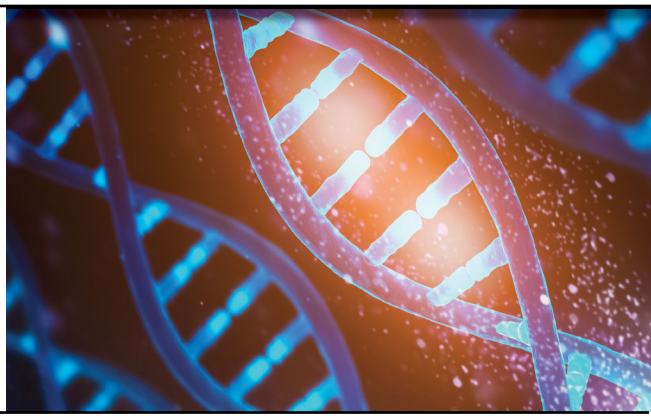
Smithsonian

SCIENCE
for Global Goals

BIOTECHNOLOGY!



Part 2:

Biotechnology and Food Systems

SUSTAINABLE DEVELOPMENT GOALS

developed by

Smithsonian
Science Education Center

in collaboration with

iap SCIENCE HEALTH POLICY
the interacademy partnership

Smithsonian Science Education Center greatly appreciates the efforts of all the individuals listed below in the development of Biotechnology! *How can we ethically create a sustainable future using biotechnology?* Part 2. Each contributed his or her expertise to ensure this project is of the highest quality. For a full list of acknowledgments please refer to the acknowledgments section at the beginning of this guide.

Smithsonian Science Education Center Guide Development Staff

Director - Dr. Carol O'Donnell

Division Director for Curriculum, Digital Media, and Communications - Laurie Rosatone

Science Curriculum Developers - Heidi Gibson, Logan Schmidt

Contributing Interns
Songhan Pang
Khadijah Thibodeaux

Research Mentors
Mwamy Mlangwa
Matin Qaim, Ph.D.

Technical Reviewers
Moira J. Sheehan, Ph.D.

The contributions of the Smithsonian Science Education Center staff, Project Advisors, Research Mentors, and Technical Reviewers are found in the acknowledgments section.

Image Credits
Cover - Charnchai/iStock/Getty Images Plus
Figure 2-1 - Heidi Gibson, Smithsonian Science Education Center
Figure 2-2 - Heidi Gibson, Smithsonian Science Education Center
Figure 2-3 - Heidi Gibson, Smithsonian Science Education Center
Figure 2-4 - chemicalbilly/E+/Getty Images Plus
Figure 2-5 - ipopba/iStock/Getty Images Plus
Figure 2-6 - Heidi Gibson, Smithsonian Science Education Center
Figure 2-7 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-8 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-9 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-10 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-11 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-12 - georgeclerk/E+/Getty Images Plus
Figure 2-13 - joakimbkk/iStock/Getty Images Plus
Figure 2-14 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-15 - Logan Schmidt, Smithsonian Science Education Center
Figure 2-16 - SimonSkafar/E+/Getty Images Plus; JohnnyGreig/E+/Getty Images Plus
Figure 2-17 - ribeirorocha/iStock/Getty Images Plus
Figure 2-18 - tazytaz/E+/Getty Images Plus

Smithsonian | SCIENCE for Global Goals

PART 2 BIOTECHNOLOGY AND FOOD SYSTEMS

Part 2

Find out More!

For additional resources and activities, please visit the *Biotechnology!* StoryMap at https://bit.ly/3pQUDpc.

Planner

Activity	Description	Materials and Technology	Additional Materials	Approximate Timing	Page Number
Task 1: Should we use biotechnology to change the food we eat?					
Discover	Analyze your food to investigate food systems in your community and around the world. Then interpret global hunger data.	• Paper • Pens or pencils		40 minutes	50
Understand	Investigate genetic modifications, then work as a group to design genetically modified plants that address common food security issues around the world.	• Paper • Pens or pencils	Printout of Figure 2-6 (optional)	40 minutes	54
Act	Explore hopes and concerns about the use of GMOs to combat food insecurity, then investigate your country's GMO policy and what can be done to support or change it.	• Paper • Pens or pencils	*Ethical Concerns List* (Part 1)	25 minutes	59

Activity	Description	Materials and Technology	Additional Materials	Approximate Timing	Page Number
Task 2: How can biotechnology help food systems contribute to a more sustainable future?					
Discover	Model the amount of farmable land in the world to identify harmful farming techniques and their impact on your local community.	• Paper • Pens or pencils • Scissors		25 minutes	66
Understand	Explore how biotechnology is helping restore and create farmable land around the world and in your community.	• Paper • Eight small objects • Pen or pencils • Specific investigations may need additional items		25 minutes + community investigation time	73
Act	Communicate your findings and ideas on farming techniques to take sustainable action.			15 minutes + action time	81

Task 1: Should we use biotechnology to change the food we eat?

People need food. But sometimes people do not have access to the food they need or want. In this task you will first ***discover*** more about the way food systems work. Then you will investigate different scenarios to ***understand*** the way **biotechnology** might change food systems. Finally, you will use this information to decide how you want to ***act*** now and in the future.

Meet Your Research Mentor

Meet Dr. Matin Qaim. Matin (pronounced ma-TEEN) is one of the many researchers around the world thinking about how to create a sustainable food system.

Matin is a professor of agricultural economics and director at the Center for Development Research at the University of Bonn, Germany. He has a PhD in agricultural economics. However, he also has knowledge and perspectives that came from other parts of his identity. Since Matin is now working with you, it is important to understand who he is.

To help you, Matin filled out an identity map, just like you did in Part 1. Matin's identity map includes the following things.

- 52-year-old man
- Family: "I'm married to a wonderful wife and with two lovely daughters (17 and 15 years old)."
- Tall: "I am a very tall guy (usually the tallest person around) and have black hair (now getting gray)."
- Born in Germany and lives in Bonn. "My mother is German, but my father is originally from Pakistan, so I grew up in a mixed-culture family."
- "I ride my bike to the office every day, a nice 7-km tour along the river Rhine."
- Researcher: "I am analyzing how the situation of poor people in the Global South could be improved. Much of my research relates to small-scale farmers in countries of Africa and Asia."

- Likes traveling and has seen many different countries and places; loves getting to know new places and cultures
- Likes eating and cooking good food, if possible together with family and friends
- Loves nature and enjoys hiking

Before you begin this task, think quietly to yourself about Matin's identity map.

- Are there things you have in common with Matin?
- Are there ways in which you are different from Matin?
- Can you see anything about Matin's identity, in addition to his university degrees, that would help him understand different perspectives or ideas about sustainable food systems?

Throughout this task you will notice Matin sharing ideas and experiences with you. He may help you understand better ways to do your research, or share some of the research he has done.

Discover: *What are the challenges to food systems?*

Most people eat food most days. But you may not know much about where your food comes from or how it gets to you. Sometimes people do not get the food they need because of problems in the food system. In this activity you will find out more about the food system and how it works.

1. Get out a piece of paper and something to write or draw with.
2. On the top of the paper draw a picture of your favorite or most recent meal, or write a description, if you prefer.
    a. Include all the parts of the meal you can remember, like if you had dessert. Do not worry if your drawing is not perfect; this paper is just to help you think.
3. Draw an arrow underneath and pointing toward your meal.
4. Now think about where the food you ate came from. For example, was it bought at a store, a market, or at a restaurant? Did you grow or catch it yourself? Draw or write what you know about where your meal came from. If the food came from more than one place, draw or write all the places you can remember.

