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Feeding the World Using Genetically Modified Organisms: A Survey of GMO Technology and its Impact on Agricultural Production

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Introduction and Rationale

The current population of the planet is roughly 7.4 billion people. Of these 7.4 billion people, 1 billion are considered to be chronically undernourished. By the year 2050, there will be at least 2.5 billion additional people on the planet, and most of these people will live in regions where chronic undernourishment and famine are already problematic.[1] What's more is that the agricultural productivity of the planet may be in jeopardy due to the looming threat of climate change, which is predicted to result in increased desertification, changes in rainfall patterns, pest ranges, and salinity.[2,3] This is especially true in arid and semi-arid regions where food shortages are already a stark reality for millions of people. These two problems are made even worse by the fact that they are intricately linked: more people require more food, more food requires more productive land, more productive land is not available, more food is not available, and ultimately people become increasingly undernourished or face famine.

Genetically modified organisms (GMOs) have shown promise in increasing crop yields in stressed environments and may prove vital in feeding this growing population.[4] However, many people are mis- or underinformed about GMOs and their benefits and costs. I feel it is vital that as the next generation of voters/consumers/scientists, my students should understand the magnitude of the global food crisis, its interconnectivity with climate change, and the role GMOs may play in addressing this issue. This newly developed unit that enhances my Land Use and Agriculture section of my Advanced Placement Environmental Science (APES) course is the first step toward helping my students achieve that understanding. In this unit, students work to develop a scientific understanding of what GMOs are and how/why/where they are being used, as well as an evidence-based opinion on their role in feeding the planet moving forward. This unit challenges students to integrate information across disciplines to form a better understanding of GMOs and their role in feeding a growing population.

School Profile and Course Specifics

William Penn High School is a public high school in the Colonial School District in New Castle County, DE. It is the only high school in the district and it is the largest high school in the state of Delaware, serving approximately 2,200 students in grades 9-12. The school district is mostly suburban, with small portions of the district being considered urban (the far northern portion of the district pulls from southern Wilmington) and some being considered rural (the far southern portion of the district pulls from farmland situated on either side of the Chesapeake and Delaware Canal). In total, the district serves over 10,000 students and expects to increase in size as the New Castle area experiences a revitalization of industry and job growth.

In order to make every student college and career ready, William Penn High School is divided into three college academies: the STEM College Academy, the Humanities College Academy, and the Business College Academy. Each college offers majors, or pathways of study. Incoming students decide on a pathway of study and must earn three consecutive credits related to that pathway as a requirement for graduation. AP Environmental Science (APES), the course for which this unit will be written, is the capstone course for the Environmental and Natural Resources (ENRS) pathway. Students in the ENRS pathway take Introduction to Agriscience, Natural Resources and Ecology, and Environmental Science Issues. The motivation behind this pathway is to provide students with access to the content knowledge and career skills necessary to continue on to study environmental science in their post-secondary education and/or to be ready to enter the environmental workforce upon graduation. To that end, students in this pathway get field experience, four credits of environmental science, and access to internships in related fields. The ENRS program at William Penn is uniquely positioned to take advantage of several educational resources, including the school's chemistry and biology labs, a multi-acre farm operated by the district (Penn Farm), an aquaponics facility, a greenhouse, and partnerships with higher educational institutions and local businesses. Several of these resources will prove vital to students during this agriculture-based unit.

Learning Objectives

The "Feeding the World Using GMOs" unit focuses briefly on the science of genetic engineering technology, the varieties of genetically modified crops, their potential to alleviate world hunger and to lessen the impact of climate change on agricultural yield, and finally the costs, benefits, and controversies surrounding their use. It also provides a template for teachers of similar content to incorporate aspects of the Next Generation Science Standards (NGSS) into AP courses by incorporating current events, creation of student models, analysis of data, and communication through various forms of media. Since this unit connects to several other common themes in the APES curriculum, it can be used as a model integrative phenomenon that can be revisited throughout the school year as students develop an increased understanding of environmental science. My overarching goal for this unit is for students to develop an evidence-based opinion on the role of GMOs in feeding a growing population while simultaneously dealing with threats to agricultural productivity because of climate change.

There are several course objectives and aspects of the three-dimensional Next Generation Science Standards (NGSS) that are addressed in this unit. Specific to the course, students learn that: (1) food production needs to be increased significantly by 2050 to meet the demands of a growing population, (2) crop yields and the amount of arable land on the planet are threatened by climate change, (3) genetic modification (GM) is a more refined version of selective breeding that focuses on altering/inserting/deleting specific genes, and (4) GMOs are a viable option for feeding a growing population but must be part of a larger multi-pronged approach.

Content Objectives

Student Prior Knowledge

At this point in my course, students have studied the following topics: The Living World, Human Population, and Agricultural Land Use. The Living World covers everything from energy and matter flow through ecosystems to the diversity of life on earth and major climate regions and biomes of the world. The Human Population unit covers population growth, demographics, and the stresses a growing population places on the earth. The Agricultural Land Use unit covers agriculture as a major land use, traditional practices vs the modern farming that came out of the Agricultural Revolution, and a cursory overview of the threats to agricultural output.

