soybean__
_____ 13. Is broccoli part of the root, stem, or flower of a plant? __flower and stem__
_____ 14. What plants are used to make sugar? __sugar cane, beets, com__
_____ 15. What animal produces wool? __sheep__
_____ 16. What is a steer? __male cow that has been castrated/neutered__
_____ 17. Name a breed of cow that produces milk. __Holstein, Jersey, Guernsey__
18. Name a plant that has been genetically engineered. **soybeans, corn, cotton**

19. Where are oranges grown in the U.S.?  
   **Florida and California**

20. What plant is made into raisins?  
   **grapes**

21. An acre is about the same size as a playground, a football field, or an airport?  
   **a football field**

22. I have planted trees or flowers.  

23. I have driven a tractor.  

24. I have helped bale hay or straw.  

25. What is the difference between hay and straw?  
   **hay is made of grass and straw is made of wheat**

26. Name a product made from corn that is not used for food.  
   **ethanol**

27. Who invented peanut butter?  
   **George Washington Carver**

28. What does a combine do?  
   **harvests crops**

29. What does it mean to plow a field?  
   **turn over soil and break it up**

30. What is a male pig called?  
   **boar**

31. Which state sells the most agricultural products?  
   **California**

32. Which state produces the most cattle and calves?  
   **Texas**

33. What does it mean to plant using a no-tillage method?  
   **the ground is not plowed, instead crops are planted directly into last year’s stubble**

34. How many eggs does the typical American eat in a year?  
   **251**

35. How many people does one U.S. farmer feed today?  
   **144**
Running a combine before dawn in the dead of winter in a strange field was spooky. Inside the big cab it was warm enough. The tilted picture window that started overhead and disappeared below the floor divided him off from the blowing snow that swirled in the headlights. But he didn’t know the references, didn’t know the trees silhouetted in the distance against the night sky that might serve as markers, didn’t know where the rows came out that wandered with the terraces, and watching the saw-toothed cutter bar tripping up soybeans was hypnotic. A man could lose his bearings in the dark in a strange field.

A wet November had caught a neighbor’s four hundred acres of soybeans unharvested. The neighbor had to wait until the ground froze in January to finish up. Tom Bauer had finished his own harvest by then and had some slack time, so he and two other neighbors pitched in to help, four combines in all.

Beans were a bigger challenge to pick anyway than corn. Cornstalks carried their heavy ears waist high, but the brown, rattling bean pods marched down their stiff stalks nearly to the ground. To leave a clean field you had to work the cutter bar close to the roots. (Rhodes, Richard. Farm. New York: Simon and Schuster, 1989.)

Sounds pretty interesting and very intense, doesn’t it? That is the life of a farmer. Unless you live on a farm, you may not know much about farming. This activity is designed to give you some idea about the importance of farming and how it relates to your life.
Following your teacher’s directions, move around the room to survey the other students in your class. Have each person fill out one line and initial that item. Continue until all the lines are complete.

1. Someone in my family owns a farm.
2. I have milked a cow.
3. I have planted a vegetable garden.
4. One of my ancestors or relatives worked on a farm.
5. I have cleaned out a horse stall.
6. I know what a soybean plant looks like.
7. I know that flour is ground up ________________ seeds.
8. What time of year is winter wheat harvested? ______________________________________
9. Are potatoes part of the root, stem, or leaves of a plant? ______________________________
10. Are peanuts grown above ground or under ground? ________________________________
11. Who invented the steel plow? ___________________________________________________
12. What seeds are used to make bio-diesel? _________________________________________
13. Is broccoli part of the root, stem, or flower of a plant? _____________________________
14. What plants are used to make sugar? _____________________________________________
15. What animal produces wool? ___________________________________________________
16. What is a steer? ______________________________________________________________
17. Name a breed of cow that produces milk. __________________________________________
18. Name a plant that has been genetically engineered _________________________________
19. Where are oranges grown in the U.S.?

20. What plant is made into raisins?

21. An acre is about the same size as a playground, a football field, or an airport?

22. I have planted trees or flowers.

23. I have driven a tractor.

24. I have helped bale hay or straw.

25. What is the difference between hay and straw?

26. Name a product made from corn that is not used for food.

27. Who invented peanut butter?

28. What does a combine do?

29. What does it mean to plow a field?

30. What is a male pig called?

31. Which state sells the most agricultural products?

32. Which state produces the most cattle and calves?

33. What does it mean to plant using a no-tillage method?

34. How many eggs does the typical American eat in a year?

35. How many people does one U.S. farmer feed today?
WHERE DO FOODS COME FROM?

TEACHER MANUAL

LESSON OVERVIEW

This activity is designed to help your students make the connection between the foods they eat and the practice of agriculture. They are asked to research eight different foods, discovering each food’s base animal or plant source, the part of the source it is from, and its country or region of origin.

TIMELINE

The short introductory reading will take 5 minutes for students to read. Depending upon the students’ access to reference books or the Internet, the research might take 15-30 minutes. You could assign the research as homework.

ADDITIONAL RESOURCES

- http://www.hungrymonster.com/Foodfacts/Food_Facts.cfm
- Google search engine http://www.google.com/
- Dogpile search engine http://www.dogpile.com/
WHERE DO FOODS COME FROM?

STUDENT MANUAL

One day a man brought a beautiful basket of homegrown strawberries to work. His hungry co-workers enjoyed eating them and wanted to know all about his strawberry patch. One person had never seen strawberries growing and asked, “Do strawberries grow on trees?”

If you’ve never seen strawberries on their source plant, how would you know? Just where do strawberries come from? Well, if you do a little bit of research you will find that strawberries don’t grow on trees. They grow on plants about ten inches tall and you have to get down on your hands and knees to pick the berries because they are hidden by big leaves.

What else do you know about how food is grown? Does spaghetti grow on a plant? Have you ever heard of the ‘sausage tree’ in Africa? What does an eggplant have to do with eggs? Is a pineapple really in the apple family? Do they also grow on trees? Why is a tomato really a fruit? Does a honeydew melon have honey in it? What part of a horse is used to make horseradish?

These may sound like silly questions but have you ever really thought about where foods come from? Which foods come from trees, shrubs, grasses, animals, or flowers?

If you walk into any grocery store you will find an amazing variety of foods conveniently organized for shoppers. You may have watched a store clerk stocking shelves or a produce manager putting out fresh vegetables that have just arrived at the store. You probably know that the food was delivered by truck, but think about the bigger picture for a moment. Where did the truck come from? Was there another truck or a train used to transport the food before it was loaded on to the truck that arrived at the store? Was there an airplane or a boat involved? How far did the food travel to get to your local grocery store?

Just where do foods come from?

ACTIVITY OVERVIEW

In this activity you will choose eight foods to research. If you choose to research a prepared food, you will need to subdivide it into its ingredients. (For example, brownies are made up of flour, water, eggs, sugar, and cocoa.) You will need to find out the following three things for each food:

Source = the name of animal or plant that the food comes from
Source part = the particular part of the animal or plant that the food comes from
Geographic origin = the country or region of the world that the food comes from

A dictionary is a good place to start your research and you may find everything you need there. Internet search engines like Google are also good for this kind of basic research although you will have to search through the resulting web pages for the answers you need. Record the results of your research on the following worksheet.
**WHERE DO FOODS COME FROM?**

<table>
<thead>
<tr>
<th>Food:</th>
<th>Source</th>
<th>Source part</th>
<th>Geographic origin</th>
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</tbody>
</table>
LESSON OVERVIEW

This activity is a viewing of Mark Lewis’ film “The Natural History of the Chicken” and completion of a worksheet designed to help students think about their relationship to this particular food. The student questions are divided into three sections – before watching, while watching, and after watching.

TIMELINE

The running time for the film is approximately 60 minutes. Most of the worksheet can be completed during the film viewing. The section of questions for after watching the film may be completed as homework.

ADVANCE PREPARATION

The film is distributed by PBS Home Video and may be purchased directly from PBS at http://www.shopPBS.org. The cost is $19.98 for the VHS tape or $24.98 for the DVD.

ANSWERS TO STUDENT QUESTIONS

BEFORE watching the film
1. How often do you eat chicken?  
   (Answers will vary.)
2. Have you ever seen a live chicken in person?  
   (Answers will vary.)

WHILE watching the film
1. What are free-range chickens? Is there an advantage for the chickens or farmers?  
   Free-range chickens are not confined to close quarters and they are allowed out of confinement for a certain amount of time each day in order to naturally forage for food in the field. They lay their eggs in the field. It is more labor intensive for the farmer, but the chicken has a more natural existence.
2. What is a housed chicken? Is there an advantage for the chickens or farmers?  
   Housed chickens are confined to small cages. The farmer can maintain a larger number of chickens per area and automate the care and feeding of the chickens.
3. How much money do Americans spend per year on chicken products? $40 billion
4. How many pounds of chicken do we eat per person per year? 80
5. How many chickens are slaughtered per year? 8 billion
6. How many eggs are produced per year? 250 million
7. How many eggs are eaten per person per year? 250

AFTER watching the film
1. If you were offered a McDonald’s chicken sandwich right now, would you feel different about that sandwich? If yes, how? If no, why not? (Answers will vary.)
2. Chickens seem to have some intelligence. Do you think they have emotions? (Answers will vary.)
3. Why do you think Mark Lewis made this film? (Answers will vary.)
“THE NATURAL HISTORY OF THE CHICKEN” A FILM BY MARK LEWIS

BEFORE watching the film
1. How often do you eat chicken?

2. Have you ever seen a live chicken in person?

WHILE watching the film
1. What are free-range chickens? Is there an advantage for the chickens or farmers?

2. What is a housed chicken? Is there an advantage for the chickens or farmers?

3. How much money do Americans spend per year on chicken products?

4. How many pounds of chicken do we eat per year?

5. How many chickens are slaughtered per year?

6. How many eggs are produced per year?

7. How many eggs are eaten per person per year?

AFTER watching the film
1. If you were offered a McDonald’s chicken sandwich right now, would you feel different about that sandwich? If yes, how? If no, why not?

2. Chickens seem to have some intelligence. Do you think they have emotions?

3. Why do you think Mark Lewis made this film?
LESSON OVERVIEW

Feeding the World is an activity designed to introduce students to the concept of global food production and consumption.

In the first part of the exercise, students will be asked to assess and compare land usage and subsequent crop production by graphing and analyzing provided data. The data utilized in the activity comes from the Earthscan report *World Agriculture: Towards 2015/2030. An FAO Perspective* edited by Jelle Bruinsma. Students will calculate the amount of arable land and graph predicted population growth and wheat production. Students will also be asked to assess issues of food safety by addressing the natural hazards and environmental issues for each of the countries.

In the second part of the exercise, students will address the issue of food consumption by using a loaf of bread to represent the consumption of food by various regions of the world. This activity has been adapted from a learning module entitled *Photosynthesis: Lifeline for the World* available through the Missouri Botanical Garden.

After the activity is completed, students will be asked to discuss the current and predicted crop production, current and predicted populations, and consumption. The countries presented in the activity are just suggestions. Students could also be asked to provide similar information from different resources.

TIMELINE

The activity should take a total of 50 minutes to complete, but you may want to reserve time in an additional class period for discussion. It may be helpful for students to do a little background reading on the countries being compared in the activity and if they have been assigned to look up and find data on their own, they may need an extra class period to do so.

MATERIALS

Per student:
- Graph paper
- Calculator
- Colored pencils (7 different colors would be useful)

Per class:
- Loaf of bread
- Globe or world map with country boundaries (optional)

PROCEDURE – PART I

Have the students read the background information, activity overview, and relevant terms provided in the student manual. You may want to have a globe or world map available to them for locating some of the geographic areas mentioned.

The students will be recording their work on graphs and tables in the student manual. They should calculate the area in square miles of arable land using Table A. They should then use Table B to graph the current and predicted populations for each of the countries. Table C will be used to graph the harvested area for wheat, the yield for wheat, and wheat production. Students can use colored pencils to plot the data for each individual country on each of the graphs.
PROCEEDURE – PART II

Divide the students into 5 groups representing the 5 major geographic regions of the world. The number students in each group should be proportional to the percent of the world’s population represented by each of the geographical regions:

- Latin America and the Caribbean = 8%
- Africa = 13%
- North America = 5%
- Europe = 13%
- Asia and Oceania = 61%

Distribute a loaf of bread so that each group receives a percent of the total number of slices proportional to the percent of the world’s food supply consumed by that geographical region:

- Latin America and the Caribbean consume 6%
- Africa consumes 2%
- North America consumes 29%
- Europe consumes 45%
- Asia and Oceania consume 18%

Tell the students that they must share the bread within their group and that this is all the food they will get for this meal and every meal. Guide them through the discussion questions at the end of the activity.

HINTS AND TROUBLESHOOTING

- Some students may need assistance setting up the graphs in Part I. How much assistance you provide is your choice. Advanced students should be able to set up the graphs without assistance.

REFERENCES

Several Internet resources provide information on each country and its various attributes.

- The CIA Factbook contains information on almost every country in the world and can be downloaded. [http://www.cia.gov/cia/publications/factbook/index.html](http://www.cia.gov/cia/publications/factbook/index.html)
- The State Department website can also be very useful. [http://www.state.gov](http://www.state.gov)
- [http://future.state.gov/](http://future.state.gov/)
- [http://www.cityfarmer.org/sublatinamer.html](http://www.cityfarmer.org/sublatinamer.html)
- [http://www.welcometothe-caribbean.com/agriculture.htm](http://www.welcometothe-caribbean.com/agriculture.htm)
- [http://europa.eu.int/comm/agriculture/envir/index_en.htm](http://europa.eu.int/comm/agriculture/envir/index_en.htm)
- [http://www.library.cornell.edu/colldev/lastatistics.html](http://www.library.cornell.edu/colldev/lastatistics.html)
Each year, 79 million people are added to the world population. Practically all of the increases in the global population will be in the developing countries. For example, it is predicted that sub-Saharan Africa’s population will grow by 2.1 percent in 2025-2030. However, for countries with an already low consumption rate and significant levels of undernourishment, the economic growth rates are likely to fall short of what is needed to reduce poverty rates. In 2015, there could be still be 6 percent of the world’s population (462 million) living in countries with very low levels of food consumption.

Cereals will continue to be by far the most important source (in terms of calories) of total food consumption. The world cereal totals must also increase by another billion tons by 2030 in order to feed the growing number of people on the planet. The world food economy is being increasingly driven by the shift of diets toward livestock products. In developing countries, the consumption of meat has been growing by 5-6 percent and that of milk and dairy products by about 3-4 percent in the last few decades. However, much of the growth has been taking place in a small number of countries with large populations such as China and Brazil. The world meat economy has been characterized by a rapid growth in poultry consumption. Poultry will continue to increase its share in the world meat output and the meat trade will expand.

The developing countries have some 2.8 billion hectares of the land with the potential for cultivation. Of this, 960 million hectares are already under cultivation. Many countries in South Asia and the Near East/North Africa region have virtually no spare land left. Much of the land not in use is less suitable for agriculture.

In addition, some of the land with agricultural potential is under forest or in protected areas, in use for human settlements, or suffers from lack of agricultural infrastructure and incidence of disease. Eleven percent (1.5 billion hectares) of the globe’s land surface (13.4 billion hectares) is used in crop production (arable land).

The land balance (land with crop production and potential not in agricultural use) is very unevenly distributed among the regions and countries of the world. Some 90 percent of the land suitable for agricultural use can be found in Latin America and sub-Saharan Africa. At the other extreme, there is virtually no spare land available for agricultural expansion in South Asia and Near East/North Africa. Also, much of the land suffers from ecological fragility, low fertility, toxicity, high incidence of disease, or lack of infrastructure.

Higher productivity is a key element to fighting rural poverty. Utilization of agricultural biotechnology can help increase harvest yields, along with increasing the returns on livestock yields, lowering the amounts of pesticides and fertilizers needed, higher product quality, better
storage and processing, and enhanced methods to monitor the health of plants and livestock. Higher productivity will result in lower prices for food allowing consumers to spend less of their overall incomes on food.

How will developing countries capitalize on the potential of agricultural biotechnology? Will farmers in developing countries have access to the technology and be properly trained in its usage? Think about these issues as you work through the following activities.

**ACTIVITY OVERVIEW**

In this activity, you will construct graphs of data on populations and production of food. Next, you will participate in a group exercise that will compare populations and consumption of food for various regions of the world.

Before starting, you should become familiar with the following words:

- **Acre** – unit of area equal to 4,046.86 square meters or 4,840 square yards
- **Arable** – capable of being cultivated for growing crops
- **Calorie** – a unit of energy-producing potential in food; a unit of energy equal to the heat required to raise the temperature of 1g of pure water by 1°C
- **Cereal** – plant belonging to the grass family that is cultivated for its nutritious grains; cereals include oats, barley, rye, wheat, rice and corn
- **Forage crops** – food for animals, especially crops grown to feed horses, cattle and other livestock
- **Grain** – cereal crops
- **Harvest** – the quantity of the crop that is gathered or ripens during a particular season
- **Hectare** – metric unit of area equal to metric 100 ares or 10,000 sq meters (2.471 acres)
- **Metric ton** – unit of weight equal to 1000 kg
- **Opium** – a brownish gummy extract from the unripe seedpods of the poppy that contains several highly addictive narcotic alkaloid substances, for example, morphine and codeine
- **Sisal** – a strong white fiber obtained form the leaves of the sisal plant used to make rope and rugs
- **Yield** – the amount of crop produced by cultivation

**PROCEDURE – PART I**

1. Use data from Table A to calculate the square kilometers of arable land for each country. Fill in the answers in the appropriate spaces on the table.
2. Using colored pencils and data from Table B, draw a line graph (Graph B) that represents the population growth trend based on current and predicted populations for each country. Think about the amount of arable land and the number of people for each country. Does this seem like enough land to grow the food needed for residents of each country? Look at the main crops that each produces. Are these crops that will sustain the food need of the populations?
3. Using colored pencils and data from Table C, draw three bar graphs that represent the harvested area (Graph C1), yield (Graph C2), and production (Graph C3) of wheat for each country.

In order to get an idea of how much land is being harvested and how much wheat is being produced, you may want to convert the hectares (ha) to acres, kilograms per hectare to pounds per acre, and tons to pounds.

Conversion factors:
1 hectare is equal to 10,000 square meters or 2.471 acres
1 kilogram is equal to 2.2046 lbs
1 ton is equal to 2000 lbs

4. Use your graphs and Table D to complete the Extension Questions on the last page.

PROCEDURE – PART II
1. Your teacher will divide you into 5 groups representing the 5 geographic regions of the world and their populations:
   - Latin America and the Caribbean = 8%
   - Africa = 13%
   - North America = 5%
   - Europe = 13%
   - Asia and Oceania = 61%

2. Your teacher will distribute a loaf of bread. You must decide how many slices of bread your group receives based upon the percent of the world’s food supply consumed by that geographical region.
   - Latin America and the Caribbean consume 6%
   - Africa consumes 2%
   - North America consumes 29%
   - Europe consumes 45%
   - Asia and Oceania consume 18%

3. The individuals in your group must share the bread. This is all the food your group will get for this meal and every meal.