5. Draw an arrow underneath and pointing toward what you just drew or wrote.
6. Now think about where the food came before that. For example, did a farmer harvest it and bring it to a market, did a factory produce it and ship it to a store, did a supplier buy it and deliver it to a restaurant? Draw or write what you know. It is very possible you may not be sure, and that is okay. If you are uncertain, just draw a question mark.
7. Keep using arrows and moving down the page until you either don't know any more information or you get to the place where the food was grown. An example of this sheet is shown in Figure 2-1.

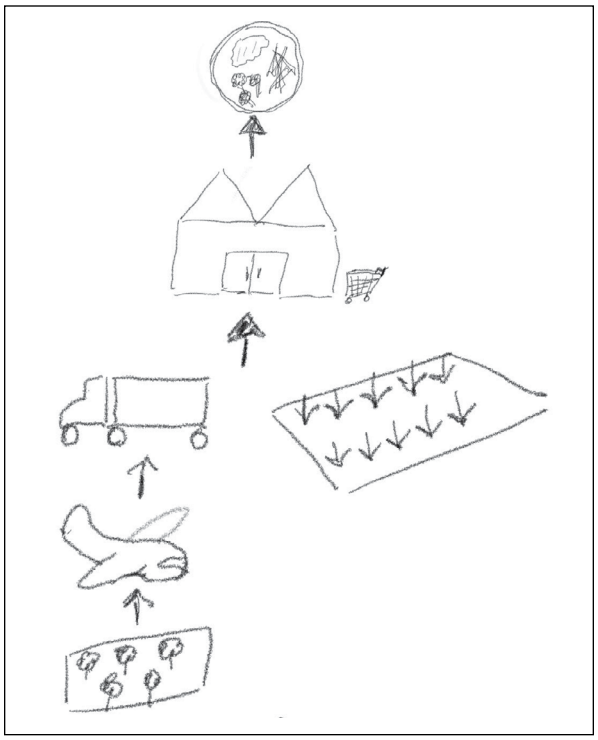


Figure 2-1: Example of a food system drawing.

8. Examine your paper. It represents what you know about your food system. How might someone else's paper be different? What if they ate different things or they lived in a different place?
9. At each step think about any problems that could arise and use words or drawings next to each arrow to show what those problems could be. For example:
    a. Maybe the food you ate was bought at a store. If you did not have much money or the price of food became very expensive, would you be able to buy it?
    b. Maybe there is a problem transporting the food from one place to another.
    c. Maybe there are problems with growing or storing the food.

10. Stop and think quietly to yourself: Have you experienced problems with the food system? Consider:
    a. Have you ever had trouble affording food? For example, sometimes food can become more expensive, which is called **inflation**.
    b. Has the food you want ever been unavailable? For example, during the COVID-19 pandemic many stores sometimes had empty shelves.
    c. Have you ever noticed or been told about farmers struggling with weather or pests when growing food?

> ⚠ **Emotional Safety Tip**
>
> It can be difficult to think about times you did not get the food you needed. It is okay to feel sad or angry. Your experience with the food system is not your fault, but you can become part of working to make the food system better.

11. Discuss with your team: What do you think the biggest challenges are to the food system? Read what Matin's says to help you think consider new ideas.

Matin says . . .

The goal of the food system is to nourish all people in a healthy way. Not only does that mean producing enough calories, it also means having enough of all the nutrients needed for healthy living. Obviously, food production plays an important role, especially with the land, water, and energy **constraints** on our planet. But there are also questions of distribution. Where are things produced? Who is producing them? Who has access? How do we limit food loss and waste? What are we eating and how does that affect the planet?

12. With your team, examine Figures 2-2 and 2-3. They show information about global **food insecurity**. Food insecurity is when a person lacks reliable access to affordable, nutritious food.

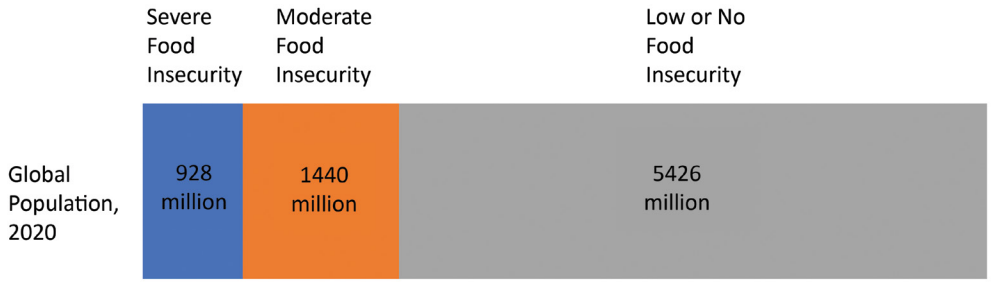


Figure 2-2: Global food insecurity, 2020[1].

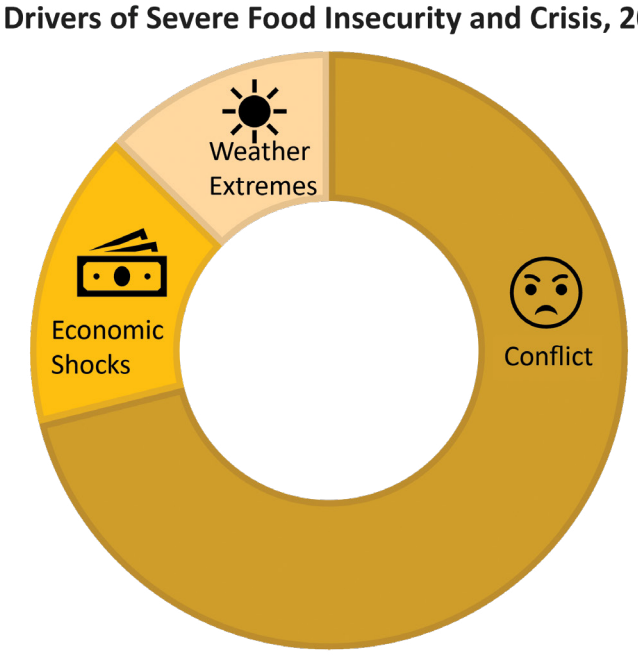


Figure 2-3: Drivers of severe food insecurity and crisis, 2021[2].

13. On a piece of paper or the board, draw three columns and label them "Notice," "Think," and "Wonder."
14. Fill in the columns with your team.
    a. In the *Notice* column, write everything you notice about the graphs. What do they show?
    b. In the *Think* column, write everything you think about what is causing the problems you noticed on the graphs.
    c. In the *Wonder* column, write everything you wonder about the graphs, especially about what would make the graphs have different information.

15. Consider what you have written in the columns and read Matin's ideas. Discuss with your team:
    a. What are your hopes for how the information in these graphs might improve in the future?
    b. What are your concerns about how the information in these graphs might get worse? Be sure to consider how growing food might be affected by the changing climate, which can cause severe weather events such as heat waves, drought, floods, and hurricanes.

Matin says . . .

Many people are poor and under-nourished today. And populations are growing. Estimates tell us we need to be able to nourish 10 billion people in the future. And at the same time climate change is a major challenge to the food system. The challenges are so big that we need all of the tools that can help. It is not either/or. We really need to bring technology and many other things together to help create a **sustainable** food system.

Understand: *How can biotechnology help solve food system challenges?*

We eat many types of food, but one of the most important types are plants. The plants grown for food around the world have changed over time. Farmers and scientists have been working on making plants better for people for thousands of years.

1. Work with a partner to answer the following questions, if you can.
    a. How do you think people have modified plants over time? Remember what you learned in Part 1.
    b. Think about the biotechnology tools you are familiar with. Which ones do you think could be used to change a plant's **DNA**?
2. Read *Overview of Agricultural Biotechnology* and discuss what you learned with your partner.

Overview of Agricultural Biotechnology

There are several ways to use biotechnology techniques to **modify** or change plants and their DNA.

