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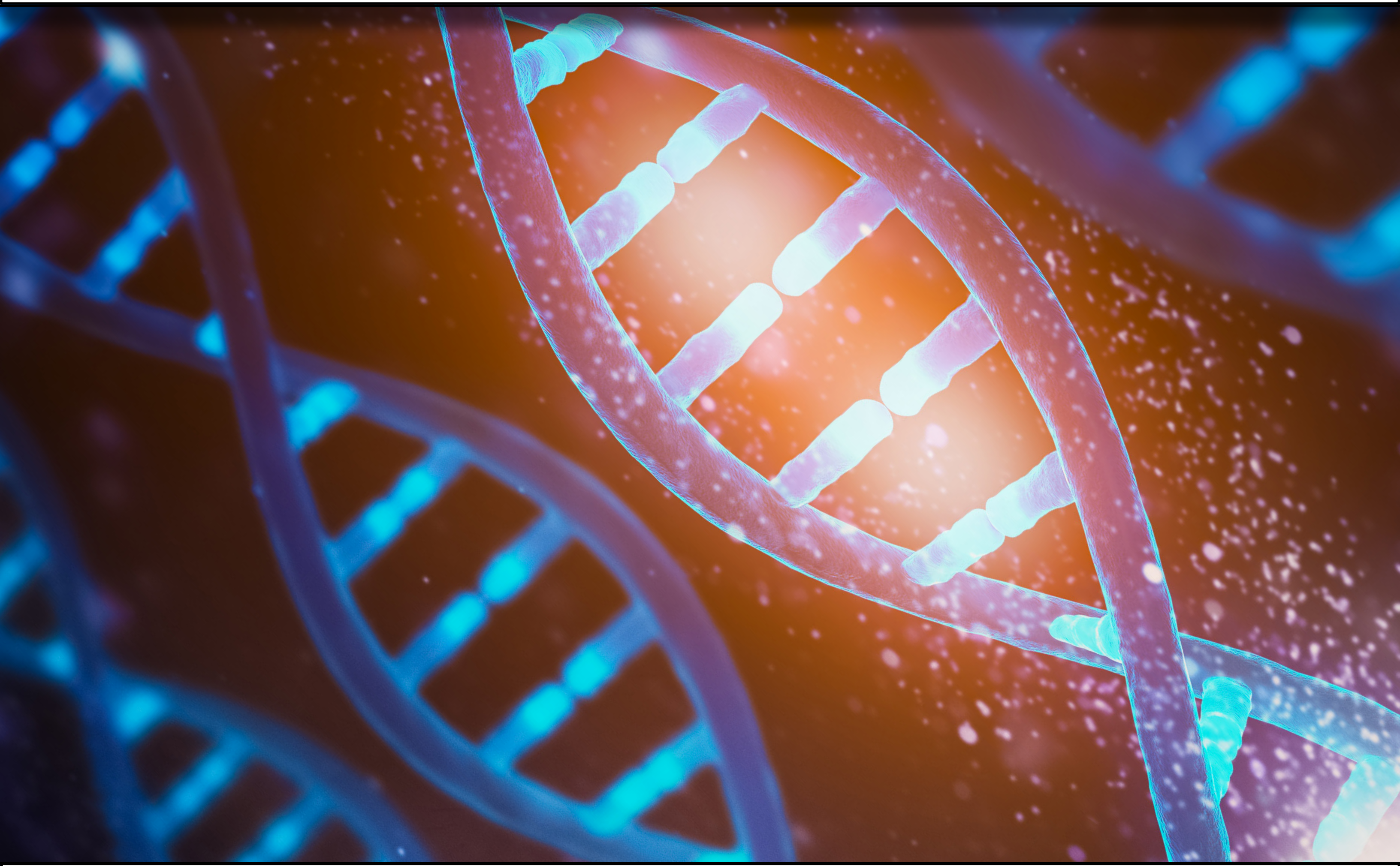
SCIENCE *for Global Goals*

BIOTECHNOLOGY!

How can we ethically create a sustainable future using biotechnology?



SUSTAINABLE DEVELOPMENT GOALS

developed by

Smithsonian Science Education Center

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Biotechnology!

How can we ethically create a sustainable future using biotechnology?

Community Research Guide

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Smithsonian Science Education Center

The Smithsonian Science Education Center (SSEC) is operated by the Smithsonian Institution to improve the teaching and learning of science for students in the United States and throughout the world. The SSEC disseminates information about exemplary teaching resources, develops curriculum materials, supports the professional growth of science teachers and school leaders, and conducts outreach programs of leadership development and technical assistance to help school districts implement inquiry-centered science programs. Its mission is to transform the teaching and learning of science in a world of unprecedented scientific and technological change.