DISCUSSION QUESTIONS
1. Look around the room at the other groups representing other global regions. How does their percent consumption compare to their percent population?
2. Discuss with your classmates the result of the consumption exercise. Which countries got the most bread? Compare this to their populations.
3. Look at the countries that were used for Part I of this activity. To what regions do they belong? What percentage of the world’s food do they receive?
### Table A: Country Profiles

<table>
<thead>
<tr>
<th>Country</th>
<th>Area (sq km)</th>
<th>Percent arable land (%)</th>
<th>Arable land (sq km)</th>
<th>Main crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Republic of Tanzania</td>
<td>945,087</td>
<td>4.52</td>
<td></td>
<td>Coffee, sisal, tea, cotton</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>647,500</td>
<td>12.13</td>
<td></td>
<td>Opium, wheat, fruits, nuts</td>
</tr>
<tr>
<td>Yemen</td>
<td>527,970</td>
<td>2.78</td>
<td></td>
<td>Grain, fruits, vegetables</td>
</tr>
<tr>
<td>Bolivia</td>
<td>1,098,580</td>
<td>2.67</td>
<td></td>
<td>Soybeans, coffee, coca, cotton</td>
</tr>
<tr>
<td>Nepal</td>
<td>140,800</td>
<td>21.68</td>
<td></td>
<td>Rice, corn, wheat, sugarcane</td>
</tr>
<tr>
<td>Mongolia</td>
<td>1,564,116</td>
<td>0.77</td>
<td></td>
<td>Wheat, barley, potatoes, forage crops</td>
</tr>
<tr>
<td>Albania</td>
<td>28,748</td>
<td>21.09</td>
<td></td>
<td>Wheat, corn, potatoes, vegetables</td>
</tr>
</tbody>
</table>

### Table B: Actual and Projected Human Populations (in millions)

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>United Republic of Tanzania</td>
<td>33.5</td>
<td>49.3</td>
<td>65.6</td>
<td>82.7</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>20.8</td>
<td>35.6</td>
<td>50.5</td>
<td>72.3</td>
</tr>
<tr>
<td>Yemen</td>
<td>16.9</td>
<td>33.1</td>
<td>57.5</td>
<td>102.3</td>
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<tr>
<td>Bolivia</td>
<td>8.0</td>
<td>11.2</td>
<td>14.0</td>
<td>17.0</td>
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<tr>
<td>Nepal</td>
<td>22.0</td>
<td>32.1</td>
<td>41.7</td>
<td>524</td>
</tr>
<tr>
<td>Mongolia</td>
<td>2.5</td>
<td>3.1</td>
<td>3.6</td>
<td>4.1</td>
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<tr>
<td>Albania</td>
<td>3.1</td>
<td>3.4</td>
<td>3.8</td>
<td>3.9</td>
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</table>
Graph B: Predicted Population Growth Over Time

<table>
<thead>
<tr>
<th>Color code</th>
<th>Country</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>United Republic of Tanzania</td>
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<td>Afghanistan</td>
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<td></td>
<td>Mongolia</td>
</tr>
<tr>
<td></td>
<td>Albania</td>
</tr>
</tbody>
</table>

Human Population (in millions of people) vs. Time (in years)
### Table C: Harvested Area, Yield, and Production of Wheat

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Harvested Area (ha)</th>
<th>Yield (kg/ha)</th>
<th>Production (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Republic of Tanzania</td>
<td>1979-1981</td>
<td>57,000</td>
<td>1605</td>
<td>91,000</td>
</tr>
<tr>
<td></td>
<td>1989-1991</td>
<td>49,000</td>
<td>1738</td>
<td>85,000</td>
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<tr>
<td></td>
<td>1997-1999</td>
<td>70,000</td>
<td>1526</td>
<td>108,000</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>1979-1981</td>
<td>2,065,000</td>
<td>1240</td>
<td>2,561,000</td>
</tr>
<tr>
<td></td>
<td>1989-1991</td>
<td>1,623,000</td>
<td>1063</td>
<td>1,725,000</td>
</tr>
<tr>
<td></td>
<td>1997-1999</td>
<td>2,112,000</td>
<td>1270</td>
<td>2,681,000</td>
</tr>
<tr>
<td>Yemen</td>
<td>1979-1981</td>
<td>77,000</td>
<td>1066</td>
<td>82,000</td>
</tr>
<tr>
<td></td>
<td>1989-1991</td>
<td>93,000</td>
<td>1497</td>
<td>139,000</td>
</tr>
<tr>
<td></td>
<td>1997-1999</td>
<td>100,000</td>
<td>1441</td>
<td>145,000</td>
</tr>
<tr>
<td>Bolivia</td>
<td>1979-1981</td>
<td>98,000</td>
<td>661</td>
<td>65,000</td>
</tr>
<tr>
<td></td>
<td>1989-1991</td>
<td>92,000</td>
<td>793</td>
<td>73,000</td>
</tr>
<tr>
<td></td>
<td>1997-1999</td>
<td>169,000</td>
<td>886</td>
<td>149,000</td>
</tr>
<tr>
<td>Nepal</td>
<td>1979-1981</td>
<td>372,000</td>
<td>1195</td>
<td>444,000</td>
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<tr>
<td></td>
<td>1989-1991</td>
<td>599,000</td>
<td>1404</td>
<td>840,000</td>
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<tr>
<td></td>
<td>1997-1999</td>
<td>649,000</td>
<td>1637</td>
<td>1,063,000</td>
</tr>
<tr>
<td>Mongolia</td>
<td>1979-1981</td>
<td>414,000</td>
<td>617</td>
<td>255,000</td>
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<tr>
<td></td>
<td>1989-1991</td>
<td>531,000</td>
<td>1144</td>
<td>607,000</td>
</tr>
<tr>
<td></td>
<td>1997-1999</td>
<td>296,000</td>
<td>673</td>
<td>199,000</td>
</tr>
<tr>
<td>Albania</td>
<td>1979-1981</td>
<td>196,000</td>
<td>2514</td>
<td>492,000</td>
</tr>
<tr>
<td></td>
<td>1989-1991</td>
<td>185,000</td>
<td>2741</td>
<td>508,000</td>
</tr>
<tr>
<td></td>
<td>1997-1999</td>
<td>129,000</td>
<td>2743</td>
<td>352,000</td>
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**Graph C1: Wheat Harvested Area Over Time**

<table>
<thead>
<tr>
<th>Color code</th>
<th>Country</th>
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<tbody>
<tr>
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<td>United Republic of Tanzania</td>
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<td>Afghanistan</td>
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<td></td>
<td>Yemen</td>
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<td></td>
<td>Bolivia</td>
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<td></td>
<td>Nepal</td>
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<tr>
<td></td>
<td>Mongolia</td>
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<td></td>
<td>Albania</td>
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</table>
**Graph C2: Wheat Yield Over Time**

<table>
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<tr>
<th>Color code</th>
<th>Country</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>United Republic of Tanzania</td>
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<td></td>
<td>Afghanistan</td>
</tr>
<tr>
<td></td>
<td>Yemen</td>
</tr>
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<td></td>
<td>Bolivia</td>
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<tr>
<td></td>
<td>Nepal</td>
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<tr>
<td></td>
<td>Mongolia</td>
</tr>
<tr>
<td></td>
<td>Albania</td>
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</table>
FEEDING THE WORLD GRAPH C3

Graph C3: Wheat Production Over Time

<table>
<thead>
<tr>
<th>Color code</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>United Republic of Tanzania</td>
</tr>
<tr>
<td></td>
<td>Afghanistan</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Bolivia</td>
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<td></td>
<td>Nepal</td>
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<tr>
<td></td>
<td>Mongolia</td>
</tr>
<tr>
<td></td>
<td>Albania</td>
</tr>
</tbody>
</table>
Table D: Natural Hazards and Environmental Issues

<table>
<thead>
<tr>
<th>Country</th>
<th>Natural hazards</th>
<th>Environmental issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Republic of Tanzania</td>
<td>Flooding on the central plateau during the rainy season; drought</td>
<td>Soil degradation; deforestation; desertification; destruction of coral reefs threatens marine habitats; recent droughts affected marginal agriculture; wildlife threatened by illegal hunting and trade, especially for ivory</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>Damaging earthquakes occur in Hindu Kush mountains; flooding; droughts</td>
<td>Limited natural fresh water resources; inadequate supplies of potable water; soil degradation; overgrazing; deforestation (much of the remaining forests are being cut down for fuel and building materials); desertification; air and water pollution</td>
</tr>
<tr>
<td>Yemen</td>
<td>Sandstorms and dust storms in summer</td>
<td>Very limited natural fresh water resources; inadequate supplies of potable water; overgrazing; soil erosion; desertification</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Flooding in the northeast (March-April)</td>
<td>The clearing of land for agricultural purposes and the international demand for tropical timber are contributing to deforestation; soil erosion from overgrazing and poor cultivation methods (including slash-and-burn agriculture); desertification; loss of biodiversity; industrial pollution of water supplies used for drinking and irrigation</td>
</tr>
<tr>
<td>Nepal</td>
<td>Severe thunderstorms; flooding, landslides, drought, and famine, depending on the timing, intensity, and duration of the summer monsoon</td>
<td>Deforestation (overuse of wood for fuel and lack of alternatives); contaof of minated water (with human and animal wastes, agricultural runoff, and industrial effluents); wildlife conservation; vehicular emissions</td>
</tr>
<tr>
<td>Mongolia</td>
<td>Dust storms; grassland and forest fires; drought; “zud,” which is harsh winter conditions</td>
<td>Limited natural fresh water resources in some areas; the policies of former Communist regimes promoted rapid urbanization and industrial growth that had negative effects on the environment; the burning of soft coal in power plants and the lack of enforcement of environmental laws severely polluted the air in Ulaanbaatar; deforestation, overgrazing, and the converting of virgin land to agricultural production increased soil erosion from wind and rain; desertification and mining activities had a deleterious effect on the environment</td>
</tr>
<tr>
<td>Albania</td>
<td>Destructive earthquakes; tsunamis occur along southwestern coast; floods; drought</td>
<td>Deforestation; soil erosion; water pollution from industrial and domestic effluents</td>
</tr>
</tbody>
</table>
1. Think about the amount of arable land and population for each country. Does this seem like enough land to grow the food needed for residents of each country?

2. Look at the main crops that each country produces. Are these crops that will sustain the food need of the populations?

3. When we compare the yields of wheat for each country and then look at the predicted populations, what conclusions can we make?

4. Look at the natural hazards and environmental issues outlined in Table D. How will they affect each country’s ability to increase is crop yields? What are some ways that each country might address its issues?
HISTORY’S HARVEST

TEACHER MANUAL

LESSON OVERVIEW

This activity is a viewing of the film “History’s Harvest: Where Food Comes From” and completion of a worksheet designed to help students think about science and agriculture. The worksheet is divided into three sections – questions to answer before watching, note taking while watching, and questions to answer after watching.

The film description quoted below is from the American Society of Plant Biologists website:

_History’s Harvest_ presents a sweeping view of 10,000 years of agricultural history, shown against a backdrop of spectacular footage from locations in India, Mexico, the United States and Britain. The film is fast-paced, informative, and visually engaging. Scientific information is presented in a straight-forward manner so that the general public can easily understand.

The film traces the developments in agriculture that led to major breakthroughs including the genetic engineering of crops. It shows how genetic engineering is an extension of what has gone on before and how new technologies are important for the developing world. The film talks about the progression of science and how this has allowed civilization to thrive.

ASPB’s Education Foundation developed this film to provide accurate information to the public on the importance of plant biology in addressing world hunger and to educate the public on where food comes from. In addition to the vivid scenes of people, life and agriculture on three continents, the film includes interviews with prominent scientists.

The film takes viewers from the fields where crops are grown, into the homes in India where food is prepared, into the labs where the latest research is conducted, and into the grocery stores of America where every kind of produce can be found in beautiful abundance. There are discussions with farmers in Iowa, Mexico and India. There are interviews with restaurant owners in California and leading scientists from around the world. The film’s inclusion of scenes that most of us can relate to — today’s supermarkets — adds to its appeal to today’s audiences.

TIMELINE

The running time for the film is just under 62 minutes. If you must cut the viewing time down to fit within your class period, it is recommended that you cut from the beginning of the film rather than the end. Most of the worksheet can be completed during the film viewing. The section of questions for after watching the film may be completed as homework.

ADVANCE PREPARATION

The film is available as a VHS cassette or DVD and may be purchased from the American Society of Plant Biologists at the following website: http://www.aspb.org/education/foundation/history harvest.cfm.

The film is also available as a free download from unitedstreaming, an educational digital video library located at http://www.unitedstreaming.com/. Check to see if you have access to the website through a school or district subscription.
“HISTORY’S HARVEST: WHERE FOOD COMES FROM” PAGE 1

History’s Harvest presents a sweeping view of 10,000 years of agricultural history, shown against a backdrop of spectacular footage from locations in India, Mexico, the United States and Britain. The film is fast-paced, informative, and visually engaging. Scientific information is presented in a straightforward manner so that the general public can easily understand.

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A. BEFORE watching – Assess your prior conceptions by responding to these questions.

1. What does the term “natural food” mean to you?

2. What relationships do you think exist between science and agriculture?
B. **WHILE watching** – As you watch, note specific information presented in the program that helps you understand the relationships that exist between humans, science, and agriculture. Use the space below to take your notes.
C. AFTER watching – Review your notes and answer the following questions.

1. What did corn look like 10,000 years ago and how have humans modified it?

2. Describe how science has affected agriculture during the past 10,000 years.

3. What are the three biggest challenges facing farmers? How do they deal with these challenges?

4. Describe the similarities and differences between synthetic and natural pesticides.
5. Compare and contrast subsistence farming and modern farming practices.

6. How do you think developments in agriculture will affect third world countries?

7. How is genetic engineering being used in agriculture today?

8. In 1900, 60% of the people in the US worked on farms and the average lifespan was 45 years. In 2000, less than 2% of the people in the US worked on farms and the average lifespan was 75. How do you predict agriculture will change in the next 100 years?
BACKGROUND INFORMATION

Humans have been domesticating both animals and plants for thousands of years. Part of the process of domestication involves selective breeding for the presence of desirable phenotypes or traits. When comparing the phenotypes of progenitor species and modern derivatives, like teosinte and corn, the change brought about by human forced selection is dramatic (see photo in student manual).

All students will say they understand that there are different breeds of dogs and that crossing different breeds will result in mongrel or mutt puppies that are a combination of traits from the mother and father’s breeds. They easily understand inheritance of traits. However, many students do not think deeper to the history of dog breeding and realize that the selective breeding of dogs with different traits over hundreds of generations is what has resulted in the vastly different phenotypic breeds we see today. They tend to have a limited understanding of the significance of time in selective breeding. And, most fail to comprehend how farmers, pet breeders, ranchers, etc., utilize the natural genetic variation found in all organisms to their (and our) advantage, by selectively breeding for those traits found most desirable by humans.

It might be helpful to introduce the concept of selective breeding as artificial or directed selection and compare it to Darwinian natural selection. You have probably covered the idea of natural selection within a unit on evolution.

The concept of survival of the fittest requires that there be genetic variability within a species over evolutionary time. There must be genetic possibilities to answer the challenges of the environment over incredibly large stretches of time. Likewise, the concept of directed selection requires that there be a good degree of genetic variability within the organism we wish to improve for our use and it requires a significant amount of time for those desirable traits to become fixed.

LESSON OVERVIEW

This competitive card game was invented to give students a hands-on activity to simulate the process of selection for desirable traits over successive generations. The game focuses on the idea of selection only, leaving out the complication of parental cross breeding. While this over-simplifies the real world situation, it does allow for students without any knowledge of agriculture to understand the point of artificial selection.

Each card suit (hearts, diamonds, spades, clubs) will represent a particular trait with agronomic value. The students will select genes (cards) from the gene pool (deck) to secure the presence of desirable traits in their crop plant (corn). Each student will be working to make a flush (five cards of the same suit) during each round of play (generation). They will earn points from each flush towards the securing of the trait in their crop. A trait is secured when 50 points are achieved in that suit. The students will be...
recording the results of their selection (points) on a
data sheet and they will use plant picture pieces to
represent the traits gained in their crop over time.

Discussion questions will help the students
place the game within the context of actual
agricultural practices and help them understand
the significance of time (generations) and natural
genetic variation (gene pool) in selection.

TIMELINE

Your students should be able to play the game
and fill out their data sheets within one 50-minute
class period. If time is available, you may want to
lead the students through the discussion questions
immediately following the game. If there is not
time for discussion you may assign the discussion
questions as homework in addition to the graph of
results.

MATERIALS

Per group of 4 students:
1 deck of standard playing cards (all face
cards removed, jokers retained)
4 starting plants (small corn stalks)
4 rapid maturity plants (large corn stalks)
4 drought tolerance root systems
8 pest resistance dead bugs
8 increased yield fruits (ears of corn)
4 copies of the student manual
4 pencils or pens

ADVANCE PREPARATION

• Depending upon your class size, you may need
as many as 8 game sets (32 students).
• You will need to remove all face cards from the
decks before play. Leave in the jokers.
• You will need to make a set of the plant picture
pieces (starting plants, rapid maturity plants,
drought tolerance root systems, pest resistance
dead bugs, and increased yield fruits) for each
game set.
• You will want to keep each game set separate
so that the cards and plant pieces do not get
mixed up between sets. Large clasp envelopes
or zip lock bags could be used to store each
game set.
• Lamination of the plant picture pieces will make
them last longer.

RULES OF PLAY

1. Each player will begin with a small corn stalk
   as a starting plant.
2. The plant picture pieces should be placed in a
   pile in the middle of the table. (Players will
   add different picture pieces to their starting
   plants as trait points are accumulated.)
3. One player may shuffle the deck of cards and
   deal each player 7 cards, face down. The
   dealer will stack the remaining cards face
down in the middle of the table.
4. Once the players have reviewed their cards,
   the top card in the leftover stack is to be
   placed face up in the middle of the table.
5. The first player to take a turn has the option of trading a card for the face up card, or picking the top face down card from the leftover stack. Play continues around the table until all cards from the leftover stack have been used.

6. One round through the card stack equals one generation. Each player should end up with the same number of cards with which they began – seven.

7. The goal of each round is to make a flush (5 cards of the same suit) in order to score points toward the ultimate goal of creating a superior plant. The cards’ suits represent desired traits.
   - Hearts = Increased yield
   - Diamonds = Rapid maturity
   - Spades = Pest resistance
   - Clubs = Drought tolerance

8. At the end of the round, players are to show the five cards they choose to use and determine if anyone has completed a flush. A player with a flush will count the total number of points that the numeric cards represent and record the total in the column of the data sheet for that particular trait (suit). Aces count as one point.

9. Only five cards can be counted towards the flush total, even if a player has six or seven cards of the same suit.

10. The two joker cards will act as naturally occurring spontaneous mutations. Any player holding a joker at the end of the round must show the joker.

a. Presence of one joker in a player’s hand will represent a deleterious mutation and cost the player 10 points. The player should take the 10 points from his flush total if he has a flush. If the player does not have a flush, he should take the 10 points from the trait of his choice.

b. Presence of both jokers in a player’s hand will represent an advantageous mutation and award the player 50 points. The player can add the 50 points to the trait of his choice. A player with a flush and a pair of jokers may count the points from both.

11. To start each new round of play, the dealer should collect all cards, shuffle the deck, deal each player seven cards, and set up the card stack as before.

12. As players gain points towards particular traits, they may add representation of those traits to their plants using the plant picture pieces. A trait picture may be added when 50 points have been earned for that trait. When a player secures the rapid maturity trait, he places the larger corn stalk picture piece on top of his original small starting plant.

13. PLAY ENDS WHEN ONE PLAYER IS THE FIRST TO SECURE ALL FOUR DESIRABLE TRAITS IN HIS CROP PLANT. The winning player’s plant must be large (rapid maturity), have a root system (drought tolerance), have fruit (increased yield), and have a dead bug placed nearby (pest resistance).
HINTS AND TROUBLESHOOTING

- Although students thoroughly enjoy playing this game, you may find yourself needing to remind them that they were really not playing a game, but striving to select for a superior crop.
- You may need to explain how to record points and keep track of running totals on the data sheet. The left column for each suit/trait is for keeping track of the points earned in a single round of play or generation. The right column is for keeping track of the total points earned over the course of all previous rounds of play.
- To lengthen the game, and increase the number of generations necessary to secure desirable traits, you may choose to increase the trait point value to 100.
- To shorten the game, you may choose to assign the student groups a single trait or two that they are to secure in their crop in order to win.
- Many high schools prohibit decks of playing cards in school. Therefore, the game is played with all of the face cards omitted. This prevents students from playing “normal” card games and also allows science teachers to override the administrative prohibition on decks of playing cards.

ANSWERS TO STUDENT DISCUSSION QUESTIONS ON WORKSHEET

1. During each round of the game you could only work on getting a flush in a single card suit at one time. What did this mean for you as a farmer practicing trait selection? I could only select for one desirable trait in my crop during each generation.

2. Did any player lose a trait because of the presence of a single joker (loss of points) and then have to work to get it back? Explain what happens using genetics terminology. A deleterious mutation caused a loss of the trait phenotype in my crop. The trait had to be selected for again.

3. In the game each suit represented a particular desirable trait, and the cards in each suit represented genes. How many genes were in the plant gene pool for each trait? If there were fewer cards in each suit, how would that have affected the game? There were ten cards in each suit (ace, 2, 3, 4, 5, 6, 7, 8, 9, 10). If there were fewer cards then it would have been harder to get a flush during each round. What does this mean for genetic variability and artificial selection in crop plants? If there are fewer genes in the gene pool then the genetic variability in the crop is low. This means there are fewer genes and gene combinations that result in desirable phenotypic traits. This means there are fewer possibilities for artificial selection.
4. Was any player able to secure a desirable trait in only one round? Explain why or why not.

No one could get 50 points in a single round with only a flush because the highest flush point total possible is 40. However, if someone has the two jokers, he is awarded 50 points (plus any flush total) and he could get a trait in only one round.

Now explain the significance of generations of selection in securing a desirable trait.

One generation of selection is usually not enough to secure a desirable trait in a crop plant. Many generations are necessary to secure the gene combinations that result in a desirable trait phenotype. Spontaneous advantageous mutations are rare.

5. Is the card game a good model of for multigenic traits? Why or why not?

Yes, the card game is a good model for multigenic traits because several genes must be secured (50 points earned) before the desirable trait shows up in the phenotype (trait piece gets put on plant).
COPY MASTER: FOUR ROOT SYSTEMS
ACTIVITY A6: TRAIT SELECTION GAME: TEACHER

COPY MASTER: EIGHT EARS OF CORN/EIGHT BUGS
COPY MASTER: TWO MATURE CORN STALKS
Humans have been domesticating both animals and plants for thousands of years. Part of the process of domestication involves **selective breeding** for desirable phenotypes or traits. When comparing the phenotypes of progenitor species and modern derivatives, like teosinte and corn, the change brought about by human forced selection is dramatic.

You probably know that there are different breeds of dogs and that crossing different breeds will result in mongrel or mutt puppies that are a combination of traits from both the mother’s and the father’s breeds. This is a familiar example of inheritance of traits. However, people usually do not think deeper into the history of dog breeding and realize that the selective breeding of dogs for different traits over hundreds of generations is what has resulted in the vastly different phenotypic breeds we see today. Most people tend to have a limited understanding of the significance of time in selective breeding. And, most fail to comprehend how farmers, pet breeders, ranchers, etc., utilize the natural genetic variation found in all organisms to their (and our) advantage, by selectively breeding for those traits found most desirable by humans.

It is now time it introduce the concept of selective breeding as **artificial or directed selection** and compare it to **Darwinian natural selection**. You have probably covered natural selection within a unit on evolution. The concept of **survival of the fittest** requires that there be genetic variability within a species over evolutionary time. There must be genetic possibilities to answer the challenge of survival in the environment over incredibly large stretches of time. Likewise, the concept of directed selection or artificial selection, such as a farmer would use, also requires that there be a good degree of genetic variability within an organism we wish to improve for our use and it requires a significant amount of time for those desirable traits to become fixed. A farmer would use directed selection or breeding over many generations to change an animal so that it has desirable traits. For example, he might choose to breed only his largest pigs, hoping to create a consistently larger type of pig so that he can sell more pounds of pork.
per animal. This larger type of pig is not really an unnatural development, it is just one that had not developed through the process of natural selection. The farmer uses directed selection to create an animal with traits more useful to humans.

**ACTIVITY OVERVIEW**

In the following activity you will use a card game to simulate the practice of trait selection in corn. You will play the role of a plant breeder or farmer working to secure advantageous traits in your crop. Playing this game and working through discussion questions should help you to understand the significance of time and genetic variability in the practice of selective breeding.

