STEPWISE

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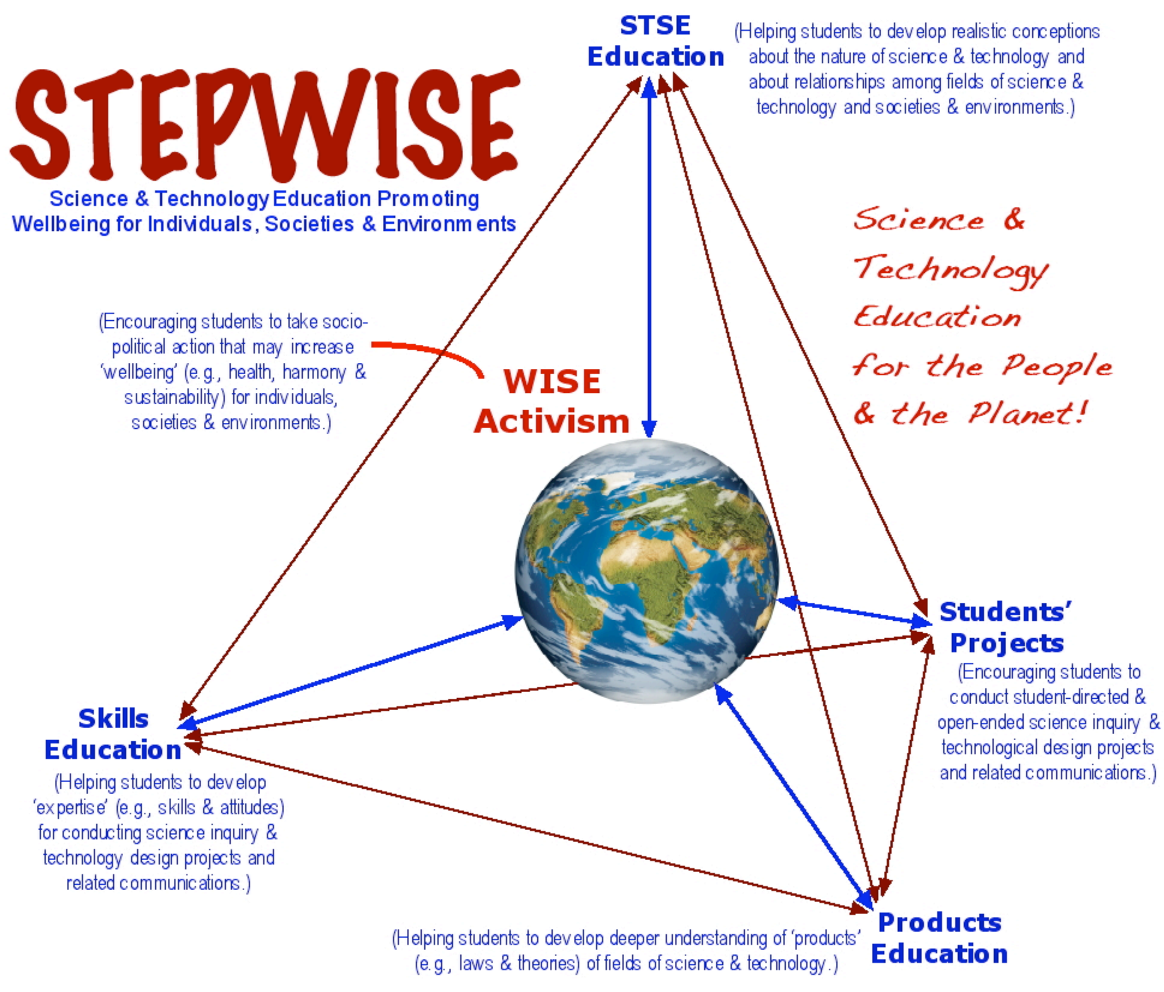
GENETICALLY MODIFIED CROPS

Case Method

The case method provided here is based on the STEPWISE curriculum and instructional framework provided below. This and other case methods provide some basic information about a 'WISE' issue, such as possible problems relating to genetically-modified crops. Teachers then provide instruction in each of the STEPWISE elements, and encourage students to conduct research to enhance their knowledge, skills and findings (in the case of Students' Projects) — related to the STEPWISE framework. Instruction and student work culminate in students' WISE Activism; i.e., action(s) to address the WISE issue.