A Growing Population

In this portion of the course, students learned that the human population has grown essentially exponentially since the advent of the Industrial Revolution, with most of the growth occurring in Europe and Asia. They learned about how advances in medical and agricultural technology paved the way for massive population growth, and about the environmental pressures that this growth placed (and continues to place) on the planet. They also learned about demographics and how and why populations change over time (deemed the demographic transition). Students learned that the current population is 7.4 billion people, and that by 2050 it is predicted to increase to nearly 10 billion, before leveling off in 2100 between 11 and 13 billion people. Most of this growth will occur in Sub-Saharan Africa (SSA) and Southeast Asia (SEA), areas that are already food stressed and have the highest incidences of under and malnutrition worldwide.[5] This information is critical as a set up to the problem of feeding a growing population, and I make several hints to this in my instruction during this unit.

Modern Agriculture

When I ask my students to imagine a farm, their descriptions often go something like this: a small farm with a few acres of several crops, some livestock (perhaps chickens, pigs, and dairy cows), a red barn and green tractor, and other idyllic images of a bucolic scene. The family sells most of their harvest and keeps some for themselves, making enough money to live a comfortable and manageable life. However, this is an extremely outdated and naïve view of what modern agriculture has become in the wake of the Industrial Revolution. Considering that in order to feed the growing population referenced above, worldwide food production must be increased anywhere from twenty-five to seventy percent by 2050,[6] the fantasy farm I just described would spell doom for humanity if it were reality. Instead, farming is, and has been for quite some time, a commercial/industrial operation. The mechanization of all aspects of agriculture has significantly increased yields worldwide, while the actual number of farms has plummeted. The emergence of the biotechnology industry has coincided with the consolidation of smaller farms into supermassive factory farms. The reality is that the majority of our crops are grown in monocultures (when farmers plant acres and acres of just one genotype) by a decreasing number of farmers and harvested by massive machinery. Enormous quantities of fertilizer are used to increase yields, while heavy doses of pesticides and herbicides are used to ward off crop losses, and irrigation is used extensively to make previously non-arable land highly productive. These factory farms can be considered both high input and high output. They are highly dependent on the use of fossil fuels for the development of those fertilizers, pesticides, and herbicides, as well as for running the machinery needed on the farm.[7] However, all of these inputs lead to incredible crop yields. For example, between 1866 and 2014, US yields of corn increased from 1.63 tons per hectare to 10.73 tons per hectare. This represents a more than 500% increase in yield. These statistics are repeated worldwide, as every major agricultural region has experienced dramatic yield increases through advances in technology.[8]

This reality of modern farming often comes with a negative connotation, but there are several environmentally friendly farming techniques being implemented as a way of increasing crop yields in the long term without all of the harmful side effects familiar to modern agriculture. These include many practices used by early farmers, including crop rotation, polyculture, and integrated pest management (IPM).[9,10] Crop rotation is a process where crops are rotated through fields according to their nutrient demands and ability to restore fertility. Some crops require high amounts of nitrogen, while others can help put back nitrogen into the soil[11] (this occurs through a symbiotic relationship with nitrogen-fixing bacteria and is beyond the scope of this unit). By moving crops from field to field, natural processes can restore soil fertility and reduce the need for high inputs while maintaining yields. Polyculture is a technique that mimics the biodiversity of natural ecosystems whereby several crops are grown in concert with one another. Coffee plantations are well-known for growing several fruits alongside their coffee plants in order to maximize agricultural output without having to increase acreage. Essentially this works due to varying heights of plants, sunlight/water/nutrient requirements, and differences in planting/harvesting times. IPM is an approach to dealing with pests that employs several methods in concert or succession and requires an understanding of the ecology of the pests. The goal of IPM is not necessarily to eradicate the pest but to manage its population at acceptable levels. One outcome of IPM is that the amount of chemical pesticides is reduced. No two IPM plans are exactly the same because plans must be targeted to specific situations, but in general, IPM involves using such strategies as polyculture, intercropping, planting pest repellent crops, natural pest predators, crop rotation, routine monitoring and data collection, mechanical controls, and as a last resort, targeted applications of chemical pesticides.