**MATERIALS**

Per group of 4 students:
1. 1 deck of standard playing cards (all face cards removed, jokers retained)
2. 4 starting plants (small corn stalks)
3. 4 rapid maturity plants (large corn stalks)
4. 4 drought tolerance root systems
5. 8 pest resistance dead bugs
6. 8 increased yield fruits (ears of corn)
7. 4 copies of the student manual
8. 4 pencils or pens

**PROCEDURE HOW TO PLAY**
1. Each player will begin with a small corn stalk as a starting plant.
2. The remaining plant picture pieces should be placed in a pile in the middle of the table. (Players will add different picture pieces to their starting plants as trait points are accumulated.)
3. One player may shuffle the deck of cards and deal each player 7 cards, face down. The dealer will stack the remaining cards face down in the middle of the table.
4. Once the players have reviewed their cards, the top card in the leftover stack is to be placed face up in the middle of the table.
5. The first player to take a turn (person to the left of dealer) has the option of trading a card for the face up card, or trading for the top face down card from the leftover stack. Play continues around the table until all cards from the leftover stack have been used. You may only take the top card from the leftover stack.
6. One round through the card stack equals one generation. Each player should end up with the same number of cards with which they began – seven.
7. The goal of each round is to make a flush (5 cards of the same suit) in order to score points toward the ultimate goal of creating a superior plant. The cards’ suits represent desired traits.
   - Hearts = Increased yield
   - Diamonds = Rapid maturity
   - Spades = Pest resistance
   - Clubs = Drought tolerance

8. At the end of the round (generation), players are to show the five cards they choose to use and determine if anyone has completed a flush. A player with a flush will count the total number of points that the numeric cards represent and record the total in the column of the data sheet for that particular trait (suit). Aces count as one point.

9. Only five cards can be counted towards the flush total, even if a player has six or seven cards of the same suit.

10. The two joker cards will act as naturally occurring spontaneous mutations. Any player holding a joker at the end of the round must show the joker.
   a. Presence of one joker in a player’s hand will represent a deleterious mutation and cost the player 10 points. The player should take the 10 points from his flush total if he has a flush. If the player does not have a flush, he should take the 10 points from the trait of his choice, possibly causing a loss of this trait. (In this event, the trait picture must be removed from the plant.)
   b. Presence of both jokers in a player’s hand will represent an advantageous mutation and award the player 50 points. The player can add the 50 points to the trait of his choice. A player with a flush and a pair of jokers may count the points from both.

11. To start each new round of play, the dealer should collect all cards, shuffle the deck, deal each player seven cards, and set up the card stack as before. (Player to left of dealer always starts the new round.)

12. As players gain points towards particular traits, they may represent those traits on their plants by using the appropriate plant picture pieces. A trait picture may be added when 50 points have been earned for that trait. Whenever a player totals enough points for the rapid maturity trait, he places the larger corn stalk picture piece on top of his original small starting plant.

13. PLAY ENDS WHEN ONE PLAYER IS THE FIRST TO SECURE ALL FOUR DESIRABLE TRAITS IN HIS CROP PLANT. The winning player’s plant must be large (rapid maturity), have a root system (drought tolerance), have fruit (increased yield), and have a dead bug placed nearby (pest resistance).
**TRAIT SELECTION GAME DATA SHEET**

**Directions:** At the end of each round of play (generation), record any points you scored for one of the four traits. You should only be adding points to one trait in any given generation, although mutations (jokers) may negatively affect the point value in a different trait during that generation. When you have a total of 50 points in a trait column, you may add that trait picture to your crop plant.

<table>
<thead>
<tr>
<th>Generations</th>
<th>Hearts Points for Increased Yield</th>
<th>Diamonds Points for Rapid Maturity</th>
<th>Spades Points for Pest Resistance</th>
<th>Clubs Points for Drought Tolerance</th>
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TRAIT SELECTION GAME DISCUSSION QUESTIONS

1. During each round of the game you could only work on getting a flush in a single card suit at one time. What did this mean for you as a farmer practicing trait selection?

2. Did any player lose a trait because of the presence of a single joker (loss of points) and then have to work to get it back? Explain what happened using genetics terminology.

3. In the game each suit represented a particular desirable trait, and the cards in each suit represented genes. How many genes were in the plant gene pool for each trait? ________
   If there were fewer cards in each suit, how would that have affected the game?

   What does this mean for genetic variability and artificial selection in crop plants?

4. Was any player able to secure a desirable trait in only one round? Why or why not?

   Now explain the significance of generations of selection in securing a desirable trait.

5. Is the card game a good model for multigenic traits? Why or why not?
Directions: Use information from your data sheet to make a bar graph of your trait selection results. The graph should compare the number of generations required to secure each of four traits in your crop plant. Be sure to provide a title, additional axes labels, and a legend or key, if necessary.
SECTION B

BIOTECHNOLOGY AND THE EVOLUTION OF AGRICULTURE

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BACKGROUND INFORMATION

Students easily understand how farmers practice artificial selection. Typically, plants or animals are grown and those with desirable traits are used as the parent generation. However, your students may be unfamiliar with the fact that farmers now use biotechnology in a method of selection for breeding plants and animals called marker-assisted selection.

Marker-assisted selection involves the identification and use of DNA markers, which are associated with, or linked to, other genes that are of value to a breeder or farmer. When a marker gene is found that is always associated with a certain desirable trait, then a breeder can test his plants or animals for the presence of the marker gene and assume that the desirable trait will also be present. With this technology, a breeder can determine the eventual phenotype of a plant or animal before it reaches maturity. Simple DNA testing of offspring during an early developmental stage (even in-utero) can give the breeder information about the eventual value of a plant or animal. The main point is that DNA markers can be used as a substitute for normal examination of phenotype, with the advantage of earlier identification of desirable traits.

Many traits that are desirable in agronomic products are multigenic, meaning there may be more than one gene coding for a particular trait. This obviously complicates the use of marker-assisted selection. Meiotic chromosomal recombination events, like crossing over and independent assortment, may make it difficult to find a single marker that is always associated with the several genes responsible for that one trait. In a multigenic trait situation it is necessary to use more than one DNA marker to assist in the selection process. Markers that are always associated with a trait are called closely linked. Markers that are highly (but not always) associated with the trait are called loosely linked. Loosely linked markers may not be linked to the genes of interest after every generation. Obviously, closely linked markers are more valuable to a breeder than loosely linked markers. When using data from DNA markers to help in selective breeding, more genetic testing must be done in successive generations to determine if the marker genes are still associated with, or linked to, the desirable trait. This is an on-going cost for breeders who use this technology.

The use of DNA markers in selective breeding increases the accuracy of selection. Most current animal breeding schemes already have a high degree of selection accuracy for certain traits, in some cases even close to 90%. So, marker-assisted selection is most useful for traits where the accuracy of conventional selection is low, such as the following:

• Traits that have low heritability (think of this as low genetic predictability)
• Traits that are difficult or expensive to measure (ex. disease resistance)
• Traits that cannot be determined until late in life, meaning measuring of the trait is not possible at the time of selection
• Traits that cannot be measured until the animal has been slaughtered and the carcass examined (ex. marbling, meat quality)
• Traits that are currently not selected for because they are not regularly measured (ex. beef tenderness)
• Traits that are phenotypically associated with a trait that you do not want to increase (ex. marker associated with increased milk production but not high fat content of milk)

The other way that marker-assisted selection can help in the overall selective breeding plan is to shorten the generation interval. Conventional animal breeding schemes may be fairly accurate, but they are still dependent upon the time necessary for development of phenotypic traits. As stated earlier, use of DNA markers provides the advantage of earlier identification of desirable traits. Depending upon the lifecycle of a particular crop or animal, this technology can be leveraged to shorten the time between generations. In 1991, scientists were able to shorten generation time in cattle selection by harvesting and testing oocytes from calves while the calves were still in utero. In this velogenetics (speed genetics) scheme the harvested oocytes were matured and fertilized in vitro and then transferred to a surrogate mother cow. A small number of embryonic cells were tested for marker genotypes and then embryos with the desired DNA profile were allowed to develop. Oocytes from those in utero calves were harvested and the cycle continued.

The average cattle farmer interested in using marker-assisted breeding will benefit from the establishment of nucleus herds, made up of animals with known DNA marker profiles. These animals, or their young, are then incorporated into other herds. A breeder can purchase bulls with known DNA marker profiles, or select sires from within his herd and establish their DNA marker profiles. The marker profiles will, more than likely, not be the same for different bloodlines, so each sire line would need to be tested.

Marker-assisted selection should become more useful and less expensive as the identification of more markers increases. The success of the Human Genome Project has influenced efforts at genomic sequencing and identification of genes in other organisms, including cattle. In the future, cattle breeders might be able to test for the presence of DNA sequences that have been identified as being the specific gene for a particular desirable trait.

An important point to be made is that the biotechnology used in marker-assisted breeding does not involve genetic engineering or recombinant DNA technology. Breeders using marker-assisted selection are not making GMOs (genetically modified organisms). Humans have been selectively breeding plants and animals for desirable traits for thousands of years. Use of DNA markers is a modern selection tool that can make the process more efficient.
REFERENCES AND ADDITIONAL RESOURCES


In October 2003, the University of Turin and the Food and Agriculture Organization of the United Nations organized an international workshop entitled “Marker assisted selection: A fast track to increase genetic gain in plant and animal breeding?” The 11 papers from the workshop are available in PDF format at <http://www.fao.org/biotech/Torino.htm>.

The Office of Biotechnology at Iowa State University has prepared a curriculum called “From Mendel to Markers: Impact of Molecular Technologies on Animal, Plant, and Human Genetics.” It is available from ISU Extension by contacting Extension Distribution, 119 Printing and Publications Building, Iowa State University, Ames, IA 50011-3171, (515) 294-5247, fax (515) 294-2945, or e-mail pubdist@iastate.edu. The curriculum is also available in PDF format from <http://www.biotech.iastate.edu/publications/mendel/>. 
LESSON OVERVIEW

The purpose of this activity is to bring about a general awareness of the future of breeding in agriculture. Though marker-assisted selection has been used with many agricultural products we will use cattle (both dairy and beef) for the game. This is an inquiry-based activity in which the students are not given any description of marker-assisted selection but must piece together a definition as they work through the game. The game should be played by the students FIRST. They can use the discussion questions on the worksheet to help focus their thoughts. Upon completion of the game a discussion should take place, followed by the student reading.

There are two main take home points for the students. One, DNA markers can be used as a substitute for normal examination of phenotype. And two, marker-assisted breeding is an example of a use of biotechnology that does not involve making GMOs (genetically modified organisms).

TIMELINE

Your students should be able to play the game and work through a discussion of marker-assisted selection within one 50-minute class period. They may also be able to complete the reading. If time is limited you may assign the reading as homework.

MATERIALS

Per group of 2-4 students:
- 1 game board
- 16 male cow puzzle pieces
  (4 pieces per cow)
- 48 female cow puzzle pieces
  (4 pieces per cow)
- 15 Farm and Fleet cards
- 1 die
- 4 different player tokens (farmer figures)
- Fake money ($50 and $100 bills)
- 4 copies of the Breeding Board Game student manual

ADVANCE PREPARATION

- Depending upon your class size, you may need as many as 8 game sets (32 students).
- You will need to make a copy of the game board for each game set. Enlarge 200% to fit 11” x 17” paper.
- You will need to make a set of the four male cow pictures and 12 female cow pictures for each game set. Each cow should be cut into 4 puzzle pieces, using the dotted lines as a guide. It might be helpful to the students to have the bulls on a different color paper than the cows.
- You will need to make a set of the 15 Farm and Fleet cards for each game set.
ACTIVITY B1: BREEDING BOARD GAME: TEACHER

- You will want to keep each game set separate so that the cow puzzle pieces do not get mixed up between sets. Large clasp envelopes could be used to store each game set.
- Lamination of the cow puzzle pieces, Farm and Fleet cards, and game boards will make them last longer.

RULES OF PLAY
1. Each player begins the game with $200.
2. Place puzzle pieces for four male cows and 12 female cows randomly in the Cow Pen area of the board.
3. Place Farm and Fleet cards upside down in space indicated on board.
4. Establish someone to manage the Co-Op money.
5. Have each player pick a token (farmer figure) to move on the board. Place the tokens on the Homestead space.
6. Roll the die to determine the order of play. The player with the highest number begins the game and play continues clockwise.
7. At the start of a turn, the player can choose to purchase a complete cow for $500. Next, the player rolls the die to see how many spaces to move. The player will then follow the instructions on the space landed upon. Farm and Fleet cards must be returned to the bottom of the card pile after use.
8. Each time a player lands on, or passes, the Homestead, the player collects $200 from the Co-Op.
9. If a player is sent to the Cattle Auction, he must place his token in the auction area and it must remain there until his next turn. On his next turn, if he rolls a 2, 4, or 6, he may move his token to the Homestead. If he does not roll a 2, 4, or 6, he is stuck in the auction area until his next turn.
10. PLAY ENDS WHEN ONE PLAYER IS THE FIRST TO COMPLETE A HERD OF 1 MALE AND 3 FEMALE COWS.

ANSWERS TO STUDENT WORKSHEET
1. Formulate an explanation of marker-assisted selection based on what you observed in the game. Marker-assisted selection must have something to do with knowing which traits are present in a cow and selecting a cow for breeding based on this knowledge. We had to genotype our cattle to see if they had marker genes for desirable traits. When marker genes for desirable traits became available we were able to increase our herds.
2. What would be some benefits of marker-assisted selection? Cows with desirable traits can be identified before the traits are phenotypically observable or even if the traits are not phenotypically observable.
3. What is the difference between closely linked markers and loosely linked markers?
Closely linked markers are always associated with the desirable traits. Loosely linked markers are highly associated with the traits of interest but not necessarily always associated with them. Loosely linked markers may not be linked to the desirable traits after every generation so the cattle must be genotyped after each generation to check for accuracy. Which is more valuable to the farmer? Closely linked markers are more valuable to a breeder than loosely linked markers.

4. In the game the goal was to have 1 male cow and 3 females. Why isn't there a need for an equal number of male and female cows in a herd? One male can breed with multiple females. Only one male is necessary to provide sperm to the herd.

5. What is the difference between a trait that has low heritability and high heritability?
Low heritability traits are difficult to predict and can be influenced by environmental factors. High heritability traits are more easily predicted and are not influenced by environmental factors.

6. How does marker-assisted selection affect the variation in a population and of what significance would this be? (Reflect back on the virus that infected the herd in the game.) Marker-assisted selection can lower the genetic variability in a herd and this can make it more susceptible to disease.

7. What will drive the cost of marker-assisted selection down? New technology can help lower the cost of DNA collection and genotyping or genetic testing. Completion of the cattle genome project can provide more information and help lower marker development costs.
Breeder must pay to have third generation genetically tested for accuracy in breeding with markers.

**Pay $100 to Co-Op**

Cow walked into your pasture and became one of the herd.

**Pick a piece of cow from your neighbor**

Congratulations!
You have just won the GOLDEN SIRE.

**Place male in your herd**

Genetics company found DNA marker linked to fat and protein percentage.

**Earn 2 cattle pieces**

Technology company announces cattle genome is three quarters of the way completed.

**Earn 1 cattle piece**

Genetics company found DNA markers closely linked to increased marbling and appetite in cattle.

**Earn 3 cattle pieces**

Closely linked marker found for resistance to Johne’s disease, an incurable bacterial infection. Johne’s costs farmers more than $200 million annually.

**Earn 2 cattle pieces**

New technology makes marker-assisted selection less expensive.

**Everyone earns 1 cattle piece**
Progeny cow tested and found it DOES NOT carry the DNA marker genes present in its sire.

Lose 1 cattle piece to Cow Pen

Visit Agriculture Department to learn how to use marker-assisted selection.

Pay $100 to Co-Op

Because of limited genetic diversity in herd, a virus wiped out all cows.

Put ALL of your cattle pieces back into Cow Pen

Offspring shown to carry all traits associated with DNA marker.

Earn 2 cattle pieces

A DNA marker for a desirable trait has been found.

Earn 1 cattle piece

Time for cattle to be genotyped for desirable form of a DNA marker. DNA must be collected from hair, tissue, blood, or semen samples.

Pay $150 to Co-Op

A DNA marker for an undesirable trait has been found.

Earn 1 cattle piece
ACTIVITY B1: BREEDING BOARD GAME: TEACHER
ACTIVITY OVERVIEW
In the following activity you will become more familiar with the use of marker-assisted selection as you play the role of a cattle breeder working to complete your herd of one male and three female cows. The game is designed to help you identify some of the pros and cons of utilizing marker-assisted breeding.

MATERIALS
Per group of 2-4 students:
1 game board
16 male cow puzzle pieces
   (4 pieces per cow)
48 female cow puzzle pieces
   (4 pieces per cow)
15 Farm and Fleet cards
1 die
4 different player tokens (farmer figures)
Fake money ($50 and $100 bills)

PROCEDURE HOW TO PLAY
Goal of the game: While playing and working through the Farm and Fleet cards, determine a definition for marker-assisted selection and define the new vocabulary words used in the game. At the conclusion of the game be ready to discuss your findings.
1. Each player begins the game with $200.
2. Place puzzle pieces for four male cows and 12 female cows randomly in the Cow Pen area of the board.
3. Place Farm and Fleet cards upside down in space indicated on board.
4. Establish someone to manage the Co-Op money.
5. Have each player pick a token (farmer figure) to move on the board. Place the tokens on the Homestead space.
6. Roll the die to determine the order of play. The player with the highest number begins the game and play continues clockwise.
7. At the start of a turn, the player can choose to purchase a complete cow for $500. Next, the player rolls the die to see how many spaces to move. The player will then follow the instructions on the space landed upon. Farm and Fleet cards must be returned to the bottom of the card pile after use.
8. Each time a player lands on, or passes, the Homestead, the player collects $200 from the Co-Op.
9. If a player is sent to the Cattle Auction, he must place his token in the auction area and it must remain there until his next turn. On his next turn, if he rolls a 2, 4, or 6, he may move his token to the Homestead. If he does not roll a 2, 4, or 6, he is stuck in the auction area until his next turn.
10. PLAY ENDS WHEN ONE PLAYER IS THE FIRST TO COMPLETE A HERD OF 1 MALE AND 3 FEMALE COWS.
1. Formulate an explanation of marker-assisted selection based on what you observed in the game.

2. What would be some benefits of marker-assisted selection?

3. What is the difference between closely linked markers and loosely linked markers? Which is more valuable to the farmer?

4. In the game the goal was to have 1 male cow and 3 females. Why isn’t there a need for an equal number of male and female cows in a herd?

5. What is the difference between a trait that has low heritability and high heritability?

6. How does marker-assisted selection affect the variation in a population and of what significance would this be? (Reflect back on the virus that infected the herd in the game.)

7. What will drive the cost of marker-assisted selection down?
In traditional cattle breeding, farmers select which animals will be allowed to have offspring. We call this selective breeding. Calves are born, they mature, and if they have traits that are desirable, they are kept and bred. The decision to breed or not to breed a particular animal typically takes place when the animal is an adult and desirable traits have had time to become observable. However, the decision to select an animal for breeding can also be based upon observed parental traits and patterns of inheritance in the animal’s ancestry. Some traits, such as coat color, are easy to determine because they are phenotypically obvious. However, other desirable traits are more difficult to determine. Marbling in beef cattle is a trait that cannot be determined until the animal has been slaughtered and data collected from the carcass.

Breeders are interested in the heritability of desirable traits. Heritability is basically a correlation between genotype and phenotype. If a trait has high heritability then the phenotype of the offspring has a high level of predictability based on the genotype of the parents. For example, coat color is a trait thought to have high heritability in cattle. We can predict with good certainty that the offspring of a brown bull and a brown cow will be brown. Highly heritable traits are more influenced by genetic factors than by environmental factors. On the other hand, a trait that has low heritability is not easily predictable. Often traits may have low or no heritability because they are more strongly influenced by environmental factors than genetic factors. Marbling is such a trait because diet may be significantly responsible for how much marbling is present in the meat of beef cattle.

Today’s farmer can use biotechnology to assist in selective breeding. Marker-assisted selection involves the identification and use of DNA markers, which are associated with, or linked to, other genes that are of value to a breeder or farmer. If a marker gene is found that is always associated with a certain desirable trait, then a breeder could in essence determine the eventual phenotype of a cow before it reaches adulthood. By sampling blood, hair, or semen, isolating the DNA and then testing the DNA for the marker gene, a breeder could determine if a cow will have the desirable trait linked to the marker gene. This would then enable him to sell the cow as a breeder animal at an earlier stage in development – before it has been bred and the offspring observed. The data could also be used to increase the monetary value of the cow.
because it provides evidence for the existence of a desirable trait. The main point is that DNA markers can be used as a substitute for normal examination of phenotype, with the advantage of earlier identification of desirable traits.

Many traits that are desirable in dairy and beef cattle are multigenic. This simply means there may be more than one gene coding for a particular trait. For example, beef tenderness has five genes associated with it. This obviously complicates the use of a DNA marker for that trait. Occurrences like crossing over and independent assortment during meiosis make it difficult to find a single marker that is always associated with the five genes for that one trait. In a multigenic trait situation it is necessary to use more than one DNA marker to assist in the selection process. Markers that are always associated with a trait are called closely linked. Markers that are highly (but not always) associated with the trait are called loosely linked. When using data from DNA markers to help in selective breeding, more genetic testing must be done in successive generations to determine if the marker genes are still associated with the desirable trait.

Markers for cattle traits do exist and are sold or licensed for use by individual companies. However, marker-assisted selection is currently limited because not all of the genes for all of the traits in cattle have been identified. As more DNA markers are identified, the more accurate cattle selection and breeding will become.

An important point to be made is that the biotechnology used in marker-assisted breeding does not involve making GMOs (genetically modified organisms). People have been selectively breeding plants and animals for desirable traits for thousands of years. Use of DNA markers is a modern tool that can make the process more efficient.
LESSON OVERVIEW

This activity is a short reading that defines genetic modification, genetic manipulation, and genetic engineering within the context of agricultural biotechnology.

TIMELINE

The reading should take students approximately 10 minutes to complete.