For many years farmers and researchers have used **selective breeding** to develop crops that are easier to grow and harvest, are tastier, or last longer after being picked. Often, they will breed two plants together to try to have specific **traits** in their **offspring** that exist in one or both parent plants. This is known as **crossbreeding**.

There are also ways to use genetic engineering techniques to modify plants. Genetic modification in plants often has similar goals to selective breeding—for example, making the plant more resistant to pests, more nutritious, or better able to withstand harsh conditions, like a drought.

Figure 2-4: A genetic engineer at work.

One genetic modification technique involves using a **transgene**, which is a **gene** from another species. Genetic engineers can choose a gene from a different species and insert it in the DNA of a plant. This process is called **gene insertion**.

A transgene insertion often improves crops much faster than would be possible through crossbreeding. Living things that have been modified using transgenes are called **GMOs** or genetically modified organisms. GMOs have been developed and used for the past 30 years.

More recently, scientists have started using **gene editing** techniques, such as **CRISPR**, to make targeted changes to DNA without having to use a gene from another living thing. For example, gene editing techniques make small modifications to the DNA to "turn off" a gene and stop it from being expressed. Or gene editing can modify a specific gene within the DNA, creating new traits that plant breeders can use. Gene editing is a more precise tool and can be used in many ways to make small adjustments to the DNA of a plant.

Figure 2-5: Representation of small changes to DNA such as those that might be made using CRISPR.

3. You and your partner will now become genetic engineers. Read the *Genetic Engineering* guide carefully. You will be working together to decide how to modify the plants in each scenario.
4. After you read the guide, go through each Genetic Modification Card and decide whether in each scenario you should use gene insertion, gene editing, or crossbreeding. Then list which gene you would try to add or change.

Genetic Engineering Guide

Goals:

1. Consider each plant and location.
2. Decide the trait that needs to be modified.
3. Select a type of tool to modify the trait.
4. Choose what you would add or change.

Toolkit:

- **Gene insertion:** Allows you to give your plants traits of other organisms
- **Gene editing:** Allows you to change current traits in your plant
- **Crossbreeding:** Allows you to give your plants traits of other members of its species by breeding those members together

Issues modifications might address:

Drought, nutrition, space, food waste, pests, and others

Genetic Modification Card — Cotton

Scenario:

Sebastian's cotton plants are constantly eaten by an invasive species. His family grows cotton on their farm in Mexico, but lately most of their crops have been getting eaten by caterpillars. How can Sebastian's cotton be modified to resist these insects?

Genes in other organisms:

Gene CRY3Bb: Gene in soil bacteria that produces a chemical toxic to insects

Gene PYR: Gene in bacteria that helps them produce an essential nutrient

Gene CP4 EPSPS: Gene in soil bacteria that makes them resistant to herbicides (chemicals that kill weeds)

Toolkit choice (check one):

☐ Gene insertion ☐ Gene editing ☐ Crossbreeding

Which gene would you add or change? _____

Genetic Modification Card — Rice

Scenario:

Angel is a rice farmer in t he Philippines. Globally, every year lack of access to nutritious food, and especially essential vitamins, kills many children, including in the Philippines. How can Angel's family's rice be modified to be more nutritious?

Genes in other organisms:

Gene psy: Gene in maize that helps create vitamin A

Gene SIGLK2: Gene in tomatoes that controls the amount of sugar and flavor

Gene crtI: Gene in soil bacteria that helps create vitamin A

Toolkit choice (check one):

☐ Gene insertion ☐ Gene editing ☐ Crossbreeding

Which gene would you add or change? _____

Genetic Modification Card — Tomatoes

Scenario:

Carla lives in a city in Chile where the only space she has available to grow food is indoors. Carla wants to grow tomatoes, but their long vines and need for light make it difficult to grow enough tomatoes indoors to feed a family. How can Carla's tomatoes be modified for city life?

Genes in other organisms:

Gene SIER: Controls whether a tomato plant will grow tall

Gene SP5G: Controls when a tomato plant will flower or bear fruit

Gene SGR1: Controls how red a tomato will be

Toolkit choice (check one):

☐ Gene insertion ☐ Gene editing ☐ Crossbreeding

Which gene would you add or change? _____

Figure 2-6: Genetic Engineering Guide and Genetic Modification Cards. (continued)

Genetic Modification Card **Apples**

Scenario:

Jaylan is an apple farmer in the United States. He wants to make sure his apples are eaten and not wasted. Sliced apples turn brown after being exposed to air. Often people throw browned apples away even though they are still okay to eat. How can Jaylan's apples be modified to make people less likely to waste them?

Genes in other organisms:

Gene PPO: Produces an enzyme that browns apples

Gene CLV1: Controls how well apples respond to pests

Gene GA30X1: Controls the size an apple tree will grow

Toolkit choice (check one):

☐ Gene insertion ☐ Gene editing ☐ Crossbreeding

Which gene would you add or change? _____

Genetic Modification Card **Maize (Corn)**

Scenario:

Grace farms maize in Kenya. Kenya has a severe drought. Maize does not grow well without water and this has left many families without enough to eat. How can Grace's maize crop be modified to grow better in Kenya's current climate?

Wild Relatives of Maize:

Wild type relative A: Naturally sensitive to drought, grows poorly when lacking water

Wild type relative B: Naturally grows maize that's high in sugar and tastes sweet

Wild-type relative C: Naturally drought-resistant, grows well even when water is scarce

Toolkit choice (check one):

☐ Gene insertion ☐ Gene editing ☐ Crossbreeding

Which gene would you add or change? _____

Figure 2-6: (continued)

5. Gather with your team. The scenarios you just examined come from around the world. But your local community might have some challenges as well. Discuss:
   a. Are there **invasive species**, extreme weather, or other situations that make it hard to grow food in your community?
   b. Are there challenges to growing food in your community due to the changing climate?
   c. Are there other problems in your community, like poor nutrition or lack of space to grow plants, that modifying plants might help solve?
6. As a team, decide: If you had to choose one problem in your community to solve through genetic modification of plants, what would the problem be?
7. Now think about how a plant would need to be modified to help solve that problem.
   a. You can choose a modification like one of those listed in the Genetic Engineering Cards.
   b. Or you can think of a new modification you believe might be important. Read what Matin says to learn more about some of the ways genetic engineering in plants can be used.

Matin says . . .

Disease and pest resistance is an area that's incredibly important for genetic engineering. Right now, even with using pesticides, around 30% to 40% of the potential harvest is never achieved because of losses to pests and diseases. So if we could develop more resistant crops we could not only reduce the use of pesticides, we could increase the yield and production levels of many crops.

Thinking about climate change, possible modifications are not only about heat or drought or floods, although we could engineer plants to tolerate all of those things. Climate change also brings new types of pests in new places. With gene editing you can develop new mechanisms relatively quickly to resist new pests. Also, we can engineer crops that are very efficient in using soil nutrients, such as nitrogen. So that can mean even with limited nitrogen in the soil or limited fertilizer, you can have higher yields. You can also work on the root structure so more carbon is **sequestered** in the roots and in the soil and this carbon can stay in the soil even after we harvest. That's very positive from a climate change **mitigation** perspective. There are lots of interesting objectives breeders can work on.

***Act:** How should biotechnology be used to create a more sustainable food system?*

There are many challenges to our food systems. People around the world go hungry daily because of political, financial, and environmental issues. It is exciting to think about creating plants that could help feed the world affordable, nutritious food and are able to resist environmental challenges, like drought, salty soil, or invasive pests. But there are concerns. In some countries GMOs are widespread. Other countries have partially or fully banned GMOs. In some countries gene editing in plants is becoming a common technique. In other countries, gene editing of plants is very controlled. Why is it so controversial to use new biotechnologies to change plants and how do you feel about it?