Climate Change and Arable Land

Although climate change is its own unit in my APES course, there are several aspects of it that creep into other portions of the course. The impact of climate change on agriculture and arable land is one of those portions. The Intergovernmental Panel on Climate Change (IPCC) reports that some portions of the planet will become more suitable for agriculture while others will become less suitable. The areas of the planet that are predicted to become more arable are mostly limited to the high latitude boreal regions. Much more of the planet is predicted to become less arable, including areas in SSA and SEA.[12] As previously stated, this is problematic because these regions already face the problems of food security and under and malnutrition. The IPCC also reports that warming above 3^{o} C will result in significant yield declines across major crops that cannot adapt (whether through natural or artificial means) even when gains in yield due to additional rainfall and CO_2 are accounted for.[13]

The mechanisms for the shift in arability aren’t terribly important for student success at this point in the course, but it is important that they have at least a superficial understanding of the processes at work. In areas that experience an increase in arability, it is mostly due to prolonged growing seasons caused by an increase in surface temperatures as a result of the enhanced greenhouse effect brought about by increased concentrations of atmospheric CO_2. The reasons for decreased arability are more numerous and slightly more complex: in some regions, increased surface temperatures lead to decreased crop yields as the plants are no longer suitable for that environment. In others, increased temperatures lead to decreased soil moisture making it difficult to grow crops without frequent irrigation. In others, pests may become more prevalent or may expand into new areas. In still other areas, precipitation patterns shift so that rains are less frequent/more frequent/more irregular, leading to decreases in crop yields.[14,15] These impacts offer an opportunity for the use of GMOs in order to sustain or increase food production in threatened areas such as SSA and SEA.

Key Unit Content

Conventional Breeding Techniques

Selective breeding, which is also known as artificial selection, is the original process by which domestication of plants and animals occurred.[16] In this process, traits that are deemed desirable by humans are “selected” for, meaning that individuals that possess those traits are bred to advance that trait in the next generation.[17] The expression of those traits are observed as the organism’s phenotype. The timeline of selective breeding is painstakingly slow, as favorable traits can only be passed down as fast as organisms can reproduce (or as fast as researchers can create breeding pairs). This process occurs incrementally and takes many generations to obtain the desired outcomes. And just like evolution by natural selection, there must exist variation in the population to begin with for artificial selection to occur. If there isn’t variability in the trait of interest, then selective breeding may not be possible.

Cross breeding is another version of artificial selection that is depicted in Figure 1 below.[18] In this technique, two compatible species are bred to create a variety of the species that has the most desirable traits of the parents.