REFERENCES

Genetically modified, genetically manipulated, genetically engineered… What do these terms mean? Do they mean the same thing? The following reading will help you sort through the differences in these terms and understand how to use them when you are discussing issues in agricultural biotechnology.

The term **genetic modification** itself can be simply defined as changes in the DNA sequence of an organism. Changes to DNA sequences within the cells of organisms happens constantly due to mistakes in DNA replication or due to exposure to specific environmental factors. However, whether these changes occur in somatic (body) cells or germ (sperm and egg) cells results in a significant difference. Changes in DNA sequences of somatic cells only have a consequence for the organism in which they occur. Changes in the DNA sequences of germ cells can have a consequence for the organism’s offspring. Think of UV exposure causing mutations to the cells in the skin of your arm, which only has a consequence for you (possible skin cancer), versus X-ray exposure causing mutations to your egg or sperm cells, which has a consequence for your future children (possible heritable genetic disease or disorder).

A genetic modification event may be the result of a natural occurrence and the resulting unique organism may be referred to as a **natural variant** or a **naturally occurring mutant**. Much of the differences in phenotype seen within a particular species are the result of these natural genetic modifications. Farmers have historically taken advantage of the natural variety in plants and animals by breeding for selected traits that are advantageous. What started as a few mutant individuals within a cattle population may have become the standard type as a farmer chose to breed the herd in a way that resulted in an increased presence of the mutant phenotype.

The mechanism of the genetic modification, or the way in which the genetic modification was achieved, is often at the center of a debate. Scientists have identified many chemical substances that are capable of producing DNA change. These **mutagens** have been used to induce genetic modification in organisms. Some people may believe that any time scientists are involved in genetic modification that the result is inherently unnatural. If a scientist uses a naturally available chemical substance to induce genetic modification, would you consider the resulting mutant to be natural or unnatural? Is an induced mutation ever...
natural? Inducing mutations in a crop plant and then looking for beneficial mutants was one of the first techniques of agricultural biotechnology and it is still in practice today. Researchers routinely use induced mutation to learn about gene function and development.

While the term genetic modification can include both natural and human-induced changes to DNA, the terms genetic manipulation and genetic engineering refer specifically to the deliberate alteration of genes by human intervention. You can use the term genetic manipulation to describe techniques used to cause a change (increase or decrease) in the normal production of a protein within an organism such that the organism exhibits a different trait. Techniques for “knocking out” a particular gene function would most likely fall into the category of genetic manipulation. The term genetic engineering is more often used when describing techniques that create production of a novel or foreign protein in an organism through the insertion of foreign DNA. The terms cloning, recombinant DNA technology, and gene splicing all qualify as genetic engineering. It is often a combination of genetic manipulation and engineering that results in the modern agricultural biotechnology products on the market today.

As you have probably realized, the terms genetic modification, genetic manipulation, and genetic engineering all overlap to a certain degree. You will find that they are often used interchangeably. It might help to think about them as categories, as in the diagram above. Within the broad category of genetic modification there are naturally occurring and human-induced changes to DNA. Within human-induced changes to DNA, there are techniques of genetic manipulation and genetic engineering.

Now that you know something of the different degrees or types of genetic modification, you might see the labeling of a food product as “GM” as kind of vague. Depending upon how you view genetic modification, genetic manipulation, and genetic engineering, it might actually be important to you to know more about what the “GM” designation means for that particular product. Some people may find the manipulation of an organism’s existing genes acceptable but the insertion of foreign genes to be unacceptable. Some people might find the insertion of DNA from a closely related species to be more acceptable than insertion of DNA from a very distantly related species. And some people may think that DNA is DNA, so it is no big deal if we move it around a bit between organisms.
ENVIROPIG AND OTHER GMOs

TEACHER MANUAL

LESSON OVERVIEW

This activity consists of a longer reading that explores some actual GM products. In each case a particular problem is presented and the GM product solution is explained. Novelty GMOs are also presented. Completion of a worksheet follows the reading.

TIMELINE

The reading and worksheet will take 30 – 40 minutes.

REFERENCES


ANSWERS TO STUDENT WORKSHEET
1. How does pig farming cause a problem for the environment? Pig farming generates tons of manure. The manure contains high levels of phosphorus and phytate, which pollute water systems, causing overgrowth of plants and algae.
2. How does EnviroPig alleviate this problem? EnviroPig can digest phytate on its own because of the addition of a phytase gene into its genome. Therefore supplemental phosphorus in its diet is not necessary and it has lower levels of phytate in its manure.
3. What does VAD stand for and what can VAD cause? VAD stands for Vitamin A deficiency. It can cause a weakened immune system, increasing the risk of infections such as measles and malaria, and causing someone sick to remain sick for a longer period of time. Severe deficiencies can cause partial or total blindness. Women with VAD are more likely to die during or after childbirth.
4. Explain how golden rice is a good solution to VAD. Rice is the primary food source for many developing countries but it is not a source of beta-carotene, the precursor to vitamin A. Golden rice contains an additional three genes necessary for the production of beta-carotene. Therefore golden rice is a source of beta-carotene while wildtype rice is not. Switching to golden rice would help developing countries combat VAD.
5. Explain how golden rice is not a good solution to VAD. The amount of beta-carotene produced by golden rice is still far below the required amount to combat VAD. Also, adequate amounts of zinc, protein, and fats are required for the body to absorb beta-carotene, which are lacking in a diet of only rice.
6. How is the landmine detection plant like the research plan for GloFish? Both involve the production of a color change in the presence of a specific environmental element – the thale cress will turn red in the presence of nitrogen dioxide and the GloFish will fluoresce in the presence of a water borne environmental toxin.
7. What do you think about Eduardo Kac’s “GFP Bunny?” (Answers will vary.)
ENVIROPIG

Modern pig farming often involves raising thousands of pigs in a single facility, generating thousands of tons of manure a year. Because normal pigs are unable to digest phytate, a form of phosphorus present in their cereal grain diet, their manure contains high phytate levels. This inability to digest phytate means porcine diets must be supplemented with digestible phosphorus. Both phytate and phosphorus can pollute surface water and ground water. High phosphorus content in ponds and streams leads to extensive plant and algal growth, robbing the water of oxygen, eventually leading to the death of fish and other aquatic organisms. This type of pollution is also a threat to our drinking water supplies.

Attempts to minimize the phosphorus excreted in the feces of pigs basically aim to decrease their phytate intake and/or increase their phytate digestion. The fungal enzyme phytase is often included in the feed of pigs, increasing the amount of phosphorus absorbed by the small intestine while simultaneously minimizing its excretion in the feces. Work is also being done to develop crops that contain phytase in the seeds (or reduced amounts of phytate itself). Other technological solutions have also been investigated. For example, mixing limestone with pig manure reduces its phosphorus content. This is, however, expensive and requires lots of effort to implement.

The proposed alternative is to genetically engineer pigs able to digest phytate on their own, without the use of supplemental phytase. Canadian researchers have patented such an organism as the “EnviroPig.” These scientists combined a bacterial gene coding for phytase production with a mouse gene that causes phytase to be secreted specifically in saliva. Together these genes modify a pig’s digestive abilities and allow for almost complete digestion of all the phytate found in a grain diet. (It is important to note that the enzyme is stable and fully functional in the stomach but is degraded in the small intestine, so it is not excreted in feces.)

Thus, the EnviroPig is desirable for its reduced phosphorus excretion and increased phosphorus absorption without the use of supplemental phosphate or enzymes. Genetically engineered pigs currently under study have growth rates and reproductive characteristics similar to those of wildtype pigs. However, though EnviroPig appears environmentally friendly, many environmentalists are opposed to it because it is a genetically modified organism. Additionally, many environmentalists disagree with the industrial nature of pig farming and believe that fewer pigs should be raised in bigger outdoor spaces. Even those who welcome the creation of EnviroPig are in agreement that testing over an extended period of time is necessary to ensure that genetically engineered pigs have no deleterious effect on the environment and produce pork safe for human consumption.
**GOLDEN RICE**

Vitamin A deficiency (VAD) is a condition afflicting millions of people in developing countries, particularly children and pregnant women. VAD can weaken a person’s immune system, increasing the risk of infections such as measles and malaria, and causing someone who gets sick to remain sick for a longer period of time. In severe deficiencies, partial or total blindness can result. Women with VAD are more likely to die during or after childbirth. Many of the countries in which VAD is a problem depend on rice as the major staple food. Since the part of the rice plant consumed by humans (the endosperm) does not produce beta-carotene (a precursor to vitamin A), those people without access to other vitamin A-rich foods become susceptible to VAD.

Organizations such as the World Health Organization (WHO) and the United Nations’ Children’s Fund (UNICEF) have attempted to solve the problem of VAD with dietary supplements (vitamin capsules, just like the kind you might take everyday) and fortification (adding the vitamin directly to food). There has also been an attempt to educate people in the VAD-afflicted areas about the importance of diversity in food choice, hopefully leading them to choose a more balanced, nutritious diet. Unfortunately, none of these solutions is really considered sustainable in the long run. Dietary supplements and fortification can be expensive to implement, especially for countries with poor economies. Along the same lines, people who eat rice and rice only usually do so because they are too poor to have any other food options.

In an effort to pursue other possible solutions, and in consideration of rice as the existing staple food, two university-based scientists developed “Golden Rice,” rice genetically engineered to produce beta-carotene. This effort is similar to the introduction of iodized salt as a way to reduce mental retardation and goiter resulting from iodine deficiency. Beta-carotene production gives the rice a distinctive yellow or “golden” color.

Engineering rice to produce beta-carotene required the engineering of an entire biosynthetic pathway. There are multiple steps and multiple intermediate products in the production of beta-carotene. In the first version of Golden Rice, three genes provided the three necessary enzymes: phytoene synthase (psy) and lycopene cyclase (lyc) from the daffodil *Narcissus pseudonarcissus*, and phytoene desaturase (ctr1) from the soil bacterium *Erwinia uredovora*. These genes were inserted into the rice genome and placed under the control of an endosperm-specific promoter. A promoter is a DNA sequence at which transcription begins. Thus the genes would only be transcribed and the enzymes produced in the endosperm, not in the entire plant. The use of the *ctr1* gene was espe-
cially ingenious, in that it is capable of catalyzing more than one step in the desired biosynthetic pathway. While this project resulted in a strain of rice able to produce levels of beta-carotene much greater than that found in white rice, this level of beta-carotene production may not be large enough to help prevent VAD.

On behalf of the Humanitarian Rice Board, industry-based scientists at biotech company Syngenta developed a second version of the rice. In Golden Rice 2, the photoene synthase gene from daffodil was replaced with the equivalent gene from corn. This change resulted in a 20-fold increase in grain carotenoid levels over the first strain. The research team estimates that a single serving of Golden Rice 2 could provide 50% of the recommended daily allowance of vitamin A for a 1- to 3-year old child. However, it is important to note that adequate amounts of zinc, protein, and fats are required for the body to absorb beta-carotene and the actual conversion of beta-carotene from Golden Rice to vitamin A must be confirmed in human studies.

The scientists who developed the first strain of Golden Rice experienced a good number of complications regarding intellectual property rights. Intellectual property rights are the exclusive rights of an individual to an idea, invention, or anything else created intellectually, so that others may not commercially profit from it. With Golden Rice 2, the Humanitarian Golden Rice Network has obtained free licenses for humanitarian use from the 32 different companies and universities holding patents on the involved technology. This means that Syngenta can work with breeders in rice-producing countries to make locally adapted varieties of Golden Rice 2 freely available to low-income farmers.

Golden Rice 2 seems like a perfect solution to VAD. However, it has encountered opposition to its genetically engineered nature. There are questions of the necessary rules and regulations regarding its environmental impact, its possible allergic effects, and other such issues brought up against all genetically modified organisms (GMOs) considered as food products. While biotech companies and government regulatory agencies address these types of questions prior to a GM product entering the market and this case is generally regarded as benefiting the common good, there is concern that Golden Rice will legitimize a more widespread use of GMOs that may not be as obviously beneficial or necessary.

Finally, there are concerns with the dependence of so many people’s diets on a single crop, or monoculture. Dependence on a monoculture leads to a vulnerable food supply. Any sort of problem afflicting one field (blight or pests) will affect all of the fields when they all contain the same crop. Of course, this is a problem with monoculture in general, genetically modified or otherwise. There are many who believe that a balanced and diverse diet, supplying a full range of foods and nutrients, is the only way to prevent nutritional deficiencies. While this is entirely accurate, it is questionable how feasible it is in poorer agricultural regions. Other possible non-GMO solutions include the development of family home
garden (to allow for a more diverse diet), public education campaigns to encourage the diversification of food crops, and other such small-scale, low technology solutions.

**OTHER TRANSGENIC PLANTS**

Genetic engineering research is generating some other plants with more unusual problem-solving capabilities.

Selenium is a toxic heavy metal that can become concentrated in soil as water evaporates away. Traditional methods for dealing with toxic chemicals in soil include simply digging up the soil and burying it elsewhere, and chemical treatments known as soil washing. Both of these treatment methods are expensive, labor-intensive, and environmentally damaging. Phytoremediation is an alternative method, in which plants are used to remove chemicals from the soil. The Indian mustard plant *Brassica juncea* has a natural resistance to selenium and absorbs it as it takes in water through its roots. Scientists have genetically modified this plant so that it absorbs even more selenium than usual, while still managing relatively normal growth rates.

Other research has focused upon the ability of thale cress (*Arabidopsis thaliana*) to change color depending on its environmental conditions. The genes triggering the pathway that causes leaves to turn red in the autumn have been manipulated to respond to the presence of nitrogen dioxide. Researchers hope that this could aid in the detection of underground landmines, which release nitrogen dioxide gas into the surrounding soil. Landmines are a common threat during warfare in poor nations, as they are easy to make and easy to bury. Upon detonation they cause a great amount of pain, physical disfigurement, and death. After warfare has ceased, clearing areas of landmines is a particularly dangerous problem. Current methods of detection are either life threatening (such as probing the ground with a stick) or expensive (such as using a vehicle-mounted detector). A safer alternative would be to scatter seeds from modified thale cress plants over suspect land areas from the air and then wait. A plant growing close to a landmine should turn a distinctive red color three to six weeks after taking in nitrogen dioxide through its roots.

While both these transgenic plants have amazingly beneficial properties, there are problems associated with them as well. Transgenic plants outside of a laboratory setting have the possibility of crossbreeding with other plants and of being consumed by other organisms in the environment. In the case of transgenic mustard plant, care is taken so that transgenic plants are not planted too near other plants that are close relatives, and flowers are picked as soon as they appear. Thale cress, on the other hand, almost always reproduces by inbreeding and, as a safeguard, has been genetically modified to have reduced growth without fertilizer. However, these are not foolproof guarantees. The benefits and risks of using transgenic plants in the environment must be considered carefully.
The uses of GMOs are not always as obviously beneficial as those of EnviroPig and the transgenic plants mentioned above. For example, the science of transgenic organisms has begun to appeal to the pet industry, where there is interest in new and unique varieties of animals, and to “biotech artists,” who have found a new medium in which to create art.

The common aquarium fish *Danio rerio* has had its genome supplemented with a gene for green fluorescent protein (GFP) from the jellyfish *Aequoria victoria*, so that it fluoresces under certain light conditions. The fish are marketed as GloFish and are available for purchase from a variety of pet stores and suppliers. While the commercial appeal of a glow-in-the-dark fish might be enough to spark its development, the GloFish was actually developed in a research lab as a way to detect environmental toxins in water. Part of the purchase price for the GloFish goes back to researchers who are still working on perfecting a fish that will only fluoresce in the presence of specific toxins.

In 2000, artist Eduardo Kac introduced his work “GFP Bunny” to the world. In his own words, “My transgenic artwork “GFP Bunny” comprises the creation of a green fluorescent rabbit, the public dialogue generated by the project, and the social integration of the rabbit.” Kac’s transgenic albino rabbit, named Alba, represents a new field of artistic expression, also known as biotech art. In this case, an enhanced version of the green fluorescent gene (EGFP) was inserted into the genome of an albino rabbit embryo, resulting in the development of a rabbit whose fur has the ability to glow green after exposure to a certain kind of light. In other biotech artworks, artists have genetically modified bacteria and have created exhibits that serve to create discussion about the risks of biotechnology and showcase the intersection of science and art.

While both of these novel GMOs serve purposes in their own respective ways, they also highlight the controversial nature of transgenic organisms. Using genetic engineering as a tool to improve global health and nutrition is actually not as widely accepted as using it for novel pet development. This is due to the difference in potential risk associated with those different uses. While keeping a GM pet or using genetic modification as artwork do not represent large potential risks to human health and safety, introducing GMOs into the environment and food supply represents a more significant potential risk.

Obviously the technology of genetic modification has incredible promise for improving the health of humans and the environment. Development of GMOs is now a permanent part of our scientific toolkit and includes risk assessment by government regulators before commercial products reach the market. The challenge is to educate ourselves, with the help of scientists, so that we accurately understand the potential risks and can make responsible decisions.
ENVIROPIG AND OTHER GMOs WORKSHEET

1. How does pig farming cause a problem for the environment?

2. How does EnviroPig alleviate this problem?

3. What does VAD stand for and what can VAD cause?

4. Explain how golden rice is a good solution to VAD.

5. Explain how golden rice is not a good solution to VAD.

6. How is the landmine detection plant like the research plan for GloFish?

7. What do you think about Eduardo Kac’s “GFP Bunny?”
BACKGROUND INFORMATION

Roundup® is the Monsanto trade name for glyphosate, a contact herbicide that acts systemically. When sprayed on leaves, it is absorbed and interferes with normal enzyme activity, effectively killing the plant. Glyphosate prevents EPSPS, 5-enolpyruvyl-shikimate-3-phosphate synthase protein from building aromatic amino acids essential to plant growth. This aromatic amino acid biosynthesis pathway is not present in mammals, birds, or fish and therefore use of glyphosate as an herbicide presents a low risk to human health and the environment.

Roundup® is a non-selective herbicide that is applied in the agricultural industry in the following four ways:

1. Prior to emergence (alfalfa, edible beans, grasses, peas and turf grasses)
2. Prior to or within a growing stand (apples, asparagus, barley, citrus, cotton, corn, grapes, nut crops, cherries, oats, pears, milo, soybeans, sugarcane and wheat)
3. Within established groves (avocado)
4. Using selective equipment (cotton and soybeans)

All of these different matters of application timing will affect the amount of herbicide residue on a particular crop. Additionally, improper application may interfere with plant processes. (For example, cotton has shown its reproductive cycle can be affected if sprayed too late.) Thus, it is not just a question of whether or not glyphosate herbicide is used, but also whether or not it is used at the correct time.

It should be noted that several environmental groups are opposed to the use of glyphosate. However, its use has no limits as far as the Occupational Safety and Health Administration (federal regulatory branch) and National Institute of Occupational Safety and Health (federal research branch) are concerned. It shows low-level ability to leach into soil and is naturally degraded by microbes. It has a half-life in soil of less than 60 days and in water, a half-life of less than seven days. Less than 10% residue has been noted in soil within a growing season. Most insects and animals can tolerate the levels of glyphosate released into the environment, however a few species are susceptible to harm. Monsanto has changed from using the phrase “environmentally friendly” to using the phrase “environmentally responsible” in its advertising due to claims that toxicity studies are too recent and have yet to be thoroughly tested.

Glyphosate and the other ingredients in Roundup® can be hazardous to humans if ingested or mishandled. The precautions listed on the container label should be taken seriously and students should be well supervised during spraying of Roundup®.

Roundup Ready® crops have been genetically modified (GM) to resist Roundup® herbicide. Putting a gene into crop plants that resists the action of Roundup® has opened a whole new weed management option for farmers. In the past, more expensive and toxic herbicides were the only recourse a farmer had to kill weeds. Now farmers allow weeds to grow with the crops.
Then after several weeks, when crops are about six inches tall, the weeds and crops are sprayed. The weeds die but Roundup® resistant crops survive because they have an alternative metabolic pathway provided by the added gene. A weed-free field means more water and nutrients for the crop and therefore a bigger harvest for the farmer.

Roundup® resistance was discovered in the wastewater lagoons of Roundup® production factories. Soil bacteria were able to survive the tiny amounts of glyphosate in the waste stream due to their ability to produce an alternate protein, CP4 EPSPS, which is naturally less sensitive to glyphosate inhibition. Genes from the bacteria were isolated and transferred to select crops, making them resistant to Roundup® herbicide. Canola, sugar beets, cotton, soybeans, and corn have all been genetically modified to be Roundup® resistant.

In developing and marketing GM crops, Monsanto and other agricultural biotechnology companies are required to follow stringent safety and testing guidelines mandated by the federal government. However, some people do not think the testing has been accurate for assessing long-term results and others are opposed to GM products in general.

REFERENCES
- http://ehp.niehs.nih.gov/docs/2005/113-6/ss.html#round
- http://www.blackherbals.com/glyphosate1.htm
- www.naturescountrystore.com
- http://www.biotech-info.net/problem_with_soy.html
LESSON OVERVIEW

This is an inquiry-based lab experiment designed to show high school biology students the challenges of crop farming – how crops have to be cared for in order to achieve maximum food production. Under teacher direction, students plant horticulture flats as “mini-fields” consisting of two specific rows of soybean seed (the crop), and random scatterings of corn, sunflower, and grass seed (the weeds). Information about the differences in the soybean seed is withheld from the students. One row of soybeans is wildtype and the other row is Roundup Ready®, genetically engineered to resist Roundup® glyphosate herbicide. Seven to ten days after planting, students spray their mini-fields with Roundup® to control for weed infestation. They make daily observations post-herbicide application and they must draw their own conclusions about what makes the surviving row of soybean plants different. This experiment provides students with a clearer understanding of the challenges of crop production and the use of biotechnology to solve problems.

TIMELINE

This experiment will require one 50-minute class period for students to do the initial set up and planting of mini-fields. Eight to ten days later, 10 minutes of class time will be required for students to spray Roundup® glyphosate herbicide on the experimental mini-fields. Post-herbicide application, 10 minutes of class time will be required each day for students to make and record their observations. It may take up to 7 days to see good results, however the total number of days of observation required is up to the individual teacher. It may take students 30 minutes to complete the reading and worksheet questions and this could be assigned as homework.