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STEPWISE Case Method

GENETICALLY MODIFIED CROPS

Introduction

What do you think about fish genes in your strawberries? How about bacteria genes in your potatoes? Increasingly, genetically modified crops and food are being consumed by North Americans. However, very few people have stopped to consider the possible implications of including genetically modified food in their grocery basket. The few individuals that do give genetically modified organisms (GMOs) some thought are sharply divided on the topic. As a consumer, what are your thoughts on this topic? Have you considered the impacts or benefits of GMOs in your decision on what to purchase? What if it was found that little scientific evidence existed about the health risks of GMOs; that GMOs had a negative impact on the environment; and that they were doing very little to alleviate poverty and malnutrition? Would you still eat food you knew contained GMOs? Hopefully, this case will help you consider GMOs in a new light.

But wait, hasn't biotechnology been used to manipulate food for centuries (biotechnology refers to the use of living organisms or their components, such as enzymes, to make products)? Yes, it is known that ancient civilizations (since about 4000 BC) used yeast to make bread, beer, and wine. Fermented food products like yogurt, cheese, and soy were also common. Since that time, humans have continued to manipulate crops to produce better yields, they have selected sheep to provide improved wool, and they have bred cows to produce more milk. So, you might ask, 'what's the big deal'? The big deal started on a day in 1972, when scientist Paul Berg successfully used a restriction enzyme to isolate a gene from a human cancer-causing monkey virus (SV40). He then used ligase to join the section of virus DNA with a molecule of DNA from the bacterial virus lambda, creating the first recombinant DNA molecule and the first step in the technology for modifying the genetic makeup of an organism.

"I conceived of using SV40 as a means for introducing new genes into mammalian cells much in the way that bacteriophage transduce cellular DNA among infected cells. My colleagues and I succeeded in developing a general way to join two DNAs together in vitro; in this case, a set of three genes responsible for metabolizing galactose in the bacterium *E. coli* was inserted into the SV40 DNA genome. That work led to the emergence of the recombinant DNA technology…"

However, Berg immediately realized the dangers of his experiment and terminated it before the recombinant DNA molecule was added to E. coli where it would have been quickly reproduced. He then proposed a one-year moratorium on recombinant DNA research, in what is now called the "Berg Letter", in order for safety concerns to be worked out.

Berg later resumed his studies in recombinant DNA techniques, and was awarded the 1980 Nobel Prize in chemistry for his "fundamental studies of the biochemistry of nucleic acids, with particular regard to recombinant-DNA". His discoveries laid the foundation for field of genetic engineering, and the modern biotechnology industry, which includes agricultural, pharmaceutical, environmental, and industrial applications.

Modern biotechnology involves techniques for cutting apart and splicing together different pieces of DNA. When segments of foreign DNA are transferred into another cell or organism, the substance for which they code may be produced along with substances coded for by the native genetic material of the cell or organism. Thus, these cells become "factories" for the production of the protein coded for by the inserted DNA.

WISE Issue	Resources/Factors in Decision-making			WISE Action
Impact of genetically modified organisms on the food supply	**STSE Expertise**	**Products Expertise**	**Activism Expertise**	**Possible Action Projects**
	Environmental and health impacts associated with the production, use of genetically modified crops	**Structure and function of the DNA** **Structure, function, and production of recombinant DNA**	**Assessing the benefits and hazards of a specific technology.** **Developing and carrying out an action plan.**	**Education campaign e.g. informational brochure or ad**
	NoST Expertise	**Skills Expertise**	**Project(s) Findings**	
	Opportunities to explore: the economic and cultural factors that can influence science and technology	**Expertise for: Asking questions, hypothesizing, experimenting, developing conclusions**	**Results and conclusions from experimental and correlational studies**	

Prior Knowledge

Students should be able to:

- Recall that DNA contains genetic, inheritable information.
- Recall that viruses contain DNA or RNA

Curriculum Expectations Addressed

This case is appropriate for the following grades and strands:

Grade	Course	Strand	Specific Expectations Addressed
11	SBI 3U	Diversity of Living Things	DLT1.2 assess the influence of technology on biodiversity (e.g. genetically modified crops can outperform natural crops leading to eradication, selectively bred fish used in fish farming can escape and outcompete natural populations).
		Genetic Continuity	GC1.1 research and assess the social and ethical implications of genetic technologies using sources from print and electronic media (e.g., genetic screening can result in a gender imbalance in populations; stem cell research involves the destruction of embryos).
			GC1.2 evaluate examples of Canadian contributions to knowledge, techniques, and technologies related to genetic processes (e.g., research into cystic fibrosis, injecting a human gene into safflower to produce insulin, invention of nuclear magnetic resonance).
12	SBI 4U	Molecular Genetics	MG1.1 assess the impact of biotechnology in society(e.g. the impact of cloning a sheep on the theory of differentiation; the impact of transgenic technologies in agriculture).
			MG1.2 Evaluate Canadian laws pertaining to biotechnology (e.g., prepare legislation for mandatory DNA finger printing, human cloning, the ownership of a genome, the patenting of genetically-modified organisms) and compare them to another international juristriction.
			MG3.6 describe the functions of the cell components used in biotechnology(e.g., the role of plasmids, restriction enzymes, recombinant DNA, and vectors).
			MG3.7 outline the historical contributions that have led to the further development of molecular genetics.

A Short History of Modern Biotechnology

Modern biotechnology is based on recombinant DNA technology that was first performed by Paul Berg in 1972. From that moment forward, molecular genetics and biotechnology has been going full-tilt.

1953 - *Nature* magazine publishes James Watson's and Francis Crick's manuscript describing the double helix structure of DNA.

1969 -The first gene is isolated.

1972 - Paul Berg (at Stanford) isolated and employed a restriction enzyme to cut DNA. Berg used ligase to paste two DNA strands together to form a hybrid circular molecule. This was the first recombinant DNA molecule.

1972 -In a letter to *Science*, Paul Berg and others call for the National Institutes of Health (NIH) to enact guidelines for DNA splicing. Their letter recommended that scientists stop doing certain types of recombinant DNA experiments until questions of safety can be addressed (The Berg Letter). Their concerns eventually led to the 1975 Asilomar Conference.

1973- Scientists for the first time successfully transferred deoxyribonucleic acid (DNA) from one life form into another. Stanley Cohen and Annie Chang of Stanford University and Herbert Boyer of UCSF "spliced" sections of viral DNA and bacterial DNA with the same restriction enzyme, creating a plasmid with dual antibiotic resistance. They then spliced this recombinant DNA molecule into the DNA of a bacteria, thereby producing the first recombinant DNA organism.

1974- The Proceedings of the National Academy of Sciences published a paper by Stanley Cohen and Herbert Boyer in which they demonstrated the expression of a foreign gene implanted in bacteria by recombinant DNA methods. Cohen and Boyer showed that DNA can be cut with restriction enzymes and reproduced by inserting the recombinant DNA into Escherichia coli.

1975-A moratorium on recombinant DNA experiments was called for at an international meeting at Asilomar, California, where scientists urged the government to adopt guidelines regulating recombinant DNA experimentation. The scientists insisted on the development of "safe" bacteria and plasmids that could not escape from the laboratory.

1976 - Herbert Boyer and Robert Swanson founded Genentech, Inc., a biotechnology company dedicated to developing and marketing products based on recombinant DNA technology.

1976 -The NIH released the first guidelines for recombinant DNA experimentation. The guidelines restricted many categories of experiments.

1980 - The U.S. Supreme Court ruled that genetically altered life forms can be patented and therefore allowed the Exxon oil company to patent an oil-eating microorganism. This ruling opened up enormous possibilities for commercially exploiting genetic engineering.

1982 -The US Food and Drug Administration approves the first genetically engineered drug, human insulin produced by bacteria.

1983 -The first transgenic plant is created – petunia plants genetically engineered to be resistant to kanamycin, an antibiotic.

1986 -The first field tests of genetically engineered plants (tobacco) are conducted.

1990 -Chymosin, an enzyme used in cheese-making, becomes the first product of genetic engineering to be introduced into the food supply.

1993 -The FDA declares that genetically engineered foods are "not inherently dangerous" and do not require special regulation. The FDA took the position that GM crops are identical to non-GM crops, so the agency's regulation of foods from biotechnologically altered organisms does not differ from food product regulation in general.

1994 - First commercial approval by the US FDA of a transgenic plant, the Flavr-Savr tomato.