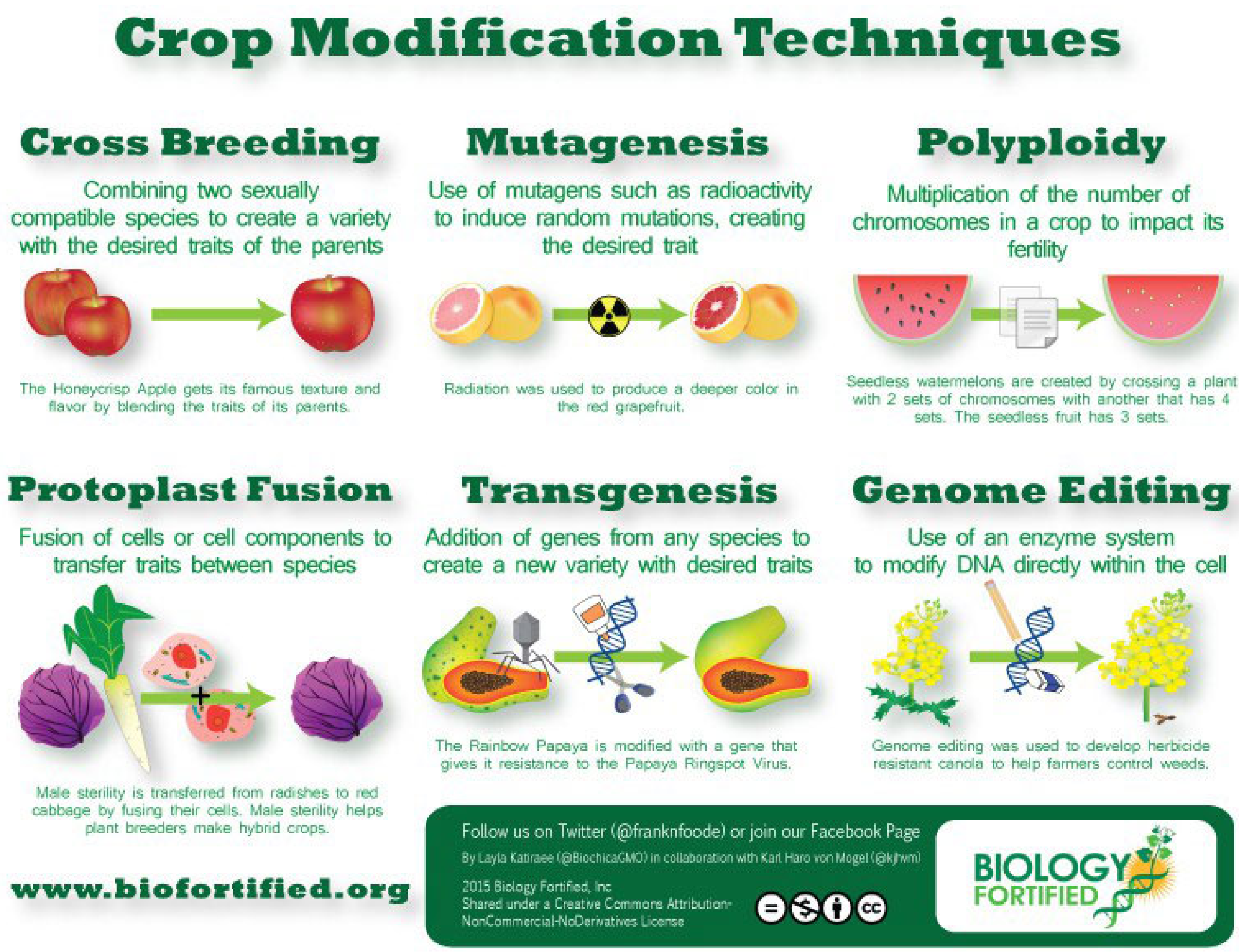

Figure 1: various crop modification techniques used to select for desirable traits in organisms.

Selective and cross breeding are methods responsible for the development and refinement of nearly every familiar agricultural species. For example, the domestication of corn in Mesoamerica was achieved by cross breeding of wild teosinte and maize plants. Through enough generations, cross and selective breeding produced the multi-eared, single stalk corn plants so ubiquitous in the Americas.[19] These simpler breeding techniques are still used throughout the world. But like selective breeding, cross breeding can take several generations to produce the desired outcome and is still blindly working off of the species' phenotype. The remainder of the techniques presented in Figure 1 are all forms of GM, some of which are discussed in the next section.

Genetic Modification

GMOs are living organisms whose genetic material has been artificially manipulated in a laboratory through genetic engineering. GMOs are often the product of combinations of DNA from plants, animals, bacteria, and viruses, and do not occur naturally or through traditional selective breeding methods.[20] At its basis, GM is simply a more precise version of the selective breeding that farmers have been doing for millennia. However, the mechanisms for GM are more complex than that and warrant some discussion so that students have a solid understanding of how traits like drought tolerance, increased protein content, or resistance to pests arise in the target organisms.

Instead of waiting for desirable phenotypes to emerge and then breeding those organisms in hope that the offspring also express that phenotype (or express it greater), scientists can use a form of GM to more precisely influence the desired phenotype. Of particular importance in the recent waves of GM are transgenesis and genome editing (Figure 1). In transgenesis, a desirable gene from one organism is inserted into another. As depicted in the figure, resistance to a virus found in the genome of a bacterium can be inserted into a popular fruit. There are several examples of GMOs of this type. For example, Bt corn, RoundUp Ready crops, and Golden Rice are all GMOs that arose from transgenesis.

“Golden Rice” is a variety of rice that produces higher amounts of beta-carotene than traditional rice. Beta-carotene is a precursor to Vitamin A, so Golden Rice is an incredibly important non-medical solution to Vitamin A deficiencies that currently cause 670,000 children to die prematurely[21] and an additional 500,000 cases of permanent blindness each year.[22] The genes for this over-production of beta-carotene are *psy* (which first came from a daffodil species but was later sourced from a maize plant), and *crtI* (which comes from a soil bacterium). The genes are engineered to only be expressed in the endosperm of the plant, which is the part that eventually gets harvested for human consumption.[23] Bt corn is a variety of corn that is resistant to certain species of moth, caterpillar, and nematode pests thanks to insertion of a resistance gene found in the soil bacterium *Bacillus thuringiensis.* The use of Bt corn was introduced as a way of reducing the use of pesticides needed to kill those moths, caterpillars, and nematodes that plagued farmers and reduced crop yields.[24] Glyphosate resistance was pioneered by Monsanto when scientists discovered that bacteria residing in the wastewater of a glyphosate production facility had evolved resistance. The gene responsible for this resistance was isolated from the bacterium and then inserted into corn using transgenesis. This allowed farmers to spray glyphosate on their fields, killing any weeds and leaving the crop unharmed.[25]

Genome editing of crops is a relatively new method of genetic technology that shows promise for creating the next generation of GMO crops. In this process, the existing DNA of an organism is directly modified using restriction enzymes[26] or Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR).[27] This allows scientists to insert specific sequences of DNA into a targeted part of the organism’s genome instead of having to transfer genes from one organism to another.[28] One potential organism that could be modified this way is the tomato: the gene sequence that codes for the production of locules in tomatoes could be altered to produce more locules (causing the plant to produce more tomato fruits). Or the fruit size could be increased, or ripening could be made to occur faster, or height could be fixed to allow for mechanization of harvest.[29] A more detailed explanation of this method is beyond the scope of this unit, but the hallmark is that those altered gene(s) can be engineered to be preferentially inherited through the germ-line, significantly reducing the cost of seed development and tinkering from year to year. Other crops that have been successfully modified using this technology include barley, corn, soy, sorghum, and rice.[30] The struggle to develop successful genome-edited crops has to do with the exact heritability that makes this technology so exciting. However, much research is needed before these GMOs hit the market and become readily available.