MATERIALS

Per group of 4 students:
- 10 Wildtype soybeans (non-GM)
- 10 Roundup Ready® soybeans (GM)
- Weed seeds (rye grass, sunflower, corn, radish)
- Planting flat or tray
- Potting soil, enough for 2-3 inches deep in planting flat
- Masking tape
- Permanent marker

Per class:
- Watering can with sprinkler head
- Spray bottle containing 1% Roundup® glyphosate herbicide solution
- Light source (deep window sill or fluorescent light bank)
ADVANCED PREPARATION

Soybean Seed
• You will need to find a local source for wildtype and Roundup Ready® soybean seed. Farm co-ops and feed stores are good places to start.

Weed Seed
• You can purchase “weed” seed at local plant nursery stores.
• Untreated rye grass may be available in small amounts from bulk bins.
• Corn, sunflower, and radish should be available in seed packets.
• You will need to plan ahead as some nurseries only carry seed packets in early spring.

Roundup®
• This experiment requires glyphosate ONLY. The agricultural Roundup® formulation may not be available at Wal-Mart®, K-Mart®, or Target®. It should be available at large home improvement centers like Lowe’s® or Home Depot®.
• You must dilute the agricultural Roundup® (41% glyphosate) down to 1% with water.
• Do NOT use the following formulations of Roundup® as they have additional active ingredients that are toxic to all plants, including Roundup Ready® soybeans:
  • Roundup® Ready to Use Plus (2% glyphosate, 2% pelargonic acid)
  • Roundup® Concentrate Plus (18% glyphosate, 0.73% diquat dibromide)

_HINTS AND TROUBLESHOOTING_

• This experiment can be done as a demonstration or class project if time and space is limited. In this case, plant only two trays – one as the experimental (to be sprayed) and the other as a control (unsprayed).
• Topsoil will work if potting soil is unavailable.
• Other types of seeds may be used as “weeds” but they should have a germination time similar to soybeans.
• The deeper the planting tray, the longer the experiment can run. Plastic “flats” from a garden supply store work very well. You can use planting cells or pots, but that will take away from the idea that the students are planting mini-fields.
• The plants will grow more quickly in a warm room. It is ideal to grow them at 80°F, but they will do fine at average room temperature (72-78°F).
• Plants will be pushing up cotyledons after 1-3 days at 80°F with good light.
• Plants placed in a windowsill (not in a greenhouse or under lights) will be up within 6 days. If the window faces north, the seedlings will tend to grow toward the window and get “leggy” as they search for better light. Turn the trays daily to counteract this type of growth.
• Do not top water plants that have just been sprayed, as it will wash off the glyphosate and adversely affect the experiment. It is best to water the plants and allow the leaves to dry prior to spraying.

• If students are interested in additional variables, different student groups can use different concentrations of Roundup®. However, in the interest of safety, do not use concentrations higher than 4%.

• Make sure that the spray bottle can deliver a uniform coating of glyphosate. Spraying as a “mist” will have a much better result than spraying as a “stream” or “foam.”

• Students should be supervised while spraying glyphosate. Spraying should take place in a well-ventilated area. Students should wear safety goggles during spraying and wash hands thoroughly after spraying.

• If plants are sprayed outdoors, place the trays on concrete or asphalt, well away from green areas. The glyphosate may drift on the wind and kill nearby plants.

ANSWERS TO STUDENT DISCUSSION QUESTIONS

1. How was your mini-field like a real crop field? How were you like a farmer? The mini-field was planted just like a real crop field, with rows of crop plants. I observed the field on a regular basis to see how it was growing. I cared for the field by watering it and getting rid of weeds.

2. Why did you not plant only soybeans? What was the purpose of the other types of seeds? If the tray was to represent a real field then it could not just have the crop plants present. It must also have weeds to accurately represent reality. The other seeds represented the random weeds that can be deposited in a field by wind, water, or animals.

3. Which seeds germinated the fastest? (Answers may vary.)

4. How would you define a weed? A weed is any plant that is taking resources (nutrients, water, etc.) away from a plant of interest. A weed is any other plant that is growing in an area designated for a specific plant.

5. Do you think the weed seeds would germinate more quickly or slowly, in nature? (Answers may vary.)
6. In our greenhouse tests, it was noticed that 4%, 2% and 1% glyphosate solutions all had about the same effect when sprayed on the plants. Why is it best to use the lowest concentration instead of the higher? *The glyphosate is not completely without toxicity. It is better to use the lowest amount necessary to get results in order to keep the environmental impact at a minimum.*

7. In your experiment, how could you tell it was the herbicide that killed the plants and not something else in the room? *None of the plants in the control field died.*

8. What could happen if the gene for herbicide resistance got into a weed? How would this affect a farmer? *The weed would become resistant to the herbicide, so the farmer could no longer rely on the herbicide to kill off that weed in his crop fields. The herbicide would no longer be useful.*

9. List three reasons why the use of Roundup® herbicide and Roundup Ready® plants is a good thing. *(Answers may vary.) Low toxicity, low environmental impact, good weed control, etc.*

10. List three reasons why the use of Roundup® herbicide and Roundup Ready® plants is a bad thing. *(Answers may vary.) We do not know the long-term impact on the environment, we may be creating Roundup® resistant weeds, it is not natural, etc.*
ACTIVITY OVERVIEW

You may have had little real contact with a farm in your life, but this is about to change! You and your partners are about to plant a mini-field and learn the challenges of crop farming. Over the next couple of weeks, your class will conduct an experiment designed to show you why a farmer would choose to use genetically modified (GM) plants to his advantage in his crop fields. Once the experiment is complete, you will be given more information about agricultural biotechnology and you will answer discussion questions.

MATERIALS

Per group of 4 students:
- 10 Wildtype soybeans (non-GM)
- 10 Roundup Ready® soybeans (GM)
- Weed seeds (rye grass, sunflower, corn, radish)
- Planting flat or tray
- Potting soil, enough for 2-3 inches deep in planting flat
- Masking tape
- Permanent marker

Per class:
- Watering can with sprinkler head
- Spray bottle containing 1% Roundup® glyphosate herbicide solution
- Light source (deep window sill or fluorescent light bank)

PROCEDURE

DAY 1 Planting

1. Using a permanent marker, label a strip of masking tape as shown below. Put your names for the Group and put today’s date for the Planting Date. Put this label firmly on one long side of your planting tray.

Group:

Planting Date: Spraying Date:
2. Label two strips of masking tape as shown below. Put the WT Soybeans label on the left side of one end of the planting tray. Put the RR Soybeans label on the right side of the same end of the planting tray.

![WT Soybeans and RR Soybeans labels]

3. Place potting soil into the planting tray to a uniform depth of 2-3 inches.

4. Plant Wildtype soybeans.
   a. Use the back end of the permanent marker to make 8 1-inch deep holes evenly spaced in a row along the left half of the field designated WT Soybeans.
   b. Drop 1 Wildtype soybean seed into each of the 8 holes and then gently cover the holes with soil.

5. Plant Roundup Ready® soybeans.
   a. Use the back end of the permanent marker to make 8 1-inch deep holes evenly spaced in a row along the right half of the field designated RR Soybeans.
   b. Drop 1 Roundup Ready® soybean seed into each of the 8 holes and then gently cover the holes with soil.

6. Plant corn and sunflower seeds.
   a. Using the same planting technique as above, randomly plant 5 corn seeds in your field.
   b. Again using the same technique, randomly plant 5 sunflower seeds in your field.

7. Plant rye grass and radish seeds.
   a. Scatter rye grass seeds over your field.
   b. Scatter radish seeds over your field.

8. Cover the entire tray with a thin layer of soil, making sure all seeds are covered.

9. Water your field gently but thoroughly. The seeds need a good soaking to start germination so be sure that water gets through to the bottom of the tray.

10. Place your tray in the designated growing area.

11. Water your field gently every day. The soil should be moist, but not soggy.
DAY 2 Spray Day
1. Using a permanent marker, record today’s date for the Spraying Date on your planting tray. (This should be 8-10 days after planting. At this point, all of your plants should have true leaves and not just cotyledons.)
2. Take your tray to the spraying area designated by your teacher.
3. Put on safety goggles.
4. Spray all of the plants in your field with 1% Roundup® glyphosate herbicide. Be sure to uniformly cover all leaves of all plants.
5. Return your tray to the growing area and wash your hands thoroughly.

NOTE: One group in your class will be designated as the control for this experiment. That group should NOT spray their field with the herbicide.

DAYS 3+ Observations
1. Each day remove your tray from the growing area and take it to your table.
2. Make careful observations of the plants in your field and record your observations in a table provided by your teacher.
3. Take a turn observing the control field for your class and record those observations.
4. Water your field gently and then return it to the growing area.
### OBSERVATIONS

<table>
<thead>
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<th>DATE:</th>
<th>EXPERIMENTAL FIELD</th>
<th>CONTROL FIELD</th>
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- **Wildtype Soybeans**
- **Roundup Ready® Soybeans**
- **Weeds**
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**ACTIVITY B4: FIELD OF BEANS: STUDENT**

NAME: ______________________________________  CLASS HOUR: _______  DATE: ____________

**OBSERVATIONS**

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Roundup® is the Monsanto trade name for glyphosate, a contact herbicide that acts systemically. When sprayed on leaves, it is absorbed and interferes with normal enzyme activity, effectively killing the plant. Glyphosate prevents EPSPS, 5-enolpyruvyl-shikimate-3-phosphate synthase protein from building aromatic amino acids essential to plant growth. This aromatic amino acid biosynthesis pathway is not present in mammals, birds, or fish and therefore use of glyphosate as an herbicide presents a low risk to human health and the environment.

It should be noted that several environmental groups are opposed to the use of glyphosate. However, its use has no limits as far as the Occupational Safety and Health Administration (federal regulatory branch) and National Institute of Occupational Safety and Health (federal research branch) are concerned. It shows low-level ability to leach into soil and is naturally degraded by microbes. It has a half-life in soil of less than 60 days and in water, a half-life of less than seven days. Less than 10% residue has been noted in soil within a growing season. Most insects and animals can tolerate the levels of glyphosate released into the environment, however a few species are susceptible to harm. Monsanto has changed from using the phrase “environmentally friendly” to using the phrase “environmentally responsible” in its advertising due to claims that toxicity studies are too recent and have yet to be thoroughly tested.

Roundup Ready® crops have been genetically modified (GM) to resist Roundup® herbicide. Putting a gene into crop plants that resists the action of Roundup® has opened a whole new weed management option for farmers. In the past, more expensive and toxic herbicides were the only recourse a farmer had to kill weeds. Now farmers allow weeds to grow with the crops. Then after several weeks, when crops are about six inches tall, the weeds and crops are sprayed. The weeds die but Roundup® resistant crops survive because they have an alternative metabolic pathway provided by the added gene. A weed-free field means more water and nutrients for the crop and therefore a bigger harvest for the farmer.

Roundup® resistance was discovered in the wastewater lagoons of Roundup® production factories. Soil bacteria were able to survive the tiny amounts of glyphosate in the waste stream due to their ability to produce an alternate protein, CP4 EPSPS, which is naturally less sensitive to glyphosate inhibition. Genes from the bacteria were isolated and transferred to select crops, making them resistant to Roundup® herbicide. Canola, sugar beets, cotton, soybeans, and corn have all been genetically modified to be Roundup® resistant.

In developing and marketing GM crops, Monsanto and other agricultural biotechnology companies are required to follow stringent safety and testing guidelines mandated by the federal government. However, some people do not think the testing has been accurate for assessing long-term results and others are opposed to GM products in general.
1. How was your mini-field like a real crop field? How were you like a farmer?

2. Why did you not plant only soybeans? What was the purpose of the other types of seeds?

3. Which seeds germinated the fastest?

4. How would you define a weed?

5. Do you think the weed seeds would germinate more quickly or slowly in nature? Why?

6. In our greenhouse tests, it was noticed that 4%, 2% and 1% glyphosate solutions all had about the same effect when sprayed on the plants. Why is it best to use the lowest concentration instead of the higher?
7. In your experiment, how could you tell it was the herbicide that killed the plants and not something else in the room?

8. What could happen if the gene for herbicide resistance got into a weed? How would this affect a farmer?

9. List three reasons why the use of Roundup® herbicide and Roundup Ready® plants is a good thing.

10. List three reasons why the use of Roundup® herbicide and Roundup Ready® plants is a bad thing.
LESSON OVERVIEW

Biopharming is the practice of genetically engineering, or transforming, plants to produce human proteins. One of the inherent challenges of genetic engineering is getting the gene of interest expressed in the target tissue of the target organism. Despite best efforts, sometimes the transgene does not express the desired protein product in the desired part of the plant. This activity will show your students that it might take several transformation events before a successful result is achieved. The students will be acting as researchers at an agricultural biotechnology company “testing” powdered potato samples from transgenic potato plants for the presence of the desired gene product, human insulin. After completing the activity and worksheet, more detailed information on biopharming can be presented.

TIMELINE

The hands-on activity and worksheet can be completed in one 50-minute class period.

MATERIALS

Per class:
- 100 1.5 mL Eppendorf tubes
- Powdered milk
- Formula 4-24 Blue

Per group of 4-5 students:
- 1 disposable transfer or dropping pipet
- 1 small container of water labeled “indicator solution”
- 1 tube rack (optional)

ADVANCED PREPARATION

- Formula 4-24 Blue is a Drosophila culture medium available from Carolina Biological (<http://www.carolina.com>, 800-334-5551, catalog number 17-3210).
- Once the materials have been acquired, the prep can be done in less than one hour.
- For each class or lab section:
  1. Fill 99 1.5 mL Eppendorf tubes to the 0.05 mL mark with powdered milk and cap them.
  2. Fill the remaining single Eppendorf tube with one part Formula 4-24 Blue to two parts powdered milk, so that the tube is filled to the 0.05 mL mark. (Select the powdery part of the Drosophila medium over that with a flaky texture.) Cap the tube.
  3. Label the tubes from 1 to 100 so that each tube represents a sample from a single transgenic potato plant.

PROCEDURE

1. Have the students read the background information and activity overview in the student manual.
2. Give each student 3 or 4 tubes of powder, depending on class size. (A single class will use all 100 tubes.)
3. Ask students to add 20 drops of “indicator solution” (water) to each of the tubes. Have them cap and shake the tubes vigorously, until the powder is completely dissolved. (The indicator, of course, is not in the water, but in the one tube.)
4. Students will find that one tube out of 100 will turn pale blue. This will approximate the actual rate of success for the plant transformation experiment.
5. Have students complete the worksheet.
6. Present additional information on biopharming as you choose.

**ALTERNATE PREPARATION 1**

If Formula 4-24 is unavailable, you can substitute with Kool-Aid® Magic Twists drink powder. Fill the single remaining tube to the 0.05 mL mark with powdered milk. Add only 0.02 g (a tiny pinch) of the gold Kool-Aid® powder to the powdered milk. Be sure to mix the powders together so that the gold powder is not immediately obvious. Be aware that a student with an acute sense of smell may recognize that something is different about that particular tube. The mixture will turn red when water is added.

**ALTERNATE PREPARATION 2**

Another option for creating the single color changing tube is to use NaOH and phenolphthalein. Fill the single remaining tube to the 0.05 mL mark with powdered milk. Add only 0.02 g (a tiny pinch) of NaOH. Be sure to mix the powders together.

The students will need to add 20 drops of water to each of the tubes. They should cap and shake them vigorously, until the powder is completely dissolved. Finally, they need to add one drop of phenolphthalein to each of the tubes. The tube with the NaOH mixture will turn pink when the phenolphthalein is added.
BACKGROUND INFORMATION

Colorado State University Cooperative Extension provides an excellent overview of biopharming at http://www.ext.colostate.edu/pubs/crops/00307.html The information below was written by Dr. Patrick F. Byrne and included with his permission.

Manufacturing pharmaceutical products in crops has been one of the promised benefits of plant genetic engineering for the past 20 years. This use of biotechnology, sometimes known as “pharming,” “bio-pharming,” or “molecular farming,” has migrated from speculation to the testing phase in fields and greenhouses across the country. Bio-pharming promises more plentiful and cheaper supplies of pharmaceutical drugs, including vaccines for infectious diseases and therapeutic proteins for treatment of such things as cancer and heart disease. “Plant-made pharmaceuticals” (PMPs) are produced by genetically engineering plants to produce specific compounds, generally proteins, which are extracted and purified after harvest. As used here, the terms bio-pharming and PMP do not include naturally occurring plant products or nutritionally enhanced foods.

Although PMP technology offers potential health and economic benefits, observers agree that it must be strictly regulated to prevent pharmaceuticals from entering the food supply and to avoid unintended effects on the environment. How are biotech drugs currently manufactured?

Many protein-based drugs are currently produced in sterile fermentation facilities by genetically engineered microorganisms or mammalian cell cultures in stainless steel tanks (Felsot, 2002). Because these fermentation plants have huge capital construction costs, industry has been unable to keep up with the growing demand. For example, the biotech company Amgen is reportedly unable to meet demand for Enbrel, a protein-based arthritis medicine made in mammalian cell cultures (Alper, 2003). Another method for obtaining biopharmaceuticals is to extract them from animal and human tissues (e.g., insulin from pig and cow pancreas, or blood proteins from human blood (Freese, 2002)). However, these are high-cost procedures that carry the risk of transmitting infectious diseases to humans. Due to advances in plant genetic engineering over the past two decades, plants can now be modified to produce a wide range of proteins. It is hoped this will result in therapeutic products at a price significantly cheaper than through current methods. For example, antibodies that currently cost thousands of dollars per gram might be produced in plants for $200 per gram (Ohlrogge and Chrispeels, 2003).
WHAT PHARMACEUTICALS COULD BE MADE IN PLANTS?

For the near-term, PMPs will be proteins because proteins are directly encoded by genes. This property makes their production through genetic engineering more straightforward than other types of biochemical compounds that are synthesized via more complex methods. See Table 1 for examples of potential bio-pharm products.

WHAT CROPS ARE BEING CONSIDERED FOR PHARMACEUTICAL PRODUCTION?

The most common PMP crops grown in U.S. field trials are corn, tobacco, and rice. Other crops being investigated include alfalfa, potato, safflower, soybean, sugarcane, and tomato. Suitable host plants must be easily engineered, capable of high levels of protein production, and have appropriate procedures for extracting the PMP from plant tissues. Knowing the agronomy, physiology, pests, and diseases of a crop is

<table>
<thead>
<tr>
<th>Product</th>
<th>Definition</th>
<th>Example</th>
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<tbody>
<tr>
<td>Antibodies</td>
<td>Specialized proteins of the immune system that initiate the body’s defense response</td>
<td>Specific antibodies could be developed to fight cancer, HIV-AIDS, hepatitis, malaria, dental caries, and other diseases.</td>
</tr>
<tr>
<td>Antigens (vaccines)</td>
<td>Compounds that stimulate the production of antibodies that protect against disease</td>
<td>Plant-made vaccines are currently under development for protection against cholera, diarrhea (Norwalk virus), and hepatitis B.</td>
</tr>
<tr>
<td>Enzymes</td>
<td>Proteins that catalyze biochemical reactions</td>
<td>Enzymes could be used both to treat and to diagnose disease. For example, lipase is an enzyme that breaks down dietary fats and is used to treat the symptoms of cystic fibrosis and other diseases.</td>
</tr>
<tr>
<td>Hormones</td>
<td>Chemical messengers active at low concentrations and produced in specialized cells</td>
<td>Insulin is produced in the pancreas and helps regulate sugar metabolism. Diabetics with insulin deficiencies must replace it via shots or pumps.</td>
</tr>
<tr>
<td>Structural proteins</td>
<td>Proteins that provide structural support to cells or tissues</td>
<td>Collagen is a structural protein found in animal connective tissues and used in cosmetics.</td>
</tr>
<tr>
<td>Anti-disease agents</td>
<td>A wide variety of proteins</td>
<td>The anti-infection agents interferon and lactoferrin, and aprotinin (to control blood loss during surgery) have been engineered in plants.</td>
</tr>
</tbody>
</table>

Table 1. Potential plant-made pharmaceuticals. Information compiled from Canadian Food Inspection Service (2001), Ohlrogge and Chrispeels (2003), and the Web sites of the Biotechnology Industry Organization (www.bio.org/healthcare/pmp/), and Meristem Therapeutics (www.meristem-therapeutics.com).
also an advantage. Ideally, the host plant is a non-food crop that does not have wild relatives in the production environment, and could not survive in the environment from seeds carried by wind or wildlife. When food crops are used, complete pollen sterility is desired, since it would prevent nearby fields of the crop from being pollinated by the biopharm crop. While this is not yet technically feasible, using self-pollinating crops or male-sterile crops can minimize pollination of food crops.

WHAT PART OF THE PLANT PRODUCES THE PMP?

Most bio-pharming applications target production and storage of the pharmaceutical protein in seeds, which naturally accumulate high concentrations of proteins and oils. Seeds are also the easiest part of the plant to store and transport to processing facilities. To achieve production of the pharmaceutical protein in seeds, seed-specific “promoters” (regulatory elements of genes that control how much of a gene product is made and where in the plant it is synthesized) are engineered into the plant. Two seed-specific promoters used in experimental bio-pharm lines are the beta-phaseolin promoter of common bean and the oleosin promoter of Brassica species (Moloney, 2000). The location of protein accumulation within the cell is also important to ensure correct folding and stability of the protein (Moloney, 2000).

While synthesis of biopharmaceuticals in seeds has many advantages, not all PMPs will be produced there. Leaves are the target tissues in some alfalfa and tobacco applications, and tubers are targeted in potato production systems (Canadian Food Inspection Service, 2001). A variation of PMP technology involves infecting plants with viruses that are engineered with the gene for the pharmaceutical protein. Upon infection (for example, of tobacco leaves), the plant’s cellular machinery produces the biopharmaceutical along with other viral proteins (Freese, 2002).