Smithsonian Institution

The Smithsonian Institution was created by an Act of Congress in 1846 "for the increase and diffusion of knowledge . . ." This independent federal establishment is the world's largest museum, education, and research complex and is responsible for public and scholarly activities, exhibitions, and research projects nationwide and overseas. Among the objectives of the Smithsonian is the application of its unique resources to enhance elementary and secondary education.

Smithsonian Science for Global Goals (SSfGG) is a freely available curriculum developed by the Smithsonian Science Education Center (SSEC) in collaboration with the InterAcademy Partnership. It uses the United Nations Sustainable Development Goals (SDGs) as a framework to focus on sustainable actions that are student-defined and implemented.

Attempting to empower the next generation of decision-makers capable of making the right choices about the complex socio-scientific issues facing human society, SSfGG blends together previous practices in Inquiry-Based Science Education (IBSE), Social Studies Education (SSE), Global Citizenship Education (GCE), Social Emotional Learning (SEL), and Education for Sustainable Development (ESD).

Thank You for Your Assistance

Thank You for Your Support

This project was supported by Johnson & Johnson through Grant #70997531 to the Smithsonian Science Education Center.

Acknowledgments

How can we ethically create a sustainable future using biotechnology?

Part 1: Introduction to Biotechnology	• Task 1: What is a sustainable future? • Task 2: How can biotechnology help create a sustainable future?
Part 2: Biotechnology and Food Systems	• Task 1: Should we use biotechnology to change the food we eat? • Task 2: How can biotechnology help food systems contribute to a more sustainable future?
Part 3: Biotechnology and Materials	• Task 1: How can biotechnology change the materials we use? • Task 2: Can we create the materials we need using cells and biotechnology?
Part 4: Biotechnology and Human Health	• Task 1: How can we diagnose diseases using biotechnology? • Task 2: How can we fix genetic diseases using biotechnology?
Part 5: Biotechnology and Genetic Data	• Task 1: How should we use and protect genetic data? • Task 2: How can environmental genetic data help identify and solve problems?

Part 6: Biotechnology and the Environment

- Task 1: How can biotechnology make our communities cleaner?
- Task 2: How can biotechnology help restore biodiversity to ecosystems?

Part 7: Biotechnology and Security

- Task 1. How can biotechnology help with security?
- Task 2: What are the threats to security presented by biotechnology?

Part 8: Taking Action

- Task 1. How will I help create a sustainable world using biotechnology?

Smithsonian
Science Education Center

Dear Parents, Caregivers, and Educators,

As a global community we face many challenges. At times, these worldwide problems can seem overwhelming. We may ask ourselves questions about how to understand these complex problems and whether there's anything we can do to make them better. This community response guide encourages young people to discover, understand, and act on the answers to these questions.

In the years leading up to 2015, people around the world worked together to share their ideas about how our world should be. These ideas became a list of goals, the United Nations Sustainable Development Goals. The goals represent a plan for a sustainable world: a world where peaceful societies collaborate; a world where we live in balance with the environment of our planet; a world in which our economies fulfill our needs; a world that is fair to all.

As youth around the globe engage with the activities in this guide, they will gain an understanding of the science that underlies the Sustainable Development Goals. They will be able to share their knowledge with their community, create tangible ways to help their community make informed decisions, and understand the best places to find additional information on these topics.

Throughout the guide, young people may find themselves asking many questions about fair treatment of people and communities. You do not need to have the answers to any of these questions. The most important thing you can offer young people is the opportunity to question, investigate, think critically and systemically, synthesize, and act. Ask the young people around you how they are feeling and what they are thinking about as they learn this content.

I am immensely grateful to the experts who helped to develop this guide—the InterAcademy Partnership, a collaboration of 140 national academies of sciences, engineering, and medicine; our colleagues across the Smithsonian Institution; and the external subject matter experts who contributed to this guide—for their perspectives and technical support in ensuring the science in this guide is accurate. I also want to say a special thank you to the developer of this guide, Heidi Gibson, for her thoughtful contributions to the *Smithsonian Science for Global Goals* project.

Working together—scientists, researchers, parents, caregivers, educators, youth—we can make a better world for all. This guide is a step toward that grand collaboration.

Thank you for partnering with us to inspire our youth to build a better world.

Best,

Carol L. O'Donnell

Dr. Carol O'Donnell, Director
Smithsonian Science Education Center

Director Letter

About this Community Research Guide

The goal of this guide is to prepare young people to take considered action on pressing global issues. Considered action means young people learn about a problem, connect it to the larger system, consider all the complexities of the problem, decide for themselves the best way to address it, and then execute a solution. Through this process young people are prepared not only to take considered action on a specific issue, but to build the skills needed to take action on all issues that affect them and their communities.