1994 – present – too many firsts to list

The Who, What, Why of Genetically Modified Crops
Genetically modified crops are conventionally bred with all the usual desired traits (yield, disease resistance, flower color, maturity date, quality) and then have a GM gene packet, representing a single trait, that is inserted using a recombinant DNA technique. Inserting this single gene packet converts a conventional plant into a GM plant. Crops are genetically modified to incorporate characteristics like herbicide tolerance, insecticide resistance, virus-resistance, enhanced oil quality, male sterility, hardier texture, and delayed ripening. Of these, two traits – herbicide resistance (HT) and Bt (*Bacillius thuringienses*) which makes a plant insecticidal – account for the majority of genetically modified crops globally. According to the Pew Initiative on Food and Biotechnology (2004), just 3 countries - the US (63%), Argentina (21%), Canada (6%) account for 90% of the 167 million acres sown to GM crops in 2003. An additional 3 (China and Brazil at 4% and South Africa at 1%) brings the total to 6 countries which jointly account for 99% of all genetically modified crops.

Out of the roughly 15 crop species which have been approved for commercialization in Canada, three account for almost all of the GM hectarage in Canada - corn, canola, and soybean (In the US, it is corn, soybean, and cotton; in Argentina and Brazil it is soy; in China and South Africa it is cotton). Other commercial genetically modified crops include: wheat, rice, cotton, potatoes, tomato, squash, flax, sunflower, papaya, lentil, and sugar-beet. You can see the details of which products/crops have been approved in Canada at the following website: http://www.inspection.gc.ca/english/plaveg/bio/dde.shtml.

Did you Know? In Canada, roughly 60% of our food has at least one genetically modified ingredient. Some estimates peg as many as 30,000 different products on grocery store shelves as "modified." That's primarily because many processed foods contain soy. In Canada, it is not mandatory for food containing GMOs to be labeled.

Why are crops being genetically modified?
The Proponents of the Technology
Genetically modified crops have been researched and promoted for a variety of benefits including:

- Increased nutrients and stress-tolerance
- Higher yields – better potential to feed the world
- Less dependence on toxic herbicides and pesticides - reduces the ecological footprint of agriculture
- Improved farm income, resulting from the combination of higher yields, lower input costs, and reduced maturation time
- Cheaper and better quality food for consumers
- New products and more efficient processing and growing techniques
- Significant profit potential (especially for companies like Monsanto, DuPont, and Novartis)

This all sounds great, right? So, what's the controversy?

The Opponents of the Technology
There are many criticisms of genetically modified crops and some of the major ones include:

- **Uncertainty about the potential long-term impacts on human health**
  - Research has suggested that GM potatoes could have a negative impact on the immune system of rats however the study was limited (Kuiper et al, 1999)
  - No clinical studies exist on human health impact of GMOs and most research showing the safety of GE foods have been conducted or funded by GE firms. (Domingo, 2000)
  - Safety test technology is inadequate to assess potential harm
  - Possibility of transfer of antibiotic resistance markers from the GMO to gut bacteria potentially making them resistant to antibiotics
  - Increase the risk of allergenic reactions
- **Uncertainty about the long-term impacts on the environment**
  - Unknown effects on other organisms (soil microbes). For example, it was found that Bt corn pollen harmed monarch butterfly larvae (Losey et al, 1999)
  - Loss of flora and fauna biodiversity
  - Increasing toxicity, which may move through the food chain (This is often overlooked because toxicity in food is tested by chemical analysis of macro/micro nutrients and known toxins)
  - Disruption to nature's system of pest control
  - Creating new resistant weeds or virus strains
  - Spreading genetically-engineered genes to indigenous plants. There is a possibility that a gene introduced into a plant may have unforeseen consequences if it gets incorporated into the genome of another plant for which it was not intended through cross-pollination. Monsanto began admitting in 2002 that research and development of GE crops will result in the spreading of GE traits to non-GE crops.

- **Management**
  - Lack of post-release monitoring programs and ill-defined indicators
  - Issues with bio-confinement including induced sterility or growth deficiency – no current method is 100% effective and it has been found that some genetically modified organisms are viable in the wild (Hampton, 2004)
  - The capacity to do risk assessment and monitoring is often lacking in developing countries

- **Access and Intellectual Property**
  - Domination of world food production by a few companies and countries – "The panel notes that the commercialization of biotechnology, including GMOs, is currently being pursued mainly by major corporations, which, understandably, seek to maximize profits." This is one of the reasons why the poorest and most vulnerable groups have not benefited from genetic engineering and are unlikely to do so unless important conditions are put in place," the report says."
  - Increasing dependence on industrialized nations by developing countries
  - Bio-piracy—foreign exploitation of natural resources
  - New advances may be skewed to interests of rich countries
  - The majority of the information collected by the industry is not in the public domain
- **Ethics**
  - Violation of natural organisms' intrinsic values
  - Tampering with nature by mixing genes among species
  - Objections to consuming animal genes in plants and vice versa

Did You Know? Over 58 countries have enacted or announced laws that restrict GE imports, commercialization of GE products and/or require labeling of foods containing GE ingredients, Europe being the most important of these markets.