HOW WILL PMPS BE PRODUCED?

To be successful, pharmaceutical production in plants must be a highly sophisticated and closely regulated enterprise, and will differ from conventional crop production in many ways. Bio-pharm crops must be grown, transported, and processed using safeguards designed to ensure a consistent, high-quality product and to prevent inadvertent mixing with food crops and other negative consequences. To achieve this goal, a “closed loop identity preservation” system is envisioned, in which the crop is carefully regulated and monitored from planting to harvest to pharmaceutical extraction (Felsot, 2002). Seed will be available only to trained contract growers, and the harvested product will be delivered in sealed containers to the processing facility. Standard operating procedures developed for each specific PMP crop will govern isolation distances from conventional crops, equipment use, and field inspections during the growing season and for at least a year afterward. Meticulous record-keeping will be required at each step of the process.
WHEN WILL PLANT-MADE PHARMACEUTICALS REACH THE MARKET?

Research on PMP crops has been ongoing for many years in laboratories, greenhouses, and field trials. In 2002, PMP crops were grown at 34 field sites totaling 130 acres in the U.S. Three PMPs currently undergoing evaluation in clinical trials are designed to target non-Hodgkins lymphoma, cystic fibrosis, and E. coli/traveler’s diarrhea (Biotechnology Industry Organization, www.bio.org/healthcare/pmp/factsheet2.asp). Assuming their effectiveness and safety are demonstrated and environmental concerns are adequately addressed, therapeutic pharmaceuticals from plants may reach the market in the second half of this decade.

WHO IS DOING BIO-PHARMING?

Among the companies pursuing commercial development of PMPs are Dow AgroSciences, Meristem Therapeutics, and Ventria Bioscience. Reflecting the commercial uncertainty of the industry, some companies, including Monsanto, have discontinued development of PMP products, and the biopharmaceutical firms CropTech and Large Scale Biology Corp. have filed for bankruptcy in recent years. The companies that develop PMPs will most likely contract with a limited number of highly skilled farmers to produce bio-pharm crops.

WHAT ARE THE BENEFITS OF PLANT-MADE PHARMACEUTICALS?

- PMPs can be produced at a significantly reduced cost compared to current production methods. Therefore, the technology has the potential to benefit medical patients by providing a more affordable source of vaccines and other pharmaceuticals. However, it is not clear how large the cost reduction will be or how much of the savings will be passed on to consumers.
- Plants can be engineered to produce proteins of greater complexity than is possible with microorganisms (Collins, 2003), and to produce proteins that cannot be produced in mammalian cell cultures (Anonymous, 2002).
- A limited number of growers and production workers will likely benefit economically from this new agricultural enterprise. The number of acres required to produce a year’s worth of a given pharmaceutical will likely be quite small compared to crop acreage for food and feed use.

WHAT ARE THE RISKS OF PLANT-MADE PHARMACEUTICALS?

Risks are not uniform for all bio-pharm applications, but will vary depending on the nature of the pharmaceutical product, the crop and tissues in which the PMP is produced, and the environment in which the crop is grown. The potential risk factors of PMPs are summarized below.
- Pollen from plants engineered to produce pharmaceuticals may fertilize nearby food or feed crops of the same species. If this occurs, the pharmaceutical may be produced in seed of the neighboring
crop, with potentially negative effects on human or animal consumers of the seed and on crop markets. The risk of gene flow via pollen drift is greater in cross-pollinated crops like corn. Methods to minimize this risk include spatial and temporal isolation, the use of male sterility (i.e., plants that don’t produce viable pollen), and in the case of corn, detasseling (removing tassels before they shed pollen). When male sterility or detasseling are used, fertile male plants that lack the gene for the pharmaceutical are planted in the field to provide the pollen source.

- Commingling of PMP crops and food or feed crops may occur. This could happen through improper labeling, mixing of seed in planting, harvesting, transportation, or processing equipment, or the presence of “volunteer” PMP plants in subsequent seasons in the same field. In a recent case, ProdiGene failed to eliminate volunteer bio-pharm corn plants from a soybean crop planted later in the same field as the PMP corn (Anonymous, 2003). The company was fined $250,000 by USDA and was required to reimburse the government $3 million for expenses related to destruction of 500,000 bushels of potentially contaminated soybeans.
- The introduced gene or its product may have negative effects on the natural environment. For example, wildlife feeding on the crop may ingest harmful levels of the PMP, or soil micro-organisms may be inhibited by decomposing crop residue or substances exuded from roots of PMP plants.
- Farm workers may be exposed to unhealthy levels of a biopharmaceutical by absorbing products from leaves through their skin, inhaling pollen, or breathing in dust at harvest.
- Unexpected toxins or residues of pesticides used on the crop may contaminate the final drug product.

WHAT STEPS ARE BEING TAKEN TO PREVENT OR REDUCE THESE RISKS?

Because bio-pharm crops are genetically engineered, they are subject to U.S. federal regulations that govern all such crops. Three federal agencies, the U.S. Department of Agriculture - Animal and Plant Health Inspection Service (APHIS), the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA) all play roles in regulating genetically engineered crops, though their specific responsibilities vary depending on the type of application involved.

Besides the standard regulations that apply to all genetically engineered crops, bio-pharm crops are subject to additional regulatory oversight. One major difference between PMP crops and genetically engineered food crops is that the former require perpetual permitting by APHIS, whereas the latter crops, once approved by the three federal agencies, are considered “unregulated” and are freely available through commercial channels without permits. In September, 2002, FDA and USDA issued the draft document “Guidance for Industry: Drugs, Biologics, and Medical Devices Derived from Bioengineered Plants for Use in Humans and Animals”, www.fda.gov/cber/gdlns/bioplant.htm. In 2003, APHIS announced its intentions to impose more stringent conditions for field tests of genetically engineered crops.
that produce pharmaceutical or industrial compounds. Several of these proposed conditions are listed in the sidebar. The objective of the new regulations is to prevent contamination of food and feed crops with the biopharmaceuticals and to minimize environmental impacts. In 2004, APHIS provided additional guidance for bio-pharm permit applicants (APHIS, 2004). For example, applicants are requested to provide details on the amount of the gene product in all plant parts, the results of allergenicity testing, and an assessment of potential toxicity to non-target organisms.

FDA has the responsibility to ensure the safety and usefulness of drugs. Therefore, clinical trials and marketing of PMPs will require FDA approval. FDA will also oversee procedures for manufacturing PMPs to guarantee consistent product quality and potency.

EPA regulates the environmental effects of proteins engineered for pest resistance (such as Bt insecticidal proteins) in a PMP crop. However, EPA does not review environmental effects of bio-pharm crops at this time.

The department of agriculture of the state in which a PMP crop field test is proposed, is given the opportunity to review APHIS’ preliminary assessment of applications for field testing of genetically engineered crops. In the past, this has been a routine approval, but with PMP crops, states are taking a more cautious approach. State departments of agriculture may request additional permit conditions beyond those imposed by APHIS.

ARE BIO-PHARM CROPS LIKELY TO BE GROWN IN COLORADO?

The advantages Colorado has for bio-pharming are the ease of achieving recommended isolation distances for many crops, and the ability to obtain high yields under irrigated conditions with relatively little disease and insect pest pressure.

The French company Meristem Therapeutics applied to APHIS for a permit to grow a field test of PMP corn in Phillips County, Colorado in 2003. To assist with evaluation of this and future permit applications for PMP crops, the Colorado Department of Agriculture (CDA) formed a Technical Advisory Committee to evaluate the adequacy of conditions for gene containment and for minimizing environmental impact. Although the Meristem application was approved, the company decided not to plant the trial because the optimum planting date had passed.

In 2004, APHIS and CDA approved an application from an Iowa State University researcher to grow bio-pharm corn, and a small field plot was planted in Logan County. Whether commercial scale bio-pharm production will occur in Colorado depends on a number of business and government policy decisions, the outcomes of which are difficult to predict at present. The Colorado Institute of Public Policy has examined the issues involved in bio-pharming and published the report “Bio-Pharming in Colorado: A Guide to Issues for Making Informed Choices (www.cipp.colostate.edu/cipp-reports.html).
FINAL THOUGHTS

Like many other aspects of crop biotechnology, supporters and critics of PMP crops differ strongly over the benefits and risks of this new application. Proponents stress the societal benefits of a cheaper and more plentiful source of pharmaceuticals, while opponents emphasize the risks of contamination of the food supply and unknown effects on ecosystems. Given the uncertainties surrounding bio-pharm crops, it is difficult to predict whether and to what extent this technology will become part of our future agricultural and health care systems. Several questions remain to be answered, including: (1) Are PMPs safe and effective medicines for humans and animals? (2) Will production costs of PMPs, especially for the purification process, be reduced sufficiently to bring the promised economic benefits? (3) What will be the appropriate combinations of crop species, plant parts, growing environments, and production safeguards that will provide acceptable levels of gene containment and environmental protection? (4) Are our regulatory structures adequate to the task of regulating and monitoring bio-pharm crops, and, if not, what changes will be necessary? (5) To what extent will crop-based pharmaceuticals provide new economic opportunities for farmers and rural communities?

REFERENCES

- APHIS. 2004. Updated guidance on bioengineered plants for producing pharmaceuticals or industrial products for applicants developing these plants for release (January 2004).

WEB SITES FOR ADDITIONAL INFORMATION ON PMP CROPS
• The Biotechnology Industry Organization, http://www.bio.org/healthcare/pmp/, has a number of fact sheets on plant-made pharmaceuticals.
• The Transgenic Crops Web site, http://cls.casa.colostate.edu/Transgenic Crops/, contains introductory information on the techniques and regulation of plant genetic engineering.
• The Phyto-Pharma Online Community (www.phytopharma.org) advocates in favor of PMP’s and has a variety of news stories and opinion pieces.

ADDITIONAL REFERENCES

ANSWERS TO STUDENT WORKSHEET
1. How many of the samples changed color, indicating the presence of human insulin in the dried potato sample? One.
2. Calculate the percent success rate of the transformation experiment.
   \[
   \frac{1}{100} = 0.01 \\
   0.01 \times 100 = 1\%
   \]
3. With this success rate, do you think that producing human insulin from transgenic plants will be a profitable venture for your company? Why or why not? *Yes, because from the one successfully transformed plant you can collect seed and plant hundreds of additional plants that should produce human insulin.*

4. Who will benefit from your company’s new insulin-producing potatoes? *Insulin-dependent diabetics will benefit from having access to cheaper insulin. The company will benefit from the profits of the sale of the insulin.*

5. Should your company be granted a patent on the insulin-producing potatoes, so that others may not copy the process? Explain your reasoning. *Answers will vary.*

6. Is human welfare the only consideration in developing safeguards for transgenic plants? *No, we should also consider harm to the environment, other plants, animals, etc.*

7. What measures would you propose to ensure that the transgenes are not accidentally transferred to other plants? *Answers will vary but should include specific ideas about HOW to keep the transgenic plants from interbreeding with other plants (only grow in greenhouses, do not grow near any other potato fields, make the plants sterile, etc.).*

8. Describe some other uses you can think of for biopharming. *Answers will vary but should include ideas specific to production of human proteins in plants.*
As members of a team of researchers in an agricultural biotechnology company, you have been assigned the task of determining the success of a newly developed technique used to produce human insulin. Other companies have been producing human insulin through genetic engineering of bacteria and yeast cells since the 1980s. However, there are limitations to the quality of insulin that can be synthesized and purified from these more traditional techniques. Two years ago, your company decided to invest in biopharming, the practice of genetically engineering, or transforming, plants to produce human proteins.

The process of plant transformation does not have a 100% success rate. Sometimes the foreign genes do not get incorporated and the resulting plant is not transgenic. Sometimes the foreign genes get incorporated, but are not expressed, meaning no protein product is formed. Sometimes the foreign genes are incorporated and are expressed, but not in the target tissue. Genetic engineers must perform hundreds of transformation events, hoping that a few will give them satisfactory results.

Recently, a team of genetic engineers in your company introduced human insulin genes into potato plants using the Agrobacterium method of plant transformation. They have grown up the resulting transgenic plants in your company’s plant growth chambers and have harvested tubers. The next step in the product development process is to test these tubers for the presence of the transgene product, human insulin. Those plants that show adequate levels of insulin production will be further tested in greenhouses and then sent out for field trials.

If all goes according to the project plan, eventually the transgenic potato plants will be grown in very large numbers in farm fields, the tubers will be harvested, and the insulin will be isolated. It is hoped that this cheaper method of obtaining human insulin will be very competitive with other sources of insulin in the pharmaceutical market.
ACTIVITY OVERVIEW

The objective of your company’s new project is to produce a line of transgenic potato plants capable of producing tubers containing human insulin proteins. Tubers from the first 100 transgenic potato plants were harvested last month and samples were preserved through a freeze-drying process. Your team must test the samples to determine the extent to which human insulin is present in the tubers.

PROCEDURE

1. Your teacher will provide you with a few 1.5 mL tubes containing freeze-dried potato powder.
2. For each tube, open the cap and add 20 drops of indicator solution. Close the cap tightly and shake the tube vigorously until all of the powder is dissolved. A chemical in the indicator solution will cause the potato sample to change color if human insulin proteins are present.
3. Mark the tubes that change color and document them.
4. Obtain the results of all 100 tubes and then complete the worksheet.
1. How many of the samples changed color, indicating the presence of human insulin in the dried potato sample?

2. Calculate the percent success rate of the transformation experiment.

3. With this success rate, do you think that producing human insulin from transgenic plants will be a profitable venture for your company? Why or why not?

4. Who will benefit from your company’s new insulin-producing potatoes?

5. Should your company be granted a patent on the insulin-producing potatoes, so that others may not copy the process? Explain your reasoning.
6. Is human welfare the only consideration in developing safeguards for transgenic plants?

7. What measures would you propose to ensure that the transgenes are not accidentally transferred to other plants?

8. Describe some other uses you can think of for biopharming.
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ACTIVITY C 2: “Harvest of Fear” . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 139
ACTIVITY C 3: Build A Better Food . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 143
LESSON OVERVIEW

This activity showcases some of the ethical issues surrounding the use of GMOs in agriculture by introducing your students to the story of Canadian farmer Percy Schmeiser and his battle with Monsanto, an agricultural biotechnology company based in St. Louis, Missouri. The problem starts with the supposedly accidental appearance of GM canola plants in Schmeiser’s field of non-GM canola. This led to Schmeiser’s “possession” and “use” of GM plants that he had not purchased and licensed for use from Monsanto. A court battle followed to determine whether Schmeiser had illegally used genes and technology owned by Monsanto when he planted, harvested, and sold canola seeds containing Monsanto’s patented technology without obtaining a license from Monsanto.

The students will be divided in to two groups – one assigned to investigate Percy Schmeiser’s website and one assigned to investigate Monsanto’s website. After the website investigation, all students will read key factual findings from the Canadian federal trial court opinion written by Justice MacKay and an opinion of the case written by Clark Wolf, a bioethicist at Iowa State University. Student pairs (one from each group) will work together to complete answers to discussion questions. Additional questions are provided to facilitate a class discussion of the case and the final verdict.

TIMELINE

At least 20 minutes is needed for website investigation. The two readings may take 15 minutes to complete. Both website investigation and readings may be assigned as homework. One class period should be devoted to organized debate and discussion of the case and verdict.

REFERENCES

• Monsanto’s website, http://www.monsanto.com
• Percy Schmeiser’s website, http://www.percyschmeiser.com

ADDITIONAL QUESTIONS FOR CLASS DISCUSSION

1. Do farmers have a right to save seed from year to year for replanting their crops? What if genes in the seeds are genetically modified and patented? What if they are not?
2. If patented genes do appear in a farmer’s field, can she be sued just because they are there? Should she be sued?
3. Given that genes from GM crops can be incorporated by non-GM versions of these crops or by compatible relatives, what is a reasonable percentage of the crop that should be acceptable without any legal action? Is legal action ever justified? When?

4. Now that GM crops are widely used, does a farmer have an obligation to test for the presence of patented genes in her non-GM crops? (No.) If she elects to voluntarily test, what should she do if her crop tests positive for the patented genes? (Nothing.) Does she have to obtain a license for use from the patent holder? (No.) Does she have to destroy her crop? (No.)

5. What if the farmer knowingly uses the patented genes to her advantage? Should she be allowed to take the advantage for just that season? Is that fair to the company that owns the patent?

6. If we know that genes from GM crops can drift into non-GM crops, should we be worried that foods containing non-GM products actually do contain GM products? Is it realistic to think we can keep the GM and non-GM crops separate after harvest? What option is available for farmers and consumers that prefer not to use or consume GM crops?

7. Share Monsanto's official position with the class and ask for comments.

MONSANTO POSITION:

“It has never been, nor will it be Monsanto policy to exercise its patent rights where incidental amounts of patented traits are present in farmers’ fields by chance. Therefore, farmers that choose to plant publicly derived conventional seeds without patent protection and save seeds from their harvest for planting in subsequent years are not at risk from prosecution by Monsanto for potential incidental presence of patented traits on their farms. The facts of the Schmeiser case established Mr. Schmeiser’s intentional planting of seed containing a Monsanto patented trait. Importantly, Mr. Schmeiser’s claim that the Monsanto patented trait was present in his seeds by “chance” is false and was rejected by the courts.”
What if your neighbor’s prize winning dog hopped the fence and got your own dog pregnant? Who should pay the vet bill to make sure the puppies will be born healthy or who should pay to have them destroyed? What if your neighbor wanted to sell the puppies, due to their valuable and expensive heredity, but would not share any of the profits with you? What if he paid a “stud” fee to your family? What if you purposely used a neighbor’s pet to breed very valuable puppies and didn’t tell anyone? In any of these scenarios, who is obliged to pay and who should benefit?

Similar situations could occur in agricultural areas with GM (genetically modified) crops. These GM crops can be seen as either a potential benefit or potential problem, depending on your view, yet they are in the ecological arena and they are filling important niches in the food chain.

**ACTIVITY OVERVIEW**

In this activity you will explore the story of Canadian farmer Percy Schmeiser and his battle with Monsanto, an agricultural biotechnology company based in St. Louis, Missouri. The problem starts with the supposedly accidental appearance of GM canola plants in Schmeiser’s field of non-GM canola. This led to Schmeiser’s “possession” and “use” of GM plants that he had not purchased and licensed for use from Monsanto. A court battle followed to determine whether Schmeiser had illegally used genes and technology owned by Monsanto when he planted, harvested, and sold canola seeds containing Monsanto’s patented technology without obtaining a license from Monsanto.

Your class will be divided in to two groups – one assigned to investigate Percy Schmeiser’s website and one assigned to investigate Monsanto’s website. After the website investigation, you will read key factual findings from the trial and an opinion of the case written by a bioethicist. You will work with a partner to answer discussion questions, and then the class will participate in a group discussion.

**PROCEDURE**

1. **Assignment Monsanto:**

2. **Assignment Percy Schmeiser:**
   Go to http://www.percyschmeiser.com. Spend at least 20 minutes investigating the website and reading about Percy Schmeiser and his relationship with Monsanto. Specifically read his comments on the final verdict at http://www.percyschmeiser.com/decision comments.htm.
2. Read “Reasons for Judgment” (Student Reading 1) containing key factual findings from the Canadian federal trial court opinion written by Justice MacKay.

3. Read “Monsanto v. Schmeiser: A “Classic David and Goliath” Story?” (Student Reading 2), an opinion of the case written by Clark Wolf, a bio ethicist at Iowa State University.

4. Pair with a student who investigated the opposing side of the case. Work together to come up with answers to the discussion questions. Be sure to come up with detailed explanations for your answers.

5. Join your class in a discussion of the case. Voice your opinion on whether a proper judgment was rendered and how you think GM crops may affect you or the world populace in the future.
STUDENT READING 1

Docket: T-1593-98
Neutral Citation: 2001 FCT 256 [Federal Court Trial, Canada]
MONSANTO CANADA INC. and MONSANTO COMPANY, Plaintiffs and
PERCY SCHMEISER and SCHMEISER ENTERPRISES LTD., Defendants

REASONS FOR JUDGMENT: MacKAY J.

(Note: The factual findings of the Federal Trial Court, Canada, set forth below in the excerpted paragraphs, were upheld at the Federal Court Appeal, Canada and at the Supreme Court of Canada. These factual findings are the facts of the case. The numbers at the beginning of each paragraph are the paragraph numbers within the complete trial court opinion. This document was prepared by Drew L. Kershen, Professor of Law, University of Oklahoma College of Law.)

[2] On consideration of the evidence adduced, and the submissions, oral and written, on behalf of the parties I conclude that the plaintiffs' action is allowed and some of the remedies they seek should be granted. These reasons set out the bases for my conclusions, in particular my finding that, on the balance of probabilities, the defendants infringed a number of the claims under the plaintiffs' Canadian patent number 1,313,830 by planting, in 1998, without leave or license by the plaintiffs, canola fields with seed saved from the 1997 crop which seed was known, or ought to have been known by the defendants to be Roundup® tolerant and when tested was found to contain the gene and cells claimed under the plaintiffs' patent. By selling the seed harvested in 1998 the defendants further infringed the plaintiffs' patent.

[38] As we have noted Mr. Schmeiser testified that in 1997 he planted his canola crop with seed saved from 1996 which he believed came mainly from field number 1. Roundup® resistant canola was first noticed in his crop in 1997, when Mr. Schmeiser and his hired hand, Carlyle Moritz, hand-sprayed Roundup® around the power poles and in ditches along the road bordering fields 1, 2, 3 and 4. These fields are adjacent to one another and are located along the east side of the main paved grid road that leads south to Bruno from these fields. This spraying was part of the regular farming practices of the defendants, to kill weeds and volunteer plants around power poles and in ditches. Several days after the spraying, Mr. Schmeiser noticed that a large portion of the plants earlier sprayed by hand had survived the spraying with the Roundup® herbicide.