Prevalence of GMOs

Students should understand that many of the crops which they are familiar with are genetically modified in some way. According to industry statistics, the use of GMO crops increased from 1.7 million hectares in 1996 to 185.1 million hectares by 2016, representing a 110-fold increase. Much of this growth occurred in developing countries, who grew 54% of all GMO crops, compared to 46% for developed countries. Soybean, corn, cotton, and canola were the most widely used GMO crops.[31] GMO crops represent 75% of all crops grown worldwide.[32] Students should also realize that even non-GMO crops have been genetically altered using selective and cross-breeding practices dating back millennia to the domestication of plants and animals in the Neolithic period.

Advantages of GMOs

The benefits of using GMOs can be characterized in two ways. The first is that they have direct positive outcomes for people. For example, using GMOs can improve food security in regions like SSA and SEA where millions of people are either chronically under or malnourished, as in the case of Golden Rice. This is true for other varieties of GMOs as well, since GMOs have been proven to increase agricultural yields time and again. Their use can also increase, or at least maintain crop yields in the wake of changes to arable land as a result of climate change.[33] As previously discussed, this becomes incredibly important as weather patterns shift, pest ranges increase, and intensely farmed lands face desertification. The second characterization is that they have positive outcomes for the planet, and thus humanity in general. Using pest/disease-resistant crops can reduce the use of harmful pesticides and insecticides that threaten species biodiversity in agroecosystems, while using drought-tolerant crops can reduce the need for irrigation in water-stressed regions, lessening the need for non-direct water consumption. The potential reduction in inputs can lead to more sustainable crops overall.[34] Additionally, a reduction in inputs can lead to lower costs for consumers, so long as the agricultural industry passes along these savings.

For many years these benefits were touted by industry and stakeholders, but recently the United States Department of Agriculture (USDA) has reported that the use of GMOs does indeed represent cost savings both for consumers and farmers and has several key benefits for the environment. The report found that GMOs hold a yield advantage over conventional varieties, and that this advantage has become larger as refinements in modification technology have improved the specificity and efficacy of targeted modifications. They also report a decrease in insecticide use due to widespread adoption of Bt varieties of several crops, as well as a shift away from more toxic and persistent forms of herbicide in favor of glyphosate and glyphosate-tolerant varieties. Finally, the report demonstrates significant realized economic gains by farmers using GMO crops.[35] Table 1 summarizes the potential benefits of a widespread GMO program.

In summary, the use of GMOs has been shown to increase yield, improve the economic standing of farmers, and reduce the use of the most environmentally harmful active ingredients in herbicides and insecticides.[36] These benefits are not trivial, especially considering the scales of both the agricultural productivity and climate change issues. Consumers seeking to make a sustainable choice must give credence to such benefits when weighing GMOs as part of their diet. These benefits must also be considered by governments seeking to fight hunger and the effects of climate change simultaneously.

Disadvantages of GMOs

As discussed above, the primary arguments for GMOs consist of a body of scientific evidence that demonstrates increased yields compared to non-GMO varieties as well as early experimental evidence that GMO varieties of crops can better withstand potential harmful effects of climate change. The primary arguments against GMOs are less scientific, as the preponderance of scientific evidence shows no adverse human effects or ecological influence.[37] There are two valid concerns surrounding GMOs. The first is the business practices employed by large biotechnology companies who stand to make a large profit by selling their product. This was brought to the forefront in 1998 when Monsanto sued a Canadian farmer for unauthorized use of their GMO canola seed. The farmer claimed to have never purchased seeds from Monsanto and argued that the glyphosate resistant gene found in his crop must have transferred indirectly from a nearby farm planted with Monsanto's variety. While this argument seems plausible, Monsanto argued that the level at which the gene was present in the farmer's plants could not have been elevated to such high levels by accident. Their argument was that the farmer accidently harvested some of the neighbor's seeds and planted them in his own fields next year.[38] This story resurfaced in 2014 when the US Supreme Court ruled in favor of Monsanto's patent rights and ability to sue for infringement.[39] Although no legal wrongdoing was ever proven, the fear of such a major company using its mighty resources to squash such accidental use is very much alive and, in my opinion, valid. Another criticism of such companies' business practices is that small farms end up on a never-ending treadmill of purchasing seeds and herbicides or insecticides from the company. This is worrisome because of the limited number of vendor options, especially for those in developing countries.