1. Take out a piece of paper and divide it into two sections. Label one "Hopes" and the other "Concerns."
2. Under *Hopes* list the positive possibilities you can think of related to using genetic engineering of plants for a better future. How could GMOs or gene edited plants help solve food system problems? For example:
    a. Could genetically engineered plants help create more food using less space and allow for less food waste?
    b. Could genetically engineered plants help people adapt to a changing climate?
    c. Could genetically engineered plants help create a wider variety of crops?
    d. Could genetically engineered plants help protect **ecosystems** by limiting the need for new fields or other areas devoted to agriculture? (An ecosystem is a community of living and nonliving things.)
    e. If you need help, think about the modified plants you learned about in the Understand activity to get you started.
3. Get out your *Ethical Concerns List* from Part 1. Examine it closely with your team. Which of the ethical concerns do you think are relevant to the conversation about genetically engineered plants? List those under *Concerns*.
4. As a team, discuss the following ethical issues related to GMOs or gene-edited plants. If your team thinks an issue is important, list it under *Concerns*.
    a. Safety: What if eating genetically engineered plants causes disease or allergic reactions?
    b. Unbalanced ecosystems: There is a possibility that genetically engineered plants interact with the natural systems in unanticipated ways. For example, what if pest-resistant GMOs just encourage the development of pests that are able to overcome the pest-resistance?
    c. Persistence: GMOs put something into natural settings that did not naturally occur. Will the modification spread to other species or remain in nature even after farmers have stopped using GMO crops?
    d. Access: GMOs are often created by companies. These companies often make farmers buy GMO seeds every year; they cannot use seeds from last year's crop. Sometimes GMO plants only work if you buy the company's pesticide as well. This can get very expensive.

e. Decision-making: What if one farmer does not want to have genetically engineered plants but the neighboring farmer wants to? Many genetically engineered plants can spread and end up on a farm where they were never planted. Who should decide who can plant and where they can plant genetically engineered plants?

5. Read Matin's thoughts about the health and safety of genetically engineered plants. Do his ideas change your opinion about any of the concerns you were worried about?

Matin says . . .

Some people have a general concern that biotechnology is risky for human health, for the environment, or both. But from my perspective, we now have 30 years of scientific evidence that biotechnology techniques like GMOs or gene editing are not inherently risky. Just like the technique of crossbreeding is not inherently risky. All these techniques could create products that might be risky. For example, maybe a new crop variety has a trait that creates an environmental or health risk. We need to evaluate that. But we should evaluate all new varieties, regardless of the techniques that were used to develop them.

There are other concerns about gene editing and GMOs, such as ethical concerns, that should be considered separately. Such as who owns the technology and what do they charge to use it? Is it only owned by large corporations? How could it lead to situations where some people may not have access? Are the new technologies only being applied to large commercial crops, such as soybeans, maize and cotton? What about other crops that might be more useful in different places? If we only modify a few crops, how does that affect the overall variety of crops people grow? These are all valid concerns.

6. Quietly by yourself, think about how to balance the hopes and concerns about genetic engineering of plants.

a. Not using genetic engineering could increase the risk of not producing the amount and type of food needed. Using genetic engineering presents other risks. What do you think the balance should be?

b. Do you think there is a way to allow for genetically engineered plants to help solve food system problems?

c. If so, are there rules that could help address the concerns?

7. Write down what you think the rules should be in your country about creating and using genetically engineered plants. Be sure to consider:

   a. When genetically engineered plants should be allowed: Never? Always? Somewhere in between?

   b. Should the rules for GMOS and gene-edited plants be the same?

   c. What kinds of safeguards should there be with GMOs or gene-edited plants? What kinds of testing would be needed to make sure the environment and people are safe?

   d. When you buy something, should the label have to say whether it contains GMOs or gene-edited plants?

   e. Should companies be allowed to ban people from using genetically engineered plant seeds they have collected from their fields?

   f. Read Matin's ideas to help you.

Matin says . . .

Agricultural biotech is a transformative technology. And like all transformative technologies, we need to think about having proper regulation, ensuring there is competition and there is access. Transformative technologies have the power to aggravate certain existing power imbalances.

8. Share your ideas with your teammates. Do other people have different ideas? Listen carefully to one another while you explain your perspectives. Are there ideas you agree on? Make a note of those ideas. Can you find a compromise if you disagree on certain ideas? Try to build a team **consensus**, a balanced decision that works for everyone, on what you think the genetic engineering rules for plants should be in your country.

⚠ Emotional Safety Tip

There are no wrong or right answers. Different people can have different perspectives. Considering different perspectives helps the group think better together. It may feel difficult to disagree with someone or have them disagree with you. Remember, disagree with ideas, not with people. For example, you could say, "I disagree with that idea because . . ."

9. Find out more about what the rules are for your country. You can use a government website, a library, or other resources in the *Biotechnology!* StoryMap.
10. Discuss with your team:
    a. Do you agree with the rules in your country?
    b. If not, what would you want to change?
11. With your team, draw a circle and label it "Personal." In the circle, write or draw things you can do in your own life to encourage the rules you want to see about genetically engineered plants—for example, buying or not buying food made with genetically engineered plants.
12. Next draw a bigger circle around the first one. Label this circle "Community." In the circle, write or draw things you could do in your community to encourage the rules you want—for example, telling others about your opinion or educating them about genetic engineering in plants.
13. Next draw an even bigger circle around the other ones. Label this circle "Country." In the circle, write or draw things you could do in your country to encourage the rules you want. For example, is there a way to share your opinion with the people in the government who are making the rules?
14. Finally, draw an even bigger circle around the other ones. Label this circle "World." In the circle, write or draw things you could do globally to encourage the plant genetic engineering rules you want. For example, could you join an organization with others around the world who have similar goals?
15. Choose one thing you want to do and create a plan for how to do it.
    a. How will you get started?
    b. What steps do you need to take?
    c. How will you do them?
16. Put your ideas into action!

Task 2: How can biotechnology help food systems contribute to a more sustainable future?

People around the world eat a wide variety of foods. Each region of the world has its own special dishes, favorite beverages, and food-based traditions. But no matter what kind of food people eat, one thing remains the same: Producing food requires resources such as space, water, soil, and nutrients. A **nutrient** is something that helps a living thing survive and grow.

As you have already read, there is high demand for food around the world. Agriculture helps to meet that demand for food. But sometimes the way people produce food can cause damage to the environment. Soil, water, and nutrients can be used in unsustainable ways. For example, some farms might use large amounts of **fertilizer**, which is a kind of nutrient to help plants grow. But sometimes during rainstorms, fertilizer can run off from fields and pollute rivers, streams, and drinking water.

In this task you will ***discover*** how Earth's surface is used to produce food. Then you will use models of farms, forests, and cities to ***understand*** how people can use biotechnology to produce food in a more sustainable way. Finally, you will ***act*** to model and communicate some of those sustainable solutions to your community.

Meet Your Research Mentor

Meet Mwamy Mlangwa. Mwamy (pronounced MWAH-mee) is one of the many experts around the world thinking about how to create a sustainable food system.

Mwamy is the creator and owner of Mwamy Green Veggies, the first **hydroponic** farm in Tanzania. Her rooftop hydroponic greenhouse is located in the city of Dar es Salaam and produces lettuce and other vegetables. Mwamy has degrees in business administration and marketing and worked in corporations before switching to farming.

Mwamy also has knowledge and perspectives that come from other parts of her identity. Since Mwamy is now working with you, it is important to understand who she is.

To help you, Mwamy filled out an identity map, just like you did in Part 1. Mwamy's identity map includes the following things.