Figure 1: Sustainability Mindsets.

Learners use scientific and socio-scientific investigations to understand their local communities, scientific principles, and innovation possibilities. They then have a chance to immediately apply this information to make decisions that are informed by the results of their investigations. Along the way, young people are prompted to reflect, investigate, think critically, analyze, and build consensus. Engaging in these activities builds important skills of empowerment and agency, open-mindedness and reflection, equity and justice, and global-local interconnection. These sustainability mindsets prepare young people to take an active role in shaping the future of their communities and their world.

A Framework to Discover, Understand, and Act

Throughout the guide, young people are prompted to Discover, Understand, and Act. The three parts of their learning journey are described here.

Discover

Young people already have a lot of information and opinions about the world around them. In this guide, they are prompted to use that knowledge as an entry point. They will discover what they already know and what questions they might have. They are encouraged to consider different perspectives and priorities. This both empowers young people and provides an immediate relevance and context for their investigations.

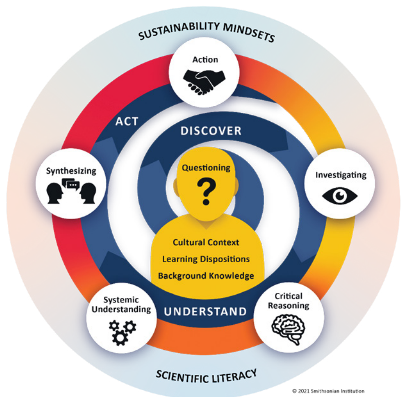

Figure 2: Global Goals Action Progression.

Understand

Gathering new information is a primary goal of science. Using a wide variety of methods to do so helps young people understand the problems related to sustainable communities. They need to understand the problems both abstractly and within the context of their local community. Designing and conducting real-world investigations and interpreting results encourages young people to think like scientists.

Act

Finally, young people apply both their existing knowledge and their newly gathered information. First, they consider personal changes they could make to help make their communities more

About the Guide

sustainable. Then, as a team, young people find consensus on what they *could* do, what they *should* do, and what they *will* do. Teams then take action and reflect on the consequences, both intended and unintended.

Pedagogy Shift

This guide may feel like a big shift from the standard method of teaching. The guide is:

Led by Young People

To make progress toward a better world, we need the ideas, enthusiasm, and energy of every young person. We need them to help design and build the world in which they want to live. This means throughout the guide young people make authentic decisions about what and how they will learn. Their goal is to understand issues in their own community and take sustainable actions to make their community and their world better.

Driven by Data Collected by Young People

In this guide, the young people you teach will become action researchers. They will gather information about what sustainable communities mean in their own local spaces. This includes scientific investigations and experiments to understand the problems better, and also using social science methods to understand their community better. Using science and social science helps young people arrive at a sustainable solution.

Focused on Action

The goal of the guide is to help young people not just learn but also do. Throughout the guide young people will conduct investigations and then use that knowledge to make decisions about the actions that would be best for their community. They will then put those decisions into practice and see the results of their actions.

Customized for Local Communities

Each community is unique. While the world has global problems, the solutions must work locally. Young people already have tremendous knowledge about their local community. This guide prompts them to use that knowledge and find out new information to figure out solutions that are sustainable in *their* community.

Structure of this Community Research Guide

Parts

This guide is made up of eight parts. Each part works with the others to help learners understand how to help their community thrive and to put that knowledge to work by taking action.

However, we recognize that time is a limiting factor in many learning spaces. Therefore, the guide is designed flexibly so it can be shortened, if necessary. The learners are guided to do this shortening work themselves at the end of Part 1. The guide prompts learners to discuss with their teacher how much time is available and then make decisions about the best way to use that time.

Tasks

Within each part there are two tasks. Each task helps learners examine a different aspect of the topic they are exploring. Within each task, there are three activities, which correspond to the Discover, Understand, Act framework. Discover activities focus on existing learner knowledge. Understand activities focus on gathering new information. Act activities focus on analyzing and applying that new information to make decisions. Tasks also include perspectives and stories from experts around the globe, so students can connect with the work of real-world scientists.

Using this Guide

Roles

The Learner's Role

Learners are the decision-makers of the guide. They will decide what information they need and what the information they gather means. Then learners use that information to decide and implement actions.

The Teacher's Role

This guide may be challenging for learners, since they may be unfamiliar with their role. Learners may need assistance in deciding what to do. Support and help them, but do not decide for them. Be patient. There are no right answers to the big questions posed by this guide.