The second argument against GMOs concerns how their use might influence resistance in weeds and pests. The long term evolutionary impacts of using GMOs is certainly concerning, but the speed by which resistance arises in agroecosystems is most troublesome. For example, from 1996 to 2002, the use of Bt corn increased from 1.1 million hectares to over 10 million hectares. Within that time, and likely a consequence of the increase in use, a Bt-resistant pest evolved. By 2011, there were at least 5 confirmed species that evolved Bt-resistance.[40] A similar story arose after the introduction of Roundup Ready crop varieties. Within ten years, twenty-four species of glyphosate-resistant weeds had independently evolved. The issue with altering the genes of crops is that it imposes an intense selection pressure on the very pests and weeds they are designed to overcome.[41]

Summary of GMO Controversy

Regardless of their opinions on GMOs, people can generally be categorized into theorists or rationalists.[42] Those who support GMOs may idealize the use of GMOs as a silver bullet in the fight against hunger, while other supporters may point to the previously discussed concrete evidence of their increased yields and economic benefits to farmers. Some of those who question the use of GMOs may point to those unproven claims of the health dangers of consuming GMOs while others may point to the previously mentioned Bt-resistance in pests and glyphosate-resistance in weeds. In my experience, the people who fall into the theorist camp tend to be the most fervent and vocal supporters and opponents of GMOs, while those who can be considered rationalists are milder in their support or opposition. These rationalists also seem to be more open to changing their mind in light of new evidence.

Table 1: summary of potential pros and cons of using GMOs

Pros	**Cons**
May require less water and fertilizer	Unknown ecological effects
Higher crop yields	Less biodiversity
Less spoilage	May harm beneficial insects
Faster growth -> greater productivity -> lower costs	May pose allergen risk
More resistant to disease, drought, frost, and insects	May result in mutations with unknown consequences
May be able to grow in saltier soils	May cause pesticide-resistant strains

Table 1, a summary of the potential pros and cons of GMOs adapted from a popular APES review book[43] is emblematic of the struggle to present arguments based on concrete evidence. The author is careful to qualify certain statements with “may” or “unknown,” playing right into the controversy between rationalists and theorists. It is my hope that this unit will help my students fall into the rationalist group.

In general, this controversy is difficult to settle because GMOs are simultaneously a scientific, political, economic, agricultural, commercial, ethical, and personal issue.[44] For example, FDA approval of a GM salmon that matures faster than natural salmon sparked outrage by prominent US politicians, including Alaskan senator Lisa Murkowski. Senator Murkowski, along with Congressman Don Young, criticized the FDA for approving something more akin to a science experiment than food. What the senator and congressman failed to realize though is that the company behind the salmon began seeking the approval process in the 1990s and only received *initial* approval in 2010. The FDA spent the next five years reviewing the scientific literature and considering objections before finally granting the final approval. In this case, Senator Murkowski and Congressman Young engaged in a misinformation campaign that muddied the otherwise crystal-clear water in part because the salmon fishing industry is worth tens of thousands of jobs and billions of dollars in revenue.[45]

Politicians on both sides of the ideological aisle routinely engage in such campaigns in order to protect the interests of their constituents (and subsequently their place in government). Part of the reason that politicians and other people in positions of power can be so successful is due to declining scientific literacy in the population. This, combined with the unbelievable amount of information available at our fingertips through the internet, makes it all too easy to stir up controversy on an issue that is relatively controversy-free among the scientists who actually study it.[46] This is exactly what has happened with GMOs; despite countless studies that demonstrate no harmful effects on human health or on the environment,[47] there still exists an anti-GMO fervor. I should note that this sentiment is much stronger in the European Union, where only twenty-three percent of people trust GMOs, while in the US people are either more accepting of their prevalence or simply ignorant to their widespread use.[48] Part of my job as a teacher is to help students wade through this controversy and identify what is simply rhetoric and what is backed up by evidence. In tackling the perceived controversy over GMOs, I have the ability to influence students to think rationally, seek evidence, and revise and update their understanding of an issue in light of new information.

Using GMOs as Part of a Broader Agricultural Strategy

The debate over GMOs would make it seem it’s either all or nothing: those in favor of GMOs envision a world where GMOs rule and less insecticide is used, there is less tillage, agricultural inputs are potentially lowered, and maybe advanced seed technology potentially lessens agriculture’s dependence on petroleum. In a world without GMOs, farmers spray large quantities of broad spectrum insecticides damaging surrounding food webs, farmers till more, which kills soil biota, and inputs of fertilizer and water are high, enhancing agriculture’s contribution to climate change. But the people who are most vested in this debate, the farmers, don’t see it that way.[49] If farmers don’t need GMOs (economically or otherwise), then they won’t use them. If they need to use pest-resistant crops because of an infestation, or drought tolerant crops in the wake of changing precipitation patterns, then they will.