- 48 years old
- African
- Female
- From Tanzania
- Tanzania and Israel are important places to her
- "I had been working for almost 18 years, and I said, that's enough, I need to do something for myself. As an African, we all grew up in the villages with farming, but it's always about local farming. So I went to Israel to study, learn about, and work in hydroponic farms. Then I came home and said, 'That's what I'm going to do!'"
- Interested in politics
- Likes playing with her dogs, walking, farming, and baking
- Tall, black hair, does not wear glasses
- Loud, funny and kind
- Parent
- Part of the Modern Agriculture Women Group
- "I am a risk taker, I am not afraid of falls in business or life."

Before you begin this task, think quietly to yourself about Mwamy's identity map.

- Are there things you have in common with Mwamy?
- Are there ways in which you are different from Mwamy?
- Can you see anything about Mwamy's identity, in addition to her degrees and training, that would help her understand different perspectives or ideas about creating a sustainable food system?

Throughout this task you will notice Mwamy sharing ideas and experiences with you. She may help you understand how to think about biotechnology and food or share some of the work she has done.

Discover: *How much of Earth's surface can we use to produce food?*

Growing food and raising livestock uses Earth's resources. How much of the planet can people actually use to meet their need for food? In this activity you will find out more about what parts of Earth's surface are used to produce food.

1. By yourself, take out a blank piece of paper.
2. Think about this question: How much of Earth's surface do you think is used for making food?
3. Now, imagine your blank piece of paper is the entire surface of Earth. Tear off a portion of the paper or use a pen or pencil to mark the area you think is used for making food.
4. Keep this piece of paper. You will need it at the end of this activity.
5. Take out another blank piece of paper.
6. Now you will model how much of Earth's surface can be used to make food.
7. Use a pen or pencil to divide your paper into 10 equal parts, as shown in Figure 2-7.

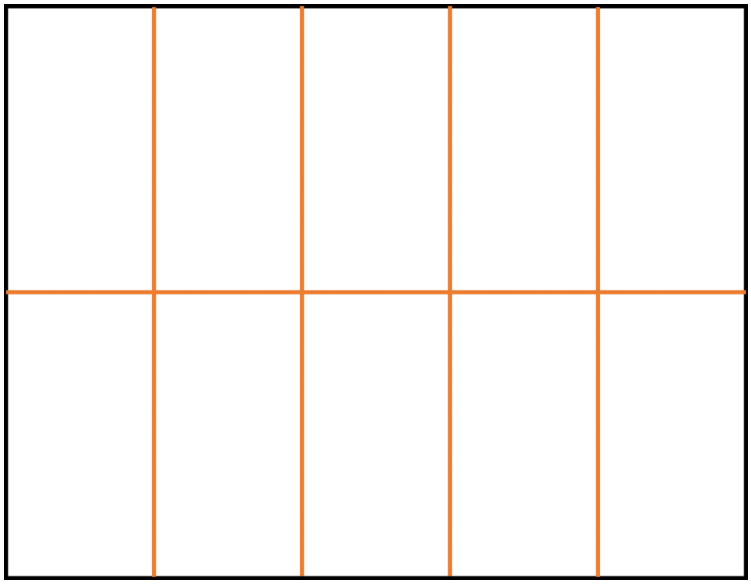


Figure 2-7: A paper model can be used to represent Earth's surface.

8. Mark out or tear off seven of those parts, as shown in Figure 2-8. Those parts represent the 71% of Earth's surface that is ocean.

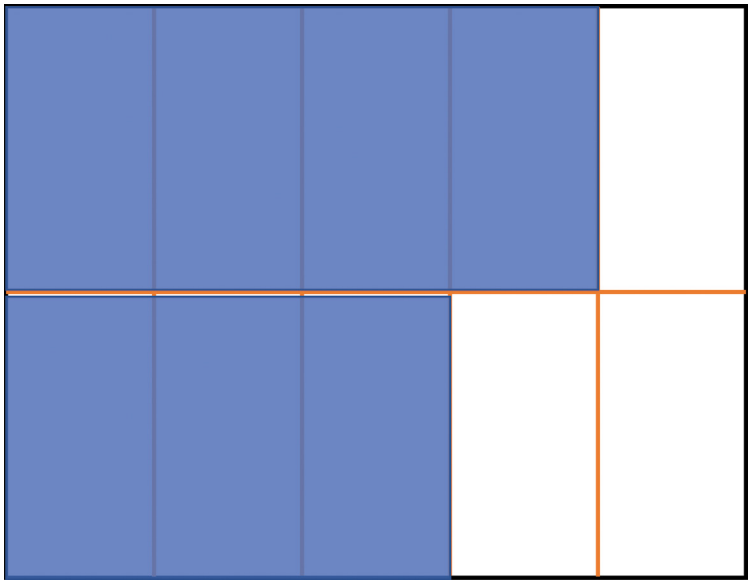


Figure 2-8: A paper model of Earth's surface with the ocean marked out.

9. You should have three parts remaining. These parts represent land. Use your pen or pencil to divide that remaining space into 10 equal parts, as shown in Figure 2-9. You might want to use a different color so you can easily see the new lines.

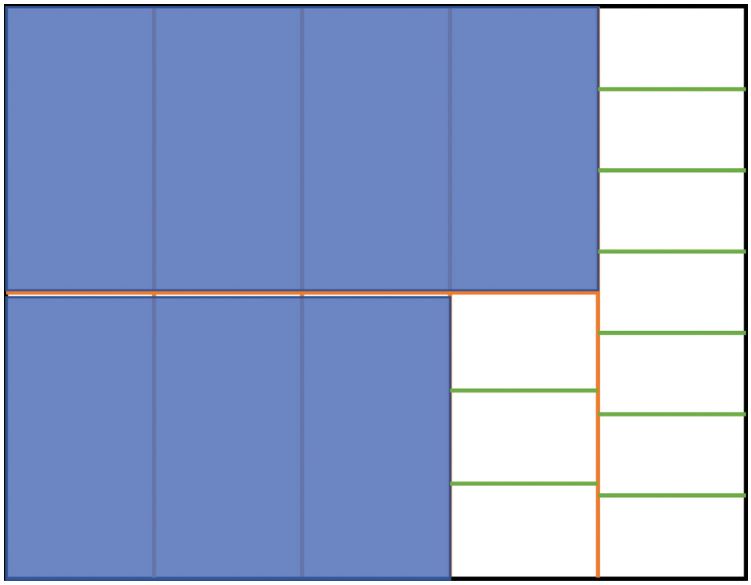


Figure 2-9: A paper model of Earth's surface with the land divided into 10 parts.

10. Mark out or tear off three of those parts, as shown in Figure 2-10. Those parts represent **barren** land, such as glaciers, bare rock, and sand dunes. Barren land is land that does not easily support the growth of living things.

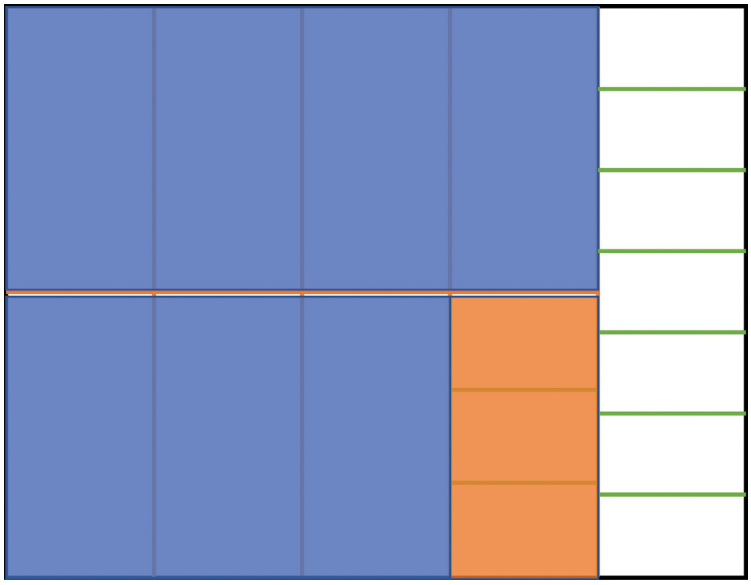


Figure 2-10: A paper model of Earth's surface with only the habitable surface remaining.