Phew, that's a lot of information. To simplify this, let's examine a couple of the key reported benefits of GMOs in more detail to see if they are in fact delivering on their promises.

Higher yield – better potential to feed the world?
Currently, over 2 billion people do not get enough to eat worldwide and in the next 40 years it is predicted that the world population will double to 12 billion people! Obviously it is critical that a sustainable means to feed these individuals is available. Are GMOs the answer? Interestingly, GM crops are not specifically bred for higher yields. However, yield benefits can occur if sufficient weed and pest control results and makes the crops more cost-effective. Thus Bt-corn can experience higher yield if populations of the cornborer pest are high but this is infrequent and unpredictable and so overall yield is not increased. In soybeans, it appears that yield is actually constrained by the HT trait – herbicide resistant soybean yields have averaged 5-10% less than conventional soybeans. Even a staunch advocate for the use of GMOs, Norman Borlaug (Spearheaded the Green Revolution of the 1970s) has recognized, "In the last century, conventional breeding produced higher yields and will continue to do so in this century." Yield aside, there are still three other issues that prevent GMOs from feeding the world. They are developed by 'for-profit' corporations and as a result, developing countries can't access them because they are too expensive. In addition, many countries, like India, oppose genetically modified crops for ethical reasons because they believe that

nature shouldn't be tampered with. Finally, no long terms clinical studies have been conducted on the impact of GMOs on human health and as a result, people are skeptical.

Environmental protection as a result of decreased biocide use?
Pesticides and herbicides have been polluting our environment for many years and countless organisms have developed resistance to them. So it would seem to be a good idea if crops could be genetically modified to be resistant to these pests. Farmers would no longer have to spend money on pesticides and the environment would not be subject to the relentless application of such toxins. Well as it turns out, this hasn't exactly been the case. The first years of herbicide tolerant crops did indeed lead to decreased use of pesticides on GM as compared to conventional crops. However, after several years of intense use, the HT trait has lead to escalating populations of herbicide tolerant weeds. There is a clear trend that over time, GM crops require more pesticides than conventional crops, not less as the industry has promised. In 2004 farmers sprayed an average 4.7% more pesticides on GM crops than they did on the identical conventional crops. Furthermore, insecticides are not typically used at all on the target of Bt corn – the European cornborer. Thus, no savings in insecticide use can come from Bt-corn. However, Bt cotton has shown more promise. Overall, HT crops *increased* biocide use by 70 million lb, Bt crops *reduced* biocide use by 19.6 million lb (almost wholly on cotton), with the net effect that cumulative biocide use in the US over the last 8 years has increased by 50.6 million pounds due to overuse of the GM crop traits. Not to mention, the weed control issues that have resulted as target weeds have become herbicide resistant.

Improved Farm Income?
It would seem obvious that with all of the hype around biotechnology and the potential of genetically modified crops that at least the farmers must be doing well. So far, farmers have not improved their income primarily because of the global refusal to buy GMOs. This market rejection is compounded by higher seed prices that farmers must absorb to access the GM technology.

Significant Profit Potential?
Bingo! Companies selling GM seeds have made considerable money. Monsanto is the biggest and in 2003, 90% of GM hectares world-wide were planted with Monsanto seeds. Monsanto had revenues of $5.5 billion in 2004 and net income of $267 million.

Rebuttal of some of the proponents of genetically modified foods

"The protesters present no valid scientific findings in support of their position. They only raise hypothetical issues. They aren't interested in the science, so presenting accurate scientific evidence about biotechnology will not be effective in countering these critics (Marwick, 2000)."

"We cannot let others hide behind unfounded unwarranted scientific claims to block commerce and agricultural advances without evidence. It's important to base our regulations on sound science and let the rest of the world also base theirs on sound science," - Michael Dunn, undersecretary, US Department of Agriculture, at the GenCon meeting (Marwick, 2000).

"We've been using biotechnology and genetic manipulation for centuries and today's gene-splicing techniques have the same goal. In fact, greater control can be exerted over the process and can reduce the likelihood of unexpected results, states a report from the Congressional Research Service, *Biotechnology in the United States: Science, Regulation, and Issues*. The process "contrasts starkly with the randomness of nature itself," observed Bernard Dixon, PhD, a British science journalist (*BMJ.* 1999:318-547-548).