Given their potential limitations, GMOs are not likely to be a one-size-fits-all solution to increasing crop yields amidst threats to productivity by climate change. Instead, they can be used alongside other farming techniques that show promise. As discussed earlier, IPM, crop rotation, and polycultures are just a few other useful strategies that can be employed alongside GMOs as modern agriculture adapts to the needs of the global population. Under this paradigm, GMOs can be used to move farmers away from the chemical-dependent practices of their predecessors without sacrificing their yields– something conventional environmentalists should be cheering, not opposing.[50]

Strategies

In order to instill in students an understanding that science is not merely a body of isolated facts but a systematic process for acquiring new knowledge, we as teachers must incorporate real aspects of the scientific process into the classroom. The National Research Council (NRC) lays out a framework for how to ensure that under NGSS students have authentic scientific experiences in their classrooms even as they learn the bodies of knowledge of the specific sciences. When implemented properly, this framework of SEPs "supports a better understanding of how scientific knowledge is produced and how engineering solutions are produced…help[ing] students become more critical consumers of scientific information."[51] This focus on process, according to the NRC, improves upon previous practices that reduced scientific procedures to isolated aims of instruction, rather than a vehicle for developing a meaningful understanding of the true scientific concept. Additionally, the process of discovering scientific truths allows students to engage in the types of critical thinking necessary to understand why the right answer is right, and perhaps more importantly, why the wrong answer is wrong. This emphasis on developing a strong evidence foundation supports student understanding of fundamentals of scientific truths. This is in stark contrast to old strategies which emphasize rote memorization of facts. In this unit, I employ several SEPs, along with other strategies to help my students understand GMOs and their role in modern agriculture.

Engaging Students using SEPs

Of particular importance in this unit are the following SEPs: "obtaining, evaluating, and communicating information," "engaging in argument from evidence," and "developing and using models." Students are tasked with finding scientifically accurate information surrounding GMOs. They interpret the information and then discuss this information with their peers. This is often challenging for students, especially for students who have yet to take an AP course. I model this process with unrelated information to help students get more comfortable with the process and make use of strategic pairing of students of different academic abilities to maximize student success. Students use the information they have gathered and interpreted to engage in a scientific argument on the topic information. Teaching students to ground their arguments in evidence is often difficult, as scientific evidence is quite different from the literary evidence they are more familiar with. I use exemplars and rubrics to help students identify good and bad use of evidence before they write or narrate their own arguments. Students also use this information to develop a model of GMO usage and its potential costs and benefits. Models are something that students are quite comfortable with when they only need to interpret them. Their comfort quickly disappears when they are tasked with creating models of their own. To that end we engage in a discussion of what makes a model easy to interpret and scientifically accurate and I provide students with the opportunity to refine their model over several stages.

Because of the three-dimensional model espoused by NGSS (the other dimensions being Disciplinary Core Ideas, known as DCIs, and Crosscutting Concepts, known as XCCs), the above SEPs were chosen as the best vehicles to make use of the XCCs with the goal of satisfying the DCIs. Three-dimensional assessment tools are used in order to accurately assess student mastery of content at the end of the unit. Specific XCCs and DCIs are presented in the Appendix entitled "Implementing District Standards."

Blended Learning

I will use our online learning management system Schoology throughout this unit. Schoology allows me to house resources students may find helpful as they progress through the unit and it helps me differentiate by providing students with different resources depending on their academic needs. In addition, it allows students to complete assignments ranging from readings to discussions to quizzes online, reducing the need for paper copies. Rubrics can be embedded into assignments on Schoology making it easier for me to provide students with constructive feedback in a timely manner. I think it is important for students to experience the blended learning approach since learning management systems like Schoology are almost ubiquitous on college campuses across the country.

Direct Instruction

Although I pride myself on ensuring that my classroom is a place where students do most of the heavy lifting, the nature of an AP course necessitates that some content is covered through direct instruction. Like with Blended Learning, this helps prepare students for the college experience. I employ a few strategies that make lecturing more engaging and beneficial for students: publishing the slides ahead of time on Schoology, embedding discussion questions and quick writing assignments into the slides, and breaking lectures into smaller chunks that can be structured around longer student-centered assignments.

Free Response Question Development

Answering the Free Response Questions (FRQs) on the AP exam can be a nightmare for students given that students are often asked to complete calculations, interpret graphs, define terms, and explain and discuss concepts in depth. In order to prepare students for answering these questions on the exam, I provide them with weekly practice. Early in the school year they answer only parts of questions and then engage in peer review using the rubrics published by the College Board. As we progress through the year and cover more and more content, I have students answer more parts of the questions.

Classroom Activities

Penn Farm Tour and Guest Lecture

Students start the unit by reading in the textbook about Agricultural Land Use and viewing a short video entitled “Feed the World.”[52] In order to provide context for several of the principles from the video, students tour the school’s fully operational farm where they see such practices as no-till farming, IPM, and various irrigation techniques. As a follow up to the tour, the farm manager delivers a short guest lecture with a question and answer session where students can ask questions based on their reading, the video, and the tour.

Progressive Model Development

In my opinion, the use of development and use of models is one of the most beneficial activities to advance understanding because they engage students in a real scientific exercise that starts with developing a model, evaluating it using evidence, using the model to illustrate, predict, or explain a phenomenon, and revising it to reflect new information. In short, it takes students through the scientific method. In this activity, students work in groups through a process I call "progressive modelling." An example of this process is demonstrated by Figure 2 below.