11. You should have seven parts remaining. These parts represent the land on Earth that is **habitable**, or land that best supports living things.
12. Mark out or tear off half the remaining space, as shown in Figure 2-11. Those parts represent natural spaces like forests, shrubs, and lakes. They also include land used for other human needs, like housing, highways, and factories. Those spaces are not typically used for producing food.

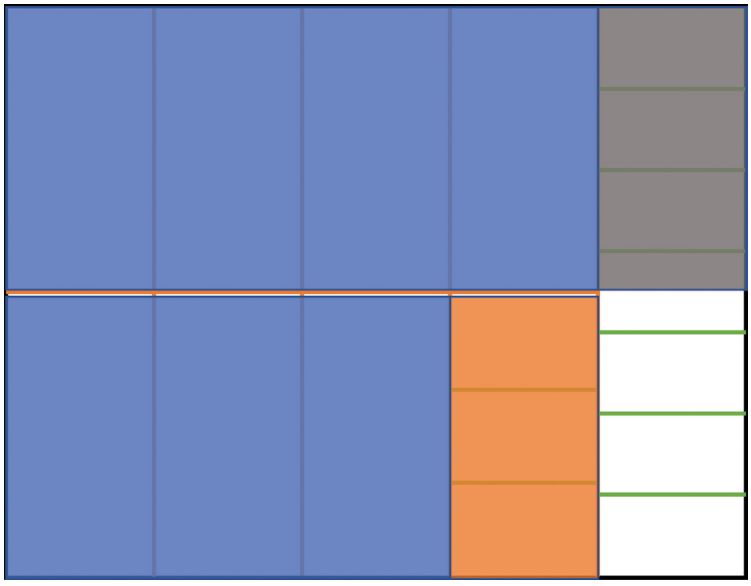


Figure 2-11: A paper model of Earth's surface showing the part that is used for producing food.

13. You should have three and a half parts remaining. Those parts represent the land on Earth's surface that currently is used for producing food. This includes using land for crops such as corn, soybeans, and rice, and also for livestock such as pigs, cows, and chickens.
14. Place the paper from step 3 and the paper from step 13 side by side.
15. Work with a partner to compare the papers and discuss your answers to the following questions.
    a. How does your guess from step 3 compare to the actual amount of Earth's land that is used to produce food through agriculture?
    b. Does the amount of Earth's land used for agriculture surprise you? Why or why not?
    c. Cutting down forests and clearing wild plants is one way to create more land for agriculture. How would you feel about using that approach to gain more space?
    d. How much land do you think is used for agriculture in your community? How could you find out?
16. Read what Mwamy says about her farm and how she grows food in the city of Dar es Salaam, which has limited space. Do you think this might be possible in your community?

Mwamy says . . .

My farm, Mwamy Green Veggies, is a hydroponic farm on a city rooftop. A hydroponic farm is a way of farming without using soil. The plants grow in water, and we deliver nutrients to each plant by putting the nutrients directly in the water.

Hydroponic farming doesn't require a big space, and not everyone can afford to have five acres. But a small space? People have that. In a small space, even on a balcony, you can still use hydroponics to produce vegetables like tomatoes, or herbs like basil or coriander. And you get a good income even if you are using a small space, because the crop yield is high, the food is high-quality, and the food is safe. For a town, hydroponics is a really ideal kind of farming.

17. Read *The Effects of Agriculture* to learn more about the effects of some kinds of agriculture, such as growing crops or raising livestock on land. You will need to consider these effects as you learn about how biotechnology can be used in agriculture.

The Effects of Agriculture

Agriculture is how people have produced most of their food for thousands of years. Recently, agriculture has generally become more **efficient**, meaning we can produce more food more quickly in the space we have. Producing large amounts of food quickly and inexpensively is sometimes called **industrial farming**. But that efficiency can sometimes come at a cost.

Water

Plants and livestock need water to grow. Industrial farms may use water from rivers, lakes, or under the ground to help water the crops. This is helpful because farmers can make sure their plants always have water, even in a drought. But using water this way can create some problems too. Taking water from rivers and lakes may remove important **habitat** for the plants, animals, fungi, and bacteria that were living in or depending on that water.

Figure 2-12: This machine sprays water onto a field. Notice the dry landscape behind the field.

Nutrients

Plants need nutrients to grow. Some industrial farmers use chemical fertilizer to help deliver nutrients to plants. But when water passes through the field, such as during a rainstorm or a flood, some of that chemical fertilizer may be washed away. A high concentration of fertilizer can act as a poison, hurting the land and water where it ends up, and the living things nearby.

Space

Plants and livestock need somewhere to grow. Sometimes, industrial farmers clear a forest, wetland, grassland, or peat bog to make more space for fields or grazing land. When a forest is turned into agricultural land, the plants, animals, fungi, and bacteria that were once living there can no longer use it as their habitat. The **biodiversity** of that area decreases. Biodiversity is the measure of how many different living things are in a certain area.

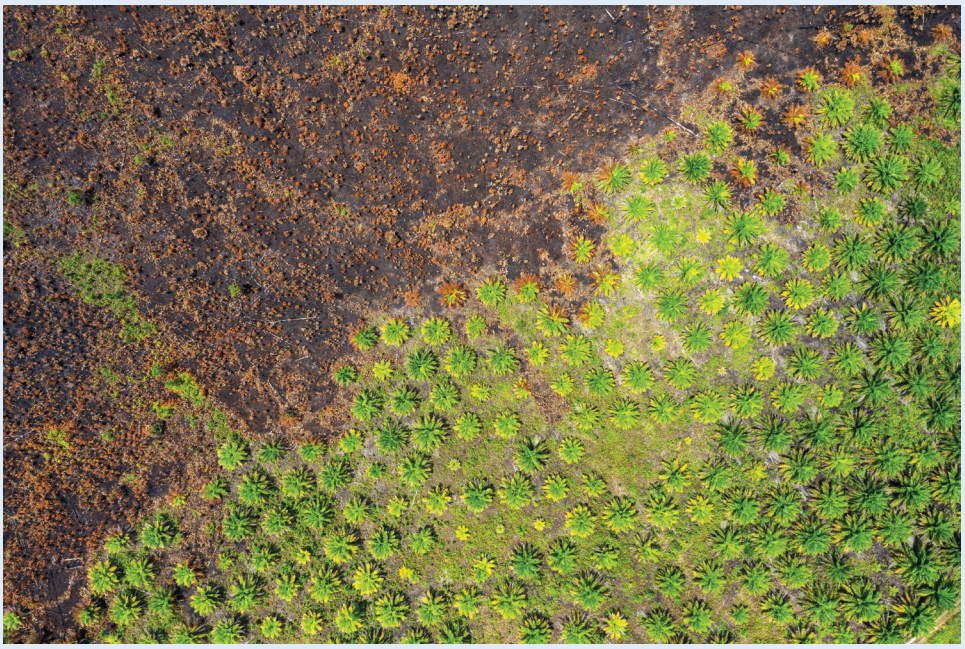


Figure 2-13: The dark area in this photograph is where the forest has been burned to make more room for a palm oil plantation (the green plants).

Carbon

Disturbing the soil and cutting down trees can also reduce the ability of the land to store carbon. Soil and trees can capture and store carbon from the atmosphere. This can help to reduce the effects of climate change. Releasing this carbon can contribute to climate change.