ACTIVITY C1: AG BIOTECH ETHICS—SEEDS AND PATENTS: STUDENT
In an attempt to determine why the plants had survived the herbicide spraying, Mr. Schmeiser conducted a test in field 2. Using his sprayer, he sprayed, with Roundup® herbicide, a section of that field in a strip along the road. He made two passes with his sprayer set to spray 40 feet, the first weaving between and around the power poles, and the second beyond but adjacent to the first pass in the field, and parallel to the power poles. This was said by him to be some three to four acres in all, or “a good three acres”. After some days, approximately 60% of the plants earlier sprayed had persisted and continued to grow. Mr. Schmeiser testified that these plants grew in clumps which were thickest near the road and began to thin as one moved farther into the field.

Despite this result Mr. Schmeiser continued to work field 2, and, at harvest, Carlysele Moritz, on instruction from Mr. Schmeiser, swathed and combined field 2. He included swaths from the surviving canola seed along the roadside in the first load of seed in the combine which he emptied into an old Ford truck located in the field. That truck was covered with a tarp and later it was towed to one of Mr. Schmeiser’s outbuildings at Bruno. In the spring of 1998 the seed from the old Ford truck was taken by Mr. Schmeiser in another truck to the Humboldt Flour Mill (“HFM”) for treatment. After that, Mr. Schmeiser’s testimony is that the treated seed was mixed with some bin-run seed and fertilizer and then used for planting his 1998 canola crop.

The evidence of Mr. Schmeiser is that seed for his 1998 crop was saved from seed harvested in 1997 in field number 2 by his hired man Mr. Moritz. That seed was placed by Mr. Moritz in the old Ford truck, then located in field number 2, directly from the combine after it was harvested from the area of that field previously sprayed with Roundup® by Mr. Schmeiser. That “testing” by him resulted, by his estimate, supported by Mr. Moritz, of about 60% of the sprayed canola plants surviving in the “good three acres” that he sprayed. The surviving plants were Roundup® resistant and their seed constituted the source of seed stored in the old Ford truck.

The 1997 samples, taken by Mr. Derbyshire from road allowances bordering fields number 2 and 5, were used for two grow-out tests, in 1997 at the University of Saskatchewan for Mr. Mitchell, and in 2000 at the university for Dr. Downey. In both tests, with the exception of one of six samples, of the seeds that germinated 100% of the plants survived spraying with Roundup® herbicide, i.e., they were Roundup® tolerant.

The HFM samples of untreated and treated seed withheld from Mr. Schmeiser were provided
1. to Mr. Mitchell for Monsanto in 1998 and by him
   a) were subject to a “quick test” which indicated to him that both samples tested were positive for the presence of the patented gene;
b) were subject to a grow-out test by Prairie Plant Systems in January, 1999 with germinating seed sprayed with Roundup® and 30 samples of leaf tissue from surviving plants, tested by Monsanto US, proved positive for the presence of the patented gene in the DNA of the leaf tissue; and

c) a subsample was sent to counsel for Schmeiser in April 1999 and by him to Mr. Freisen at Winnipeg for a grow-out test, in which 95 to 98% of germinating plants survived spraying with Roundup®;

2. to Mr. Schmeiser in July 1999 which he
   a) used in part for a grow-out test in his yard, results of which showed 63 to 65% germinating plants survived spraying with Roundup®; and
   b) forwarded to University of Manitoba for testing by Mr. Freisen who recorded results generally similar to those of Mr. Schmeiser;

3. to Mr. Freisen directly from Saskatchewan Wheat Pool in April 2000 for grow-out test from which a very high portion, 95-98%, of germinating seed survived spraying with Roundup®.

[116] In the course of their defense, it was urged by defendants that the source of contamination by Roundup® resistant canola of their 1996 crop, from which seed was saved for 1997, was uncertain. Indeed so was the source of contamination in the 1997 crop.

[117] A variety of possible sources were suggested, including cross field breeding by wind or insects, seed blown from passing trucks, or dropping from farm equipment, or swaths blown from neighbours’ fields. All of these sources, it is urged, could be potential contributors to crossbreeding of Schmeiser’s own canola or to deposit of seeds on his land without his consent. Mr. Borstmayer, who farmed on the same grid road but further north from Bruno than Mr. Schmeiser’s fields numbers 1, 2, 3 and 4, testified that in the winter of 1996-97 a bag of Roundup Ready® canola seed had fallen from his truck in Bruno and broken open, and some seed was lost before he put the broken bag back on his truck to be hauled past Schmeiser’s fields to his own. Further, after harvesting his 1997 crop he trucked it to the elevator on the grid road to Bruno, past Schmeiser’s fields, with at least two loads in an old truck with a loose tarp. He believes that on those journeys he lost some seed.

[118] It may be that some Roundup Ready® seed was carried to Mr. Schmeiser’s field without his knowledge. Some such seed might have survived the winter to germinate in the spring of 1998. However, I am persuaded by evidence of Dr. Keith Downey, an expert witness appearing for the plaintiffs, that none of the suggested sources could reasonably explain the concentration or extent of Roundup Ready® canola of a commercial quality evident from the results of tests on Schmeiser’s crop.
His view was supported in part by evidence of Dr. Barry Hertz, a mechanical engineer, whose evidence scientifically demonstrated the limited distance that canola seed blown from trucks in the road way could be expected to spread. I am persuaded on the basis of Dr. Downey’s evidence that on a balance of probabilities none of the suggested possible sources of contamination of Schmeiser’s crop was the basis for the substantial level of Roundup Ready® canola growing in field number 2 in 1997.

(Final note: The Supreme Court of Canada reversed the Federal Trial Court and the Federal Appeal Court on the issue of remedies (damages). As a result, although Mr. Schmeiser was legally found to have infringed the patent, Mr. Schmeiser was not ordered to pay damages to Monsanto Canada, Inc.)
STUDENT READING 2

“Monsanto v. Schmeiser: A “Classic David and Goliath” Story?”
Clark Wolf, Director of Bioethics, Office of Biotechnology at Iowa State University
http://www.biotech.iastate.edu/
Bioethics in Brief, Volume 7, Number 2, May 2005

Percy Schmeiser has become a folk hero of sorts. His story has quite literally become the stuff of legend and song, and he has been honored with awards from several groups that see him as a champion who stood up to a large multi-national corporation. Schmeiser is a Canadian farmer who was sued by Monsanto for violation of their intellectual property rights in the Roundup Ready® canola he raised in his fields. Schmeiser didn’t purchase the Roundup Ready® canola that was found growing on his land. Apparently the parent stock blew in from the road or from a neighboring field. When Schmeiser collected seed and saved it to plant in the following year, Monsanto’s gene was present in the saved seed and was thus present in Schmeiser’s canola. Tests identified the presence of Monsanto’s intellectual property in Schmeiser’s crop, and since he had not purchased the seed from Monsanto and had no license to use their patented Roundup Ready® technology, Monsanto brought suit against Schmeiser in the Canadian court system. On appeal, the case rose all the way to Canada’s Supreme Court, which delivered its ruling on May 21, 2004. In spite of the fact that Monsanto’s patented genes had apparently drifted onto Schmeiser’s field, the court found in favor of Monsanto. In a five to four decision, they ruled that Percy Schmeiser violated Monsanto’s intellectual property rights by growing Roundup Ready® canola without a license. For this reason, Monsanto v. Schmeiser has been represented as implying that farmers can be held liable for the unintentional and adventitious presence of patented material in their fields. In this case, since Schmeiser never used Roundup® to clear the weeds in his field, the court found that no damages were due to Monsanto. Both sides in the legal battle declared victory and retreated to their respective corners to nurse their wounds.

The Schmeiser case raises many interesting issues:
• Do farmers have a right to save seed from one year to the next?
• If patented genes drift onto one’s field, can one be sued just because they are present in one’s crop?
• Does this case imply that farmers have an obligation to test their field for the presence of patented genes?
• If farmers are surprised to discover that patented genes are present in their crops, are they obliged to obtain a license, or perhaps to destroy their crop entirely?
Some of the legal issues raised in Monsanto v. Schmeiser are peculiar to Canada’s legal system and would be different in the United States. Canada does not allow patents that cover the plant itself, so the 52 claims that constitute Monsanto's Canadian patent number 1,313,830 involve claims to the vectors, gene sequences and modified plant cells, not claims to the plant as such. The four justices who voted against Monsanto argued that these 52 claims effectively constituted a legal right in the plant and that the patent was thus invalid. In the US this issue simply would not arise because US law has recognized organisms as patentable subject matter ever since Diamond v. Chakrabarty (1980). If anything, it would seem that Monsanto would have an even stronger legal case if the same situation were to arise in the US.

**Did Schmeiser Intentionally or Knowingly Violate Monsanto’s Rights?**

Was the court wrong to rule in favor of Monsanto? Schmeiser’s advocates argue that he simply saved the seed from the previous year and that he had no contractual obligation to Monsanto since he hadn’t purchased their seed. Apparently, Monsanto’s Roundup Ready™ canola entered or was introduced to Schmeiser’s land when it was blown off of trucks or wagons of other farmers who were taking their Roundup Ready™ canola to the local grain elevator. His friends describe Percy Schmeiser as an innocent bystander who had the bad luck to be downwind of Monsanto’s crops.

But the court documents show that the case is much more complicated than the folk tale would suggest. The court did not accept Schmeiser’s claim to be an innocent bystander because it regarded his story as inconsistent with the finding that 95-98% of his 1,030 acre crop was pure Roundup Ready™ canola. The court concluded that Schmeiser must have used Roundup® to select for Monsanto’s Roundup Ready™ gene and that he segregated what he knew to be Roundup Ready™ seed and stored it separately from his other seed stock. While the initial plants may have come onto his land by accident, there seems to have been nothing accidental about his selection of the Roundup Ready™ seed. Writing for the Majority, Justices McLachlin and Fish state: “Mr. Schmeiser complained that the original plants came onto his land without his intervention. However, he did not at all explain why he sprayed Roundup® to isolate the Roundup Ready™ plants he found on his land; why he then harvested the plants and segregated the seeds, saved them, and kept them for seed; why he next planted them; and why, through this husbandry, he ended up with 1030 acres of Roundup Ready™ Canola which would otherwise have cost him $15,000. In these circumstances, the presumption of use flowing from possession stands unrebutted.”

The court was convinced that Schmeiser was not an innocent bystander, since the evidence strongly suggests that he intentionally refined his seed and specifically selected for the presence of the patented
Roundup Ready® gene. For the justices who joined the majority opinion, this finding was determinative. For this reason, their ruling does not imply that farmers have a positive obligation to test their seed, nor does it imply that farmers can be sued for accidental, unintentional, or ‘adventitious presence’ of patented plant material in their crops. Percy Schmeiser’s website argues that Monsanto v. Schmeiser is a “classic David and Goliath story.” But if Schmeiser intentionally selected for the presence of a patented gene, then it is not surprising that the court found in favor of the patent holder. Since he took steps to select his seed for the patented gene and its properties, it is hard to see Schmeiser as an innocent victim of a corporate Goliath.

Given that the court found him guilty of patent violation, Percy Schmeiser can be considered lucky to have avoided any obligation to pay damages. The court awarded no damages to Monsanto, in spite of its recognition that Schmeiser would have owed Monsanto $15,000 (Canadian) for the right to use its patented technology. The reason for this was that the court found that Schmeiser had not used Roundup® to control weeds in his canola field and had earned no economic advantage from the presence of the patented gene. Since Monsanto’s lawyers had only requested damages for the economic advantage due to the patented technology, the court ruled that the patent holder was not entitled to any compensation.

Do Farmers have a Right to Save and Select Seed?

As is shown by the narrow margin that decided this case in the Canadian High Court, there is room for differences of opinion. Normally, if your physical property finds its way onto my land and you take no steps to recover it, I can claim it as my own. It is regarded as “abandoned,” and available for claim. But intellectual property is different in this respect: Monsanto didn’t own the plants; it owned the Roundup Ready® technology.

Percy Schmeiser describes himself as a plant breeder and a seed saver. He argues that he has a right to select and refine the plants he grows and points out that many important advances in plant breeding have been accomplished by farmers like himself, not by gigantic agribusiness corporations. He claims that contamination from Monsanto’s canola cost him 50 years of research because he had been selecting and refining his canola seed each year ever since he started farming.

Although there are very good reasons why we should maintain and protect farmers’ right to save and refine their own seeds, it is far from clear that this right should protect those who specifically select for a patented trait. Plant breeders who start from patented stock are required to obtain a license before they can sell the results of their research, and it is reasonable to suppose that this requirement should apply to plant breeders who are farmers as well as those who are primarily engaged in research.
Does this ruling limit farmers’ rights? In one sense it clearly does because it implies that farmers do not have an unlimited right to breed and select plants. But as long as they start with their own stock, and as long as they avoid specific selection for patented traits, it would seem that Monsanto v. Schmeiser leaves their right intact. This result will not satisfy those who would like to preserve a farmer’s right to save and select seed as an absolute right, but neither does the ruling seem patently inappropriate.

Remaining Worries?

The ruling in Monsanto v. Schmeiser does not imply that farmers do not have a right to save seeds or that they must license or destroy their crop if they discover the presence of patented genes in their fields due to pollen drift or unintentional seed dispersal. But there are some remaining reasons for concern about this case and its implications for agriculture. While Monsanto v. Schmeiser does not provide a precedent for holding farmers legally liable for the mere adventitious presence of patented material on their land, it does not shut off the legal possibility. While it seems very unlikely that US or Canadian courts would adopt this stronger conception of liability, which, in effect, would obligate farmers to test their crops, it would put many people’s fears to rest if the issue were made clear once and for all.
1. After reading differing accounts of the case and the trial court facts, describe exactly what happened.

3. What do you think about Monsanto? What do you think they think actually happened? Did they do anything wrong? Did they handle the situation appropriately?

LEsson Overview

This activity is a viewing of a Frontline/NOVA special “Harvest of Fear” and completion of a worksheet designed to help students see both sides of the issue in the debate over genetically modified foods. The goal of the activity is for the students to form educated opinions of GM foods based in scientific fact.

TimeLine

The running time for the film is approximately 120 minutes. Students must take notes during the film viewing in order to complete the worksheet questions. The questions may be completed as homework.

Advance Preparation

The film is distributed by PBS Home Video and may be purchased directly from PBS at http://www.shopPBS.org. The cost is $19.98 for the VHS tape.

AnsWerS to student Questions

1. Throughout the film you saw the story of one scientist's fight to save the papaya crop in Hawaii from ring spot virus. Explain how the scientist went about finding a solution using biotechnology. What was a significant legal barrier to his plan? What has been the outcome of his plan?

   Dr. Gonsalves used a gene gun to transfer DNA from the ring spot virus into the genome of the papaya, conferring resistance to the disease. He used a patented DNA promoter sequence in his transformation scheme and he needed to get permission from Monsanto before he could introduce the GM papaya into crop fields in Hawaii. The GM papaya has been successful at resisting ring spot virus but some countries are hesitant to accept imports of the fruits. This has caused some Hawaiian growers to go back to the non-GM papaya and consequently the disease is back.

2. What are two main reasons Monsanto turned away from chemical controls and decided to focus efforts on genetic modification? What do you think about Monsanto’s mission? Are they doing the right thing? What do you think farmers in the United States think about Monsanto?

   Monsanto changed from chemical controls to genetic modification because pesticides were no longer economically viable and they are not good for the environment. (Opinion answers will vary.)
3. In the film what individuals and/or organizations are presented as major opponents to GM foods? Explain their position(s). Are their arguments logical or based in scientific fact? Do you think any of them have taken extreme measures to get their point across? Does this make you more likely or less likely to support their cause? Jeremy Rifkin, Greenpeace, and the Earth Liberation Front all oppose GM foods. Jeremy Rifkin and Greenpeace oppose on the grounds that more long term scientific testing is needed to determine the safety of the technology. Greenpeace and the Earth Liberation Front also oppose the corporations that develop the technology on the grounds that it is unnatural. They also believe that GM technology makes farmers negatively addicted to the products of agricultural biotechnology companies. (Opinion answers will vary.)

4. Explain how Europeans and Americans think differently about food. What historic events have influenced Europeans in their opinions of GM foods? Europeans think of specific foods as their cultural identity and place a high value on locally grown foods, often from smaller farms. Americans are used to a more disconnected relationship to food. The eugenics movement of the early twentieth century is a very negative recent memory for Europeans and so they are inherently opposed to the idea of genetic manipulation. They have recently had to deal with Mad Cow disease and while that is not an issue of genetic modification, it is an issue of food safety and so it has influenced how Europeans think about all food safety.

5. How long have we been eating GM food in the United States? How do you feel about that? Should GM food be labeled as such? We have been eating GM food since 1996. (Opinion answers will vary.)

6. What three agencies regulate the development and use of GM products? How does each agency play a role? The USDA makes sure GM products are safe to grow, the FDA makes sure they are safe to eat, and the EPA makes sure they are safe for the environment.

7. How do we know that GM foods are safe to eat? Explain the term “substantial equivalents.” Explain the difference between something being safe and minimizing risks. We know that GM foods are safe to eat because in mouse tests there is no evidence of harm even at 1000x levels of consumption. Plus, we have been eating them since 1996 and there have been no reported problems. Also, chemical testing of the products shows that they are substantial equivalents to the non-GM products. This means that they have no compounds in greater concentrations than is found in the non-GM version. We cannot say with certainty that something is safe. However we can work to minimize the risks.
8. Explain what happened in the StarLink corn controversy. What false assumption was made by Aventis that led to animal feed corn mixing with human food corn? Is the Cry9C protein a confirmed food allergy?

*StarLink corn was developed by Aventis.*

During testing it was found that it had a high concentration of Cry9C protein, a level that could cause an allergic reaction during human consumption. Rather than abandon the product, Aventis decided to market the corn for animal feed only. Aventis assumed that growers would keep animal feed corn separate from corn for human consumption. In fact, growers use the same facilities and silos for both kinds of corn. So, the StarLink GM corn was mixed in with corn that went on to make various corn-based products, most notably *Taco Bell* chips. Opponents of GM foods tested corn food products for the Cry9C protein and found it. The FDA also tested the products and confirmed the presence of Cry9C protein. The Cry9C protein has not been confirmed as a food allergy.

9. Nobel laureate Norman Borlaug thinks the world human population cannot possibly be fed using organic agriculture practices? Do you agree with his conclusion? Explain. *(Opinion answers will vary.)*

10. How is GM technology well suited to subsistence agricultural practices in developing countries? What did the Kenyan scientist mean when she said “the dreams of the poor are clashing with the rich – who don’t have a clue”? *Farmers practicing subsistence agriculture would not have to have any additional resources in order to take advantage of the benefits of GM technology. The GM crops have specific advantages built into the plants and so the farmer would not have to change how he farms in order to get the benefit. For example, a sweet potato farmer in Kenya planting crops engineered for increased yield could immediately get the benefits of more potatoes per plant without changing anything but the seed he puts in the ground. The Kenyan scientist meant that people in rich countries have the luxury of choosing not to use GM foods because food is not a scarce resource for them. They can afford to take a moral stance against GM foods because they can feed their families. For poor people in parts of the world experiencing starvation, GM foods will save lives. She thinks that giving GM technology to developing countries is actually the morally correct thing to do.*
ACTIVITY C2: “HARVEST OF FEAR” FRONTLINE/NOVA SPECIAL

During the viewing of the film you will need to take extensive notes so that you can provide complete answers to the questions below. Be sure to give concrete examples and scientific evidence in your answers.

1. Throughout the film you saw the story of one scientist’s fight to save the papaya crop in Hawaii from ring spot virus. Explain how the scientist went about finding a solution using biotechnology. What were the barriers to his plan? What has been the outcome of his plan?

2. What are two main reasons Monsanto turned away from chemical controls and decided to focus efforts on genetic modification? What do you think about Monsanto’s mission? Are they doing the right thing? What do you think farmers in the United States think about Monsanto?

3. What individuals and/or organizations are major opponents to GM foods? Explain their position(s). Are their arguments logical or based in scientific fact? Do you think any of them have taken extreme measures to get their point across? Does this make you more likely or less likely to support their cause?

4. What seems to be the main difference between American and European views on GM foods? What historic events have influenced Europeans in their opinions?

5. How long have we been eating GM food in the United States? How do you feel about that? Should GM food be labeled as such?

6. What three agencies regulate the development and use of GM products? How does each agency play a role?

7. How do we know that GM foods are safe to eat? Explain the term “substantial equivalents.” Explain the difference between something being safe and minimizing risks.

8. Explain what happened in the StarLink corn controversy. What false assumption was made by Aventis that led to animal feed corn mixing with human food corn? Is the Cry9C protein a confirmed food allergy?


10. How is GM technology well suited to subsistence agricultural practices in developing countries? What did the Kenyan scientist mean when she said “the dreams of the poor are clashing with the rich — who don’t have a clue”?

NAME: ____________________________________________________________________ CLASS HOUR: _________ DATE:____________
BUILD A BETTER FOOD

TEACHER MANUAL

LESSON OVERVIEW

Build A Better Food is a creative activity designed to promote an understanding of the real world application of genetically modified organisms (GMOs). Students will be asked to take what they have learned about agricultural biotechnology and apply it to solve a real problem. They will work in pairs to design a fictional GMO that has a practical application in the challenge to feed the growing human population. They will be presenting their product to representatives of either (1) the World Health Organization (United Nations special agency on health) or (2) a fictional biotech company. They must be able to defend their product on issues of regulation, ecology, ethics, and economics. They will present their product in a PowerPoint presentation or an advertisement format (poster, rap, radio jingle, television or radio commercial, etc.).

TIMELINE

It is recommended that students be given a week to research the issues specific to their product and create the presentation. You will need to decide how much class time you are willing to devote to this. The students should spend at least 30 minutes brainstorming and discussing the practicality of their product idea. You may choose to devote one or more class periods to the presentations.

PROCEDURE

Your students may need some assistance in identifying a particular problem to solve and you will need to approve their ideas before they go forward. The following is a list of ideas that you can use to stimulate student creative thought in the correct direction:

Increase yield
- Increase size or number of fruits, tubers, stalks, leaves, etc.
- Increase animal size or amount of production of animal product (eggs, milk, etc.)