Initial Model by Student 1 Step 1	->	Initial Model by Student 2 Step 2	->	Initial Model by Student 2 Step 3	->	Initial Model by Student 2 Step 4

Figure 2: Progressive Model Development

Each student starts by creating a basic model. Then, students trade and refine their partner's model. Next, students trade again and add a 1-2 sentence caption to the model. Finally, the model gets passed back to its original owner who evaluates it for accuracy. Later in the unit, after reading the text and participating in the lecture, students revise their model based on new information. These models now represent students' understanding of the role GMOs can play in feeding a growing population.

Lecture and Discussion

Direct instruction will be used to emphasize critical content from the reading, as well as deliver new material about the basics of GMO technology. I start with selective and cross breeding before presenting transgenesis and genome editing. At this point students engage in a discussion about the differences in these techniques by using a Think-Pair-Share, where students take a moment to think about their response, share it with a partner and refine their response, and then share out with the entire class. I then return to the problem of a growing population and the potential impacts of climate change presented in previous units and ask students if GMOs can be used as part of the solution to these problems. Students are then given time to research the pros and cons of GMOs (I provide a collated set of resources on Schoology to facilitate this process). After this, students complete a Think-Ink-Share, a variation on the Think-Pair-Share where students must formalize their response in writing before sharing. Students follow up the class lecture and discussion by watching a TedTalk by Pamela Ronald entitled "The Case for Engineering Our Food," advocating for the use of GMOs.[53] This video is posted in Schoology where students are asked to engage in a virtual discussion of the content with their peers. Each student is required to respond to the initial discussion prompt, as well as two responses offered by their peers.

FRQ Practice

Students answer the question number four from the 2009 APES exam on the topic of GMOs, available at: https://secure-media.collegeboard.org/apc/ap09_frq_environmental_science.pdf. Students do not answer part (e) of this question, as it is not directly related to the content covered in this unit. This question is an excellent summative assessment for this unit because it engages students in several of the SEPs presented above and requires them to consider the environmental and economic tradeoffs of using GMOs. It also assesses their knowledge of agricultural practices in general. Part (a) of the question requires students to examine a graph of the use of GMOs over time in developed and developing countries. They are asked to calculate the increase in area of land used to grow GMO crops in both types of countries. Then, using the slope of the line they are asked to predict the amount of land area used for GMO crops in developed countries in the future. Students are also asked to identify one cause for the difference in land area between their projected value and the actual value. In part (b), students are asked to describe one environmental advantage and disadvantage of using GMO crops. In part (c), they are asked to describe an economic advantage and disadvantage of GMO crops. Finally, in part (d), students are asked to describe two agricultural practices that farmers can use to maintain or improve soil quality.

Students are given twenty-two minutes to answer the question to simulate AP exam testing conditions. After answering the question, students trade their answers with a partner and use the rubric released by College Board to score their partner's answer. The rubric is available at https://secure-media.collegeboard.org/apc/ap09_env_sci_sgs.pdf. Part (a) is worth four points; one point is awarded for each correct answer and set up for that math, while one point is awarded for a correct identification of a cause in the discrepancy between projected and actual GMO crop land area. Part (b) is worth two points; one point is awarded for a description of an environmental advantage and disadvantage of GMOs. Part (c) is worth two points; one point is awarded for a description of a viable economic advantage and disadvantage. Part (d) is worth two points; one point is awarded for each agricultural practice that maintains or improves soil quality. Students total the amount of points earned from all parts of the question. We then use these data to project their AP exam score: s student earning between eight and ten points would be on track for a 5. Students earning between six and seven points would be on track for a 4. Students who earn five points would be on track for a 3. Students earning less than 5 points would not be on track to pass the AP exam.

Once scoring is complete, we discuss the rubric and how to approach similar questions in the future. This discussion typically includes strategies for answering the math-based portion of the question, as well as tips for structuring answers to multi-part questions and strategically using key vocabulary in order to maximize points. Since there are many possible answers to several parts of these questions, engaging with the rubric and each other's work allows students to further develop their understanding of the topic.

Appendix A: Implementing District Standards

APES Standards

This unit addresses the following APES topics: II-C-3: Natural Selection, IV-A-1: Feeding a Growing Population, and IV-A-2: Controlling Pests.

Next Generation Science Standards

This unit addresses the following NGSS DCIs: HS-LS3-2: Inheritable genetic variations arise in different manners, HS-LS4-5: Changing environmental conditions favor those most fit for such changes, and HS-LS2-2: Various factors affect biodiversity and populations in ecosystems of different scales.

The following Cross-Cutting Concepts (XCCs) are used to frame instruction: structure and function, cause and effect, and systems and systems models.

Common Core State Standards

CCSS.ELA-LITERACY.RST.11-12.2: students determine the central ideas of a text and summarize complex concepts presented in the text

CCSS.ELA-LITERACY.RST.11-12.9: students synthesize information from a range of sources into a coherent understanding of a phenomenon

CCSS:ELA-LITERACY.WHST.11-12.1A: students present precise and knowledgeable claims, establish significance for their claims, distinguish their claim from alternative or opposing ones, and use logical sequencing to their argument in support of their claim.

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