Sustainable agriculture

Not all agriculture hurts the land. Farmers and researchers are searching actively for new ideas about how to grow more food without hurting the environment. Sometimes, the best ideas are old ideas. Many farmers and researchers are starting to pay attention to traditional agricultural practices that have been more sustainable than industrial farming.

18. Think to yourself first, and then discuss with a partner:
    a. Does any of this information concern you?
    b. Think about the possible effects of agriculture. Which one feels the most important to fix or improve? Why?
    c. You have learned that Earth has limited space for producing food. Can you think of any ways to increase space for agriculture without clearing land?
19. Read Mwamy's ideas about how using biotechnology helps her reduce some of the effects of farming on the environment. Which of these effects seems most important to you, and why?

Mwamy says . . .

Hydroponics is sustainable. The amount of water we use is minimal because the water rotates, or cycles over and over, through the pipes. This saves a lot of water versus traditional farming. We don't have to cut down trees or burn bushes to clear the land. We use fewer nutrients than traditional farming. In traditional farming, once you put the nutrients in the soil, the soil has lots of organisms other than plants that then use those nutrients. But in hydroponics, only the plant is using the nutrients.

Understand: *How can new techniques enable food to be grown in new places?*

In the Discover activity, you modeled how much of Earth's surface is currently used for producing food. You also learned how certain kinds of agriculture can harm the environment.

You also know from your work in Task 1 that our planet is facing a food crisis. We need to find ways to produce more food without continuing to harm our planet. In this activity, you will use a model to think about how to use biotechnology to produce food more sustainably. Then you will apply this model to your own community.

1. Work with a partner.
2. Read *Where Can We Grow Tomatoes?* for instructions on how to set up your model.

Where Can We Grow Tomatoes?

a. Work with a partner to collect the following materials to set up your model:
   - 2 sheets of paper
   - 8 small objects (such as paper clips, scraps of paper, or coins)
   - Pen or pencil

b. Use a pen or pencil to divide each sheet of paper into eight equal parts.

c. Label one paper "Farm/Forest" and the other paper "City."

d. On the *Farm/Forest* paper, label four of the parts "Forest." You can also draw a forest, use symbols, or mark the parts in another way, as long as you can tell that it is forest. Label the other four parts "Farm." Again, you can label, draw, or use symbols. Figure 2-14 shows an example.

Farm	Farm
Farm	Farm
Forest	Forest
Forest	Forest

Figure 2-14: An example of a Farm/Forest paper.

e. On the *City* paper, use one of the following eight words to label each part, or draw, or use symbols (Figure 2-15 shows an example):

- Parking lot
- Highway
- Two-lane road
- Apartment building
- Office building
- Park
- Athletic field
- Community center

Parking lot	Highway
Two-lane road	Apartment building
Office building	Park
Athletic field	Community center

Figure 2-15: An example of a City paper.

f. Gather your eight small objects. These objects represent the tomatoes that your farming team needs to plant.

3. Place the *Farm/Forest* paper in front of you and your partner.
4. Work with your partner to plant all eight tomato plants, or as many of those eight tomato plants as you would like to. Keep these rules in mind:
   a. You can plant only one tomato plant in each space.
   b. If you choose to plant tomatoes in a *Forest* space, it means you will get rid of that section of forest.
   c. You can also choose not to plant any tomatoes in a space.
5. When you have finished planting, turn to another pair and answer the following questions.
   a. How many tomato plants did you plant?
   b. How did you decide where to plant tomatoes?

6. Gather your eight small objects again and place the *City* paper in front of you and your partner.
7. Your goal is to plant as many tomato plants as you can. Since this is a city, many of the spaces are already being used to meet the needs of people. If you choose to plant tomatoes in a particular space, you will clear whatever is in that space. You can also choose not to plant tomatoes in a space.
8. Work with your partner to do step 4 again on your *City* paper.
9. When you have finished planting, turn to another pair and answer the following questions.
    a. How many tomato plants did you plant?
    b. Did you plant more or less than you did with the *Farm/Forest* paper? Why?
    c. How did you decide where to plant tomatoes?
10. Now choose either the *Farm/Forest* or the *City* paper. You and your partner are going to make a decision again about planting tomatoes. But this time, you will consider a new perspective when making your decision. Select just one perspective about the paper you chose, either the *Farm/Forest* or the *City*.
    a. If you chose the *Farm/Forest* paper, select one of the perspectives listed here:
        - **Social:** A food bank in your community needs more fresh food. They have asked you to clear forest land and plant as many tomatoes as possible to help people in need.
        - **Economic:** You work on the tomato farm in your community. If you don't plant all eight spaces with tomatoes, you won't earn enough wages to keep paying for your home.
        - **Environmental:** The forest near your tomato farm is the only habitat for a rare orchid plant. That orchid provides food for several kinds of insects in the forest. But more people have moved into your community, and there has been a huge demand for food, so you have been asked to clear some of the forest spaces.
        - **Ethical:** Your local government has just purchased large amounts of pesticides. They will give them to farmers for free. You understand that the pesticides can have a negative effect on humans and the nearby environment, and you are worried about that. But if you use the pesticides, you can grow twice as many tomatoes per space.

b. If you chose the *City* paper, select one of the perspectives listed here:
   - **Social:** The athletic field in your city is where young people and adults play sports. Older adults meet there every week for lawn games and socializing. The field has plenty of soil, sunlight, and access to water. Some people in the community have asked to tear up the field and plant tomatoes there instead.
   - **Economic:** You have asked to use a large lawn next your apartment building to plant more tomatoes. But the owner of the apartment building wants to build another set of apartments on that space. The new apartments will bring in a lot of money for the building owner.
   - **Environmental:** The community center has a garden with native plants. Those plants provide food and habitat for several species of birds, insects, frogs, and bats. That space could also be used to grow tomatoes, which could be distributed to local residents.
   - **Ethical:** People want to travel through the city on the highway, but that means less space is available to the people who live there to relax, be in nature, or have fresh food grown nearby.

11. Now gather up your eight small objects and decide where to plant your tomatoes, considering only the one perspective you chose.
12. Did the way you planted tomatoes change? Why or why not?
13. Next, read *Vertical Farming*.

Vertical Farming

If you have ever noticed a corn or soybean field, you might have observed that growing food in soil can take up a lot of space. How can people produce the same amount of food without using as much space? **Vertical farming** is a type of biotechnology that might help solve that problem. Vertical farming grows plants in vertically stacked racks, often indoors. The racks take up less horizontal space than a field but can still produce a huge amount of food. Figure 2-16 shows an example.

Figure 2-16: The photo on the left shows the way crops are arranged on an industrial farm. The photo on the right shows how crops are arranged in a vertical farm.

The plants may grow in water, air, or in a material that provides a small amount of support, like gravel. Light is provided using either electric lights or natural sunlight (such as in a greenhouse).

What are the possible benefits of vertical farming?

- Farmers can reuse the water that flows through the racks, which allows them to use less water overall.
- Crops can be grown in places that don't have usable soil, such as a paved area or a row of buildings.
- The racks help farmers deliver water and nutrients directly to each plant.
- Controlling the temperature, light, and **humidity** inside the vertical farm allows crops to be grown all year long.
- Crops can be grown directly in the communities that use them.

What are the possible challenges to vertical farming?

- It can be expensive to set up and maintain.
- It requires construction of the racks, a water connection, and lighting.
- Farmers may need to pay for the use of the space, electricity, water, air conditioning or heat, and nutrients.
- Because the racks share a water source, when one plant gets a disease it can spread very quickly from plant to plant.
- Only certain crops can grow well in vertical racks. For example, corn is too tall to grow in racks.