Decrease farmer input
- Pest resistance, weed control, lower moisture requirement

Increase range of environmental conditions tolerated
- Drought, shade, sun, cold, heat, salt, low pH, high pH, wind, etc.

Increase amount of arable land
- Remediation of contaminated soil
- Eliminated need for crop rotation

Biopharming
- Addition of critical nutrients to human food source plant
- Addition of vaccines or medicines to human food source plant
- Production of pharmaceutical compounds
ACTIVITY OVERVIEW
In this exercise, you and a partner will work together to design a fictional genetically modified organism (GMO) that solves a particular problem related to feeding the growing human population. Once you decide upon a specific product, you and your partner will research the precise issues surrounding use of your product and then create a presentation of your product. You will be presenting your product to representatives of either the World Health Organization (United Nations special agency on health) or a fictional biotech company. You and your partner must be able to defend your product on issues of regulation, ecology, ethics, and economics.

PROCEDURE
STEP 1 Brainstorming
1. What problem would you like to address?
2. Is there a particular geographical region involved?
3. What is the root of the problem?
4. How would your GMO help to solve the problem?
5. What biotechnological method would you use to create your GMO?

STEP 2 Researching your GMO
1. What are the regulations (safety, USA, international) associated with your type of GMO?
2. Are there ecological issues or considerations surrounding use of your product?
3. Is your product ethically acceptable in the region you are proposing to use it?
4. Is your product economically acceptable in the region you are proposing to use it?

STEP 3 Creating your presentation
1. Will you be presenting your product to the WHO or a biotech company?
2. Will your product be freely available, sold at no profit, or sold at a profit?
3. Pick a type of presentation that will best showcase your product.
   - PowerPoint
   - Advertisement
   - Poster
   - Radio jingle or rap
   - Radio commercial
   - Television commercial
4. You and your partner must share the responsibility of presenting your product. It would be a good idea to have a very specific script written so that you both are able to demonstrate your knowledge of the product. You should practice your presentation in front of family and friends to make sure it fits into the time allotted.
5. You will need to anticipate questions that might be posed by your audience after seeing your presentation. Make a “possible questions” list and be sure that you and your partner can easily answer those questions.
Agri-Terminology ............................................. 147
Agriculture Crossword Puzzles ............................... 159
LESSON OVERVIEW
This activity is designed to broaden your students' agricultural knowledge through the introduction of specific terminology. It should help your students recognize the scientific complexity of farming and the environmental impacts of crop farming and raising livestock.

TIMELINE
Students may need 15-20 minutes to read through all of the terms in the glossary. Completion of the worksheet questions should take 10-15 minutes.

REFERENCES
• New Mexico State University Agriculture Glossary
  http://cahe.nmsu.edu/news/aggloss.html
• U.S. Department of Agriculture
  http://www.usda.gov/wps/portal/usdahome

ANSWERS TO WORKSHEET
1. What is the difference between an annual and a perennial? Give an example of an annual crop plant and an example of a perennial crop plant. An annual is any plant which completes its entire life cycle and dies within one year or less – example: corn. A perennial is a plant that lives for more than two years – example: apple tree. (Examples will vary)

2. Define the term “pest.” A pest is an animal or plant that is directly or indirectly detrimental to human interests, causing harm or reducing the quality and value of a harvestable crop or other resource.

3. The term “integrated pest management” (IPM) is defined as “using the best features of chemical, biological, and cultural controls in an overall pest control program.” Describe an IPM plan by providing one example of each type of control. Answers will vary, but must have one description from each category below.
   Chemical control – use bio or botanical pesticides that are made from naturally occurring chemical compounds.
   Biological control - use beneficial natural organisms to attack and control harmful plant and animal pests and weeds, including introducing predators, parasites, and disease organisms, or releasing sterilized individuals.
   Cultural control – use crop rotation (the growing of different crops, in recurring succession, on the same land) to reduce pest populations.
4. What is the difference between an exotic species and an invasive species?

*An exotic species is a non-native plant or animal species introduced by humans, but an invasive species is a non-native plant or animal species whose introduction causes or is likely to cause economic or environmental harm or harm to human health. An exotic species may not be an invasive species.*

5. Describe three specific environmental impacts associated with agriculture.

*Answers will vary, but should contain descriptions of three of the following: runoff and leaching of pesticides and fertilizers; pesticide drift and volatilization; erosion and dust from cultivation; improper disposal of animal manure and carcasses; methane release into the atmosphere; eutrophication of bodies of water; bioaccumulation of persistent pesticides; development of pesticide resistant species.*

6. Describe three specific agricultural practices that can reduce impact on the environment.

*Answers will vary, but should contain descriptions of three of the following: biological controls; contour farming; conservation tillage; no-till farming; crop rotation; use of mulch; nutrient management.*
Acre – A unit of area, 1 acre equals 43,560 square feet or 4,840 square yards.

Agribusiness – Producers and manufacturers of agricultural goods and services, such as fertilizer and farm equipment makers, food and fiber processors, wholesalers, transporters, and retail food and fiber outlets.

Agriculture – The occupation, business, or science of cultivating the land, producing crops, and raising livestock.

Agricultural chemicals – Used generally to refer to both pesticides and fertilizers and in some situations may include animal drugs.

Agricultural diversification – A system of farming that encourages production of a variety of plants and animals and their products as opposed to monoculture or large-scale specialization.

Agricultural pollution – Wastes, emissions, and discharges arising from farming activities. Causes include runoff and leaching of pesticides and fertilizers; pesticide drift and volatilization; erosion and dust from cultivation; and improper disposal of animal manure and carcasses.

Agronomy – The science of crop production and soil management.

Annual – Any plant which completes its entire life cycle and dies within one year or less.

Biological control – The practice of using beneficial natural organisms to attack and control harmful plant and animal pests and weeds is called biological control, or biocontrol. This can include introducing predators, parasites, and disease organisms, or releasing sterilized individuals.

Biopesticide – A pesticide that is biological in origin (i.e., viruses, bacteria, pheromones, natural plant compounds) in contrast to synthetic chemicals. Transgenic Bt cotton and corn already contain a biopesticide because production of a protein from the naturally occurring soil bacterium *Bacillus thuringiensis* (Bt) has been genetically engineered into the plants.

Biotechnology – The use of technology, based on living systems, to develop processes and products for commercial, scientific or other purposes. These include specific techniques of plant regeneration and gene manipulation and transfer.

Botanical pesticides – Pesticides whose active ingredients are plant-produced chemicals such as nicotine, rotenone, or strychnine. Also called plant-derived pesticides. Being “natural” pesticides, as distinct from synthetic ones, they are typically acceptable to organic farmers.

Broadcast application – The spreading of pesticides or fertilizers over an entire area.
Carrying capacity – The maximum stocking rate for livestock possible without damaging vegetation or related resources. Carrying capacity may vary from year to year on the same area, due to fluctuating forage production.

Chemigation – The application of a pesticide and/or fertilizer through any irrigation system. This delivery technique raises some concern that it may increase pollution.

Combine – A self-propelled or tractor-drawn machine that cuts, threshes, and cleans the standing crop while moving across the field. It is adapted to harvesting all the small grains, soybeans, grain sorghums, peanuts, beans, etc.

Composting – The controlled biological decomposition of organic material, such as sewage sludge, animal manures, or crop residues, in the presence of air to form a humus-like material.

Concentrated animal feeding operation (CAFO) – Generally, a facility where large numbers of farm animals are confined, fed, and raised, such as dairy and beef cattle feedlots, hog production facilities, and closed poultry houses.

Conservation – The management of human and natural resources to provide maximum benefits over a sustained period of time (see sustainable agriculture). In farming, conservation entails matching cropping patterns and the productive potential and physical limitations of agricultural lands to ensure long-term sustainability of profitable production. Conservation practices focus on conserving soil, water, energy, and biological resources.

Conservation tillage – Leaving 1/3 residue from a previous crop.

Contour farming – Field operations such as plowing, planting, cultivating, and harvesting on the contour, or at right angles to the natural slope to reduce soil erosion, protect soil fertility, and use water more efficiently.

Corn Belt – That area of the United States where corn is a principal cash crop, including Iowa, Indiana, most of Illinois, and parts of Kansas, Missouri, Nebraska, South Dakota, Minnesota, Ohio and Wisconsin.

Corporate farm – A form of farm ownership that is a separate legal entity from the owners of the farm. Changes in the tax law in the 1970s encouraged the incorporation of farms as corporate tax rates declined while individual tax rates rose, mainly because of inflation. The 1992 Census of Agriculture reports that less than 4%, or nearly 73,000, of the 1.925 million farms in the nation were corporate farms. By contrast, more than 1.653 million (86%) were individual or family-owned operations and 186,000 (10%) were partnerships.

Cover crop – A close-growing crop, planted primarily as a rotation between regularly planted crops, or between trees and vines in orchards and vineyards, to protect soil from erosion and improve it between periods of regular crops.
Crop residue – That portion of a plant, such as a corn stalk, left in the field after harvest. Crop residues are measured for farmers who use conservation tillage to implement their conservation plans to meet conservation compliance requirements.

Crop rotation – The growing of different crops, in recurring succession, on the same land in contrast to monoculture cropping. Rotation usually is done to replenish soil fertility and to reduce pest populations in order to increase the potential for high levels of production in future years.

Crossbreeding – The mating of animals of different breeds. For example, breeding a Hereford cow with an Angus bull.

Cultivator – A machine used to till the upper portion of the soil, primarily used to destroy weeds or form a moisture retaining mulch.

Disease vectors – Plants or animals that harbor and carry disease organisms that may attack crops or livestock.

Eutrophication – The process by which a body of water acquires a high concentration of plant nutrients, especially nitrates or phosphates. This nutrification promotes algae growth that, when it dies, can lead to the depletion of dissolved oxygen, killing fish and other aquatic organisms

Exotic species – A non-native plant or animal species introduced by humans, either deliberately or accidentally.

Fallow cropland – Cropland left idle during the growing season, sometimes called summer fallow. It may be tilled or sprayed to control weeds and conserve moisture in the soil.

Farm – As defined for purposes of the Census of Agriculture since 1978, a farm is any place that has, or has the potential to produce, $1,000 or more in annual gross sales of farm products.

Farmland – Land used for agricultural purposes. The federal government recognizes prime farmland and unique farmland as the most important categories. According to USDA, the United States has had roughly 1 billion acres of farmland. Farmland consists of cropland, pastureland, and grazing land.

Fertilizer – Any organic or inorganic material, either natural or synthetic, used to supply elements (such as nitrogen, phosphate and potash) essential for plant growth. If used in excess or attached to eroding soil, fertilizers can become a source of water pollution.

Field corn – Any variety of corn that is grown extensively in large fields primarily for livestock feed, as contrasted with the horticultural varieties, such as sweet corn or popcorn.

Food grain – Cereal seeds most commonly used for human food, chiefly wheat and rice.

Forage – Vegetable matter, fresh or preserved, that is gathered and fed to animals as roughage includes alfalfa hay, corn silage, and other hay crops.
**Fumigant** – A vaporized pesticide used to control pests in soil, buildings and greenhouses, and chambers holding products such as fruits to be treated.

**Grain elevator** – A building where excess grain is stored to be sold or used later.

**Green manure** – A crop planted with the intention of turning it under for use as organic matter.

**Ground water** – Water within the earth that supplies wells and springs.

**Hay** – Grass or other plants that are cut, dried, and then used later as food.

**Herbicide** – Any pesticide used to destroy or inhibit plant growth; a weed killer.

**Hydroponics** – The growing of plants without soil by using an inert medium such as sand, peat, or vermiculite and adding a nutrient solution containing all the essential elements needed by the plant for its normal growth and development.

**Irrigation** – Providing a supply of water to a dry area, to help crops grow.

**Integrated pest management (IPM)** – Using the best features of chemical, biological, and cultural controls in an overall pest control program.

**Invasive species** – Alien (non-native) species of plants, animals, and pests whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

**Legume** – A family of plants, including many valuable food and forage species, such as peas, beans, soybeans, peanuts, clovers, and alfalfas. They can convert nitrogen from the air to build up nitrogen in the soil.

**Methane** – A gas created by anaerobic decomposition of organic compounds. Natural gas is composed mostly of methane. Methane is a so-called greenhouse gas. Agricultural wastes, specifically animal wastes, are a major source of methane releases to the atmosphere.

**Monoculture** – A pattern of crop or tree production that relies on a single plant variety.

**Mulch** – A natural or artificial layer of plant residue or other material on the soil surface. Mulch reduces erosion, conserves soil moisture, inhibits weed growth, and can provide the soil with organic matter as it breaks down.

**Mycotoxins** – Toxic substances produced by fungi or molds on agricultural crops that may cause sickness in animals or humans that eat feed or food made from contaminated crops. There are between 300 and 400 known mycotoxins.

**Nematode** – Microscopic soil worm, which may attack roots or other structures of plants and cause extensive damage.

**Nitrogen** – An element found in the air and in all plant and animal tissues. For many crops, nitrogen fertilizer is essential for economic yields.
**No-till farming** – A method of planting crops that involves no seed bed preparation other than opening the soil to place individual seeds in holes or small slits; usually no cultivation during crop production; chemical weed control is normally used.

**Noxious weeds** – Undesirable plants that infest either land or water resources and cause physical and economic damage.

**Nutrient Management** – The practice of applying fertilizers and plant nutrients such as manures in a time and manner to best ensure they will be taken up by growing plants and not leach into the groundwater or wash away. The term may mean the use of natural methods of enhancing soil fertility, such as through crop rotations and green manures, and the use of soil tests to determine the fertility needs of the soil.

**Organic farming** – There is no universally accepted definition, but in general organic farming is a production system that avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives.

**Organic foods** – Food products produced by organic farming practices and handled or processed under organic handling and manufacturing processes as defined by several private and state organic certifying agencies.

**Pasteurization** – The process of heating milk to kill pathogens that may be harmful to humans.

**Pasture** – A fenced area of forage, usually improved, on which animals are grazed.

**Perennial** – A plant that lives for more than two years.

**Percolation** – The movement of water downward and radially through subsurface soil layers, usually continuing downward to groundwater. The rate at which soils permit percolation is a measure of the vulnerability of ground waters to contamination by surface waters.

**Persistent pesticides** – Pesticides that do not readily break down in the environment. Becoming long-lived components of the ecosystem, these chemicals may have enduring effects at low concentrations or may bioaccumulate, posing hazards to higher predators.

**Pest** – An animal or plant that is directly or indirectly detrimental to human interests, causing harm or reducing the quality and value of a harvestable crop or other resource. Weeds, termites, rats, and mildew are examples of pests.

**Pesticide** – A substance used to kill, control, repel, or mitigate any pest. Insecticides, fungicides, rodenticides, herbicides, and germicides are all pesticides. The Environmental Protection Agency regulates pesticides under authority of the Federal Insecticide, Fungicide, and Rodenticide Act.
Pesticide residue tolerance – The amount of pesticide residue allowed by regulation to remain in or on a food sold in interstate commerce. Whenever a pesticide is registered for use on a food or a feed crop, a tolerance (or exemption from the tolerance requirement) must be established.

Pesticide resistance – The evolutionary capacity of pests exposed to a pesticide to develop resistance to that pesticide. Some genetically engineered crops now being marketed are accompanied by pest resistance management plans to prevent or substantially retard the development of resistance.

Roundup Ready® – Refers to genetically engineered glyphosate-tolerant crops. Roundup® is the trade name for glyphosate, a broad-spectrum herbicide. Farmers planting RR crops pay more for the seed, must use certain herbicide application practices, and may not save and use their own seed as part of a pesticide resistance management plan. The benefits include a reduction in the number of herbicide applications, with potential savings in both chemical and labor costs.

Ruminant – Animal having a stomach with four compartments. Their digestive process is more complex than that of animals having a true stomach. Ruminants include cattle, sheep and goats, as well as deer, bison, buffalo, camels and giraffes.

Rural – The Bureau of the Census defines the rural population (in contrast to urban) as all persons living in the open country, plus those in places of less than 2,500 inhabitants that are beyond the densely settled (1,000 or more persons per square mile) suburban fringes of metropolitan cities.

Seed bank – A facility used for the preservation and dissemination of seed, particularly varieties that are not in commercial use and that may be threatened with extinction. The USDA administers the U.S. National Plant Germplasm System.

Silage – A crop that has been preserved in a moist, succulent condition by partial fermentation in a tight container (silo) above or below ground. The chief crops stored in this way are corn (the whole plant), sorghum, and various legumes and grasses. The main use of silage is in cattle feed.

Silo – A tall cylindrical tower used for grain storage or animal feed, makes silage.

Straw – The stalks of threshed cereal crops such as wheat or barley.

Summer fallow – Cropland in semi-arid regions that is purposely kept out of production during a cropping season mainly to conserve moisture for the next season. It is common for wheat producers in semi-arid regions to rotate half their cropland to summer fallow each year.
**Surface runoff** – Precipitation, snow melt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major cause of erosion and transporter of non-point source pollutants.

**Sustainable agriculture** – A systematic approach to agriculture that focuses on ensuring the long-term productivity of human and natural resources for meeting food and fiber needs.

**Thresher** – A machine, flail, or other implement used to separate the seeds harvested from the residue (straw, chaff, husks).

**Till** - To prepare land for growing of crops by plowing or harrowing.

**Urban and built-up areas** – A classification in the natural resources inventory, now called developed areas, that includes cities, villages, other build-up areas of more than 10 acres, industrial sites, railroad yards, cemeteries, airports, golf courses, shooting ranges, institutional and public administration sites, and similar areas.

**Water table** – The upper limit of the part of the soil or underlying rock material that is wholly saturated with water.

**Weed** – A plant, especially a wild plant, growing where it is not wanted.

**Yield** – The number of bushels (or pounds or hundredweight) that a farmer harvests per acre.
1. What is the difference between an annual and a perennial? Give an example of an annual crop plant and an example of a perennial crop plant.

2. Define the term “pest.”

3. The term “integrated pest management” (IPM) is defined as “using the best features of chemical, biological, and cultural controls in an overall pest control program.” Describe an IPM plan by providing one example of each type of control.
4. What is the difference between an exotic species and an invasive species?

5. Describe three specific environmental impacts associated with agriculture.

6. Describe three specific agricultural practices that can reduce impact on the environment.
LESSON OVERVIEW
This activity is designed to reinforce key agriculture terminology.

TIMELINE
This activity may take 10-15 minutes for students to complete.

HINTS AND TROUBLESHOOTING
This activity will be very difficult if the students have not first read over the glossary provided in Agri-Terminology. You may want to consider having that glossary available to the students as they complete this puzzle.
ACROSS
7 The occupation, business, or science of cultivating the land, producing crops, and raising livestock
8 The number of bushels that a farmer harvests per acre
9 Acronym for integrated pest management
17 43,560 square feet
18 The process by which a body of water acquires a high concentration of plant nutrients
19 Plant that lives for more than two years

DOWN
1 A systematic approach to farming that focuses on ensuring long-term productivity
2 Plant that completes its life cycle and dies within one year or less
3 A substance used to kill, control, repel, or mitigate any pest
4 Microscopic soil worm
5 Any organic or inorganic material used to supply elements essential for plant growth
6 A weed killer
10 Plants or animals that harbor and carry disease organisms that may attack crops or livestock
11 The use of technology, based on living systems, to develop processes and products for commercial, scientific, or other purposes
12 The management of human and natural resources to provide maximum benefits over a sustained period of time
13 A pest remedy that is biological in origin
14 Growing different crops, in recurring succession, on the same land
15 Providing a supply of water to help crops grow
16 A layer of plant residue or other material on the soil surface
LESSON OVERVIEW

This activity is designed to reinforce key agriculture terminology.

TIMELINE

This activity may take 20 minutes for students to complete.

HINTS AND TROUBLESHOOTING

This activity will be very difficult for students if they have not first read over the glossary provided in Agri-Terminology. You may want to consider having that glossary available to the students as they complete this puzzle.
ACROSS
1  Microscopic soil worm
4  Plant that lives for more than two years
5  A weed killer
10  The area of the US where corn is a principle cash crop
14  The process by which a body of water acquires a high concentration of plant nutrients, especially nitrates or phosphates
16  The science of crop production and soil management
20  Plant that completes its life cycle and dies within one year or less
22  A tall cylindrical tower used for grain storage or animal feed
24  Vegetable matter, fresh or preserved, that is gathered and fed to animals as roughage
25  The management of human and natural resources to provide maximum benefits over a sustained period of time
27  A systematic approach to agriculture that focuses on ensuring long-term productivity
29  To prepare land for growing of crops by plowing or harrowing
30  A building where excess grain is stored to be sold or used later
31  A layer of plant residue or other material on the soil surface
32  A pesticide that is biological in origin
34  A substance used to kill, control, repel, or mitigate any pest
35  The use of technology, based on living systems, to develop processes and products for commercial, scientific, or other purposes

DOWN
2  43,560 square feet
3  The number of bushels that a farmer harvests per acre
6  That portion of a plant, such as a corn stalk, left in the field after harvest
7  Any organic or inorganic material used to supply elements essential for plant growth
8  Toxic substances produced by fungi or molds on agricultural crops that may cause sickness in animals or humans
9  Non-native plants, animals, and pests whose introduction causes or is likely to cause economic or environmental harm or harm to human health
10  Growing different crops, in recurring succession, on the same land
11  The spreading of pesticides or fertilizer over an entire area
12  Plants or animals that harbor and carry disease organisms that may attack crops or livestock
13 A self-propelled or tractor-drawn machine that cuts,threshes,and cleans the standing crop while moving across the field
15 The occupation, business, or science of cultivating the land, producing crops, and raising livestock
17 The controlled biological decomposition of organic material
18 A machine used to till the upper portion of the soil
19 A method of planting crops that involves no seed bed preparation other than opening the soil to place individual seeds in holes or small slits
21 Providing a supply of water to help crops grow
23 A pattern of crop or tree production that relies on a single plant variety
26 Animal having a stomach with four compartments
28 A fenced area of forage on which animals are grazed
33 Acronym for integrated pest management