So What Does All of this Mean? The ~~Science~~ Politics of GMOs

It is clear that there are many perspectives on the positive and negative issues associated with genetically modified food crops. However, it is interesting that even with all of the resistance and uncertainty the fact is that North American producers are still filling our tables with GM products. Why is this? Critics of GE crops have pointed out that scientists do not have enough knowledge about several critical areas of recombinant DNA crop science including: what are the long term effects of eating GE foods, especially pesticide producing crops; how do added genes relate to the rest of the plants' genome; can damage to plant DNA that can result from inserting genes affects plants; how will inserted genes express themselves in future generations; and finally, what ecological impacts GE crops will there be over time. Are scientists ignoring data or deciding that the absence of data means that evidence is pro-GMO? Has the technology been used to control people, forcing developing countries to plant GM crops for export even though many countries have significant ethical issues with GMOs? There are many suggestions that indicate that GMOs haven't lived up to their mass-marketed potential then why are they still on the market? Isn't it a major risk to be genetically engineering the four or five most important food crops for humanity, especially without detailed and in-depth knowledge about the potential impacts? There is no question that biotechnology holds considerable promise and potential however given the risks and uncertainties about the effects of GMOs on human health and the environment, shouldn't countries be a little more cautious introducing them? The UN's FAO report on GMOs stresses that, "Every possible effort should be made to ensure that the risks are avoided." Although biotechnology is an important tool, what about investigations into viable alternative solutions that address the same problems GMOs are designed to solve? Scientific research has confirmed that rotation strategies, multiple cropping, cover crops and biological control have been found to improve crop health, environmental quality and agricultural productivity. How much does the profit motive play into the science that gets done?

A Final Thought…

"It will take years, perhaps decades, to construct a detailed theory that explains how DNA, RNA and the epigenetic machinery all fit into an interlocking, self-regulating system. But there is no longer any doubt that new theory is needed to replace the central dogma that has been the foundation of molecular genetics and biotechnology since the 1950's." …"I think this will come to be a classic story of orthodoxy de-railing objective analysis of the facts, in this case for a quarter of a century. The failure to recognize the full implications of this…may well go down as one of the biggest mistakes in the history of molecular biology." - John S. Mattick, Director of the Institute for Molecular Bioscience at the University of Queensland in Brisbane, Australia

Are scientists ignoring data and attributing the lack of available evidence regarding health and ecological impacts as support for GMOs? Are scientists holding onto a theory about the complexity of DNA that needs to be updated?

Teaching suggestions:

- Have students brainstorm what type of scientific research they would like to see conducted regarding GMOs and why? Students should prepare a presentation that outlines a design for how they believe the research should be conducted.
- Hold an in-class debate or town-hall meeting with various perspectives represented. At the end, have students prepare a self-reflection in which they discuss their own views on the topic.
- Have students investigate alternative agricultural technologies and contrast these technologies against crop biotechnology
- Have students consider the pros and cons of labeling GMOS in food products
- Have students consider whether developing countries should be influenced into using GMOs

Assessment Rubric

Criteria	Level 1	Level 2	Level 3	Level 4
Knowledge and Understanding	- demonstrates minimal understanding of the nature of genetically modified crops	- demonstrates some understanding of the nature of genetically modified crops	- demonstrates considerable understanding of the nature of genetically modified crops	- demonstrates a thorough understanding of the nature of genetically modified crops
Application	- connects knowledge of GMOs with national and international issues associated with the production and consumption of GMOs with minimal effectiveness.	- connects knowledge of GMOs with national and international issues associated with the production and consumption of GMOs with some effectiveness.	- connects knowledge of GMOs with national and international issues associated with the production and consumption of GMOs with considerable effectiveness.	- connects knowledge of GMOs with national and international issues associated with the production and consumption of GMOs with a high level of effectiveness.
Communication	-communicates information with limited clarity - Information is communicated with minimal organization.	- communicates information with some clarity - Information is communicated with some organization.	- communicates information with considerable clarity - Information is communicated with considerable organization. -employs	- communicates information with a high degree of clarity - Information is highly organized.

	-employs language skills with limited effectiveness.	-employs language skills with some effectiveness.	language skills with considerable effectiveness	-employs language skills with a high degree of effectiveness.

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