14. Work with your partner to review your choices from steps 4 through 8. Imagine that you could use vertical farming to "plant" tomatoes by stacking your objects on top of one another. Then answer the following questions:
    a. What would you do differently on the *Farm/Forest* paper if you were able to use vertical farming?
    b. What would you do differently on the *City* paper if you were able to use vertical farming?
15. Read what Mwamy says about the benefits and challenges of hydroponic farming in her community. Do her ideas make you change your mind about when you would use vertical farming?

Mwamy says . . .

Sometimes I do get some pests on my lettuce, and I don't have any choice but to remove the lettuce and burn it. You have to be very careful with your system and the people you are working with. A small mistake can kill everything. One small mistake and everything goes.

You cannot easily grow potatoes or any other root vegetable like carrots or beetroot. You can grow tomatoes, strawberries, you can grow even cucumbers because they are hanging.

The investment is a challenge. It's quite big. If you want to do commercial like me, you have to go huge—the greenhouses, the pipes, the water systems, pumps. This is one of the big disadvantages. But the market for your vegetables is there.

I mostly sell to the supermarkets in Dar es Salaam, international hotels, restaurants, and the safari camps. In Tanzania we have a lot of safari camps, and most of them are catering to Europeans, and those people want fresh salad. My salads have longer shelf life. They can stay fresh for seven days without dying because I'm selling them with the roots attached. Most of the safaris are up to seven days long. So if they buy from me, a safari chef has salad that can stay fresh for seven days. They love it!

Figure 2-17: Fresh lettuce grows in a hydroponic greenhouse.

16. Vertical farming could be a solution you use in your own community. Work with a partner or a small group to find spaces in your community that could be used for a vertical farm.
17. Read *Vertical Farming Investigation* for instructions.

Vertical Farming Investigation

a. Gather as a team.
b. Read about the kinds of materials you might need to build a vertical farm.

Materials needed for a vertical farm

- Indoor space that you are allowed to use
- A space that has climate control for temperature and humidity
- Electricity
- A source of water

- Money for materials (or donated materials)
- Tools to build the vertical growing rack
- Seeds or seedlings of plants that grow well in vertical farm spaces

c. Work with your team to think together about a space in your community that could be used for a vertical farm. Think about the materials needed for a vertical farm to help you find a space that would work well. For example, does the space you are considering have electricity and a source of water? To find a space you can:

   - Move around your community and search for buildings, warehouses, sheds, greenhouses, shipping containers, parking garages, or other spaces that are not being used.
   - Use an online mapping program (such as Google Maps) to find the buildings and other spaces in your community.
   - Talk to the people in your household, friends, or elders and ask about spaces that might be good for vertical farming.

d. Once you have found a space that might work for vertical farming, work as a team to imagine what your vertical farm might be like. Create a drawing, physical model, written description, or use another format like a video or audio recording to record the design of your vertical farm.

Figure 2-18: What would you need to change about this abandoned train station to use it for vertical farming?

18. Think about this question by yourself: What problems could vertical farming help solve in your community?

Act: *How can I help my community produce food more sustainably?*

Some parts of your community might have trouble getting affordable, reliable access to food. Biotechnology, like vertical farming, could help directly connect people in your community with food. But some people may be unfamiliar with or nervous about biotechnology. In this activity, you will ask questions in your community to learn about peoples' attitudes toward biotechnology and share your ideas for a vertical farm.

1. Start a conversation about food with a trusted adult member of your community. Use the following questions to guide your conversation.
    a. Are there parts of our community that you wish had more access to food—for example, places that don't have grocery stores nearby?
    b. If we could produce food right here in our community, what kind of food would you want?
    c. What do you think might be the good parts of being able to produce food in our community? What might be some bad parts?
    d. If I said we could use biotechnology to produce more food in our community, how does the word "biotechnology" make you feel?
2. Get out your plan for vertical farming. First, ask:
    a. Have you ever heard of vertical farming?
    b. If they haven't, explain what you have learned about vertical farming.
3. Now share your plan for a vertical farm with this adult. Explain the benefits, challenges, and what food the farm could produce.
4. Ask for suggestions about your plan from the adult. For example:
    a. Do you agree with the place I've picked for the farm?
    b. What kinds of crops do you think could grow in this place?
    c. What haven't I thought of?
    d. What are your hopes for agriculture in your community?
    e. What are your concerns about agriculture in your community?

5. Read that Mwamy says about how her community responded to her hydroponic farm. How do you predict your community will respond to using biotechnology to increase food production?

Mwamy says . . .

My community, my government responded very well to my hydroponic farm. Especially the youth! Most of the youth in Tanzania, they like farming, but they don't like the old way of farming.

Many people in Tanzania prefer cooked vegetables, but I always encourage people to try eating salad! I don't want us to stay where we were 20 years ago. Now the good thing is that people care about their health, so they go for the vegetables. I'm telling you, at first it was really hard. But now my lettuce doesn't stay more than two days in the supermarket—it is off the shelf!

Congratulations!

You have finished Part 2.

Find Out More!

For additional resources and activities, please visit the *Biotechnology!* StoryMap at https://bit.ly/3pQUDpc.

Glossary

This glossary can help you understand words you may not know. You can add drawings, your own definitions, or anything else that will help. Add other words to the glossary if you would like.

Barren: Land that does not easily support the growth of living things

Biodiversity: The many different living things on Earth, or a measurement of how many different living things are in an area

Biotechnology: Using living things, parts of living things, or things produced by living things to solve people's problems and meet their needs

Consensus: A balanced decision that works for everyone in the group

Constraints: Limitations

CRISPR: A biotechnology tool that cuts DNA in very specific places to add, delete, or change base pair sequences

Crossbreeding: The process of breeding two different parents together to try to have specific traits from parents in their offspring

DNA: A molecule in all living things that transfers and stores genetic data

Economic: About money, income, and the use of wealth

Ecosystem: A community made of living things and nonliving things

Environmental: About the natural world

Ethical: The fairness of something

Efficient: Producing goods like food more quickly using the space that we have

Fertilizer: A kind of nutrient to help plants grow

Food insecurity: Lacking reliable access to affordable, nutritious food

Gene: A section of the base pair sequence in DNA that codes for specific traits

Gene editing: Changing genes in very specific and targeted ways

Gene insertion: Inserting a gene into the DNA

GMO (genetically modified organism): Any living thing that has been changed using genetic engineering techniques such as transgene addition

Habitat: The specific conditions living things need to live and grow

Habitable: Land that best supports living things

Humidity: The amount of water vapor in the air

Hydroponic: Growing plants without soil and using water, sand, or gravel instead

Industrial farming: Producing large amounts of food quickly and inexpensively

Inflation: A general increase in prices

Invasive Species: Species artificially introduced and not native to a specific area

Mitigation: Reducing the impacts of something negative, like a changing climate

Modify: Change or adjust something

Nutrients: Something that helps a living thing survive and grow

Offspring: The children of parents

Selective breeding: The process of breeding two living things with desirable traits in the hope that their offspring will have the same traits

Sequestered: Stored and isolated away

Social: Relating to the interaction of people in a community

Sustainable: An approach that balances different perspectives and can keep working for a long time

Traits: Characteristics

Transgene: A gene moved from one species to another

Vertical farming: Growing crops in multiple layers stacked on top of one another

End Notes

1. Food and Agriculture Organization of the United Nations. 2020. *The state of food security and nutrition in the world 2020: transforming food systems for affordable healthy diets*. Vol. 2020. Retrieved from https://www.fao.org/3/ca9692en/ca9692en.pdf.
2. World Food Program. 2022. *2022 Global Report on Food Crises: Joint Analysis for Better Decisions*. Vol. 2022. Retrieved from https://www.wfp.org/publications/global-report-food-crises-2022.