Adapting the Guide for Your Context

Different Ages

This guide is designed to be used with young people between the ages of 8 and 17. This large range is deliberate to give access to these ideas to as many young people as possible. If you teach learners who are on the younger end of the age range you may need to support them a little more. For example, you might need to:

- Explain more complex words or topics
- Promote listening and tolerance in group discussions
- Support group decision-making
- Help them plan investigations in their community or accompany the teams on their investigations
- Help learners think through the feasibility of the action they plan
- Present alternate ways of capturing ideas; for example, if the guide suggests learners write, but that is too difficult or is inappropriate for your learners, they can always draw, act out, or just talk about their ideas

If you teach learners who are on the older end of the age range, the language of the guide might seem a little simple. However, older learners who can understand more complex ideas will be able to develop a more nuanced view of the problem and come up with more extensive solutions.

All young people should be able to engage with the guide in a way that is developmentally appropriate for them.

Different Resources

We have assumed you have very basic classroom resources, such as a class board (blackboard or whiteboard), paper, and pens or pencils. If it is not possible to capture learner writing, you can always have learners act out or discuss their ideas. If you do not have the capacity to print out a Community Research Guide for each learner, you or learner leaders can read the guide out loud from a single print or digital copy.

Accessibility

This guide is designed to be widely accessible. The language, tone, and format attempt to be as inclusive as possible to reach learners with a wide variety of learning styles. However, learners with specific needs may need teacher support. As mentioned earlier, the guide activities can always be adapted to fit learner abilities, either by you or by the students themselves.

Different Rules

Each place is different and may have different rules to protect young people and privacy. For example, in Part 7 of this guide there is an activity where young people explore using their fingerprints as biometric identification. Educators should follow local area guidance or regulations about privacy.

Extensions

For each part and many tasks there are additional activities, videos, and resources available digitally. They can all be found at the *Biotechnology!* StoryMap at https://bit.ly/3pQUDpc.

Teams

Much of the research, decision-making, and action is designed to be done in teams. These teams can range in size from a group of two or three learners to the whole class. As a teacher, this is something to consider before beginning the Community Research Guide.

If you have motivated and responsible learners who need minimal teacher support, you may want to break your class into small teams. Smaller teams will allow individual learners to share their opinions and have more of an impact on team decision-making. With smaller teams, the experience can be more customized to the interests of the individual learner because there are fewer interests represented.

If you have learners who need more support, you may need to keep the class together in one team or have one team for each adult in the class. If you have only one team per adult, an adult can help support learners directly while they are engaging in activities such as conducting investigations and making decisions. However, because the team is larger, individual learners will have less of a voice in decision-making and less impact on group actions.

Alternately, if you have a group of learners with mixed abilities, you can design groups that bring together learners with different strengths. These types of groups can help learners support one another rather than immediately turning to an adult for support.

If you are uncertain whether a small or large group is most appropriate for your learners, you may want to wait and observe them during Task 1. In Task 1 in the Understand activity, learners break into groups and conduct investigations. If learners are able to complete this task independently with fairly limited teacher support, they would probably be successful in a small group. If learners need a great deal of help to complete this activity, you may want to structure group size so they can have more focused adult support throughout the Community Research Guide.

Getting Started

We recommend you give the young people you work with the Student Letter to read. You may also find it useful to read through each part of the Community Research Guide in its entirety before beginning that part. We suggest you encourage your learners to be excited about this new learning adventure. Be prepared to be enthusiastic about their ideas.

Student Letter

Dear Student,

This is the last time you will be called a student in this Community Research Guide. Instead, you will take on a new role as an action researcher. Action researchers are interested in figuring out what to do to make their communities better. They use scientific investigations to help understand the natural world around them. They use social science investigations to help understand the people, cultures, and history of their communities. Then they use the information they gather to help solve problems in their own communities. This guide will help you learn more about this process. The most important thing to know is that you will control your own research and make your own decisions.

Think back to a time when you solved a problem. You first needed to know what you wanted—your goal. Then you needed to figure out what you needed to do to achieve your goal. This guide is similar. You will think about goals you have for your local community, then figure out what you need to take action to help reach those goals.

You and your classmates will work as a team to think about information you already have about the place where you live. Then you will investigate your local community and how things work. Finally, your team will decide how to make things better. Together, you will put your decision into action. Sometimes making decisions about what to do is difficult. Don't worry, this guide will give you lots of support.

How to Use this Guide

This guide is designed to help you explore and think about problems in your community. The guide is here to help you. That means you can always change it.

<u>Adapting the Guide</u>

You will notice that in this guide there are often suggestions about different ways of sharing your ideas or doing investigations. This is because different people think and work best in different ways. For example, some people like to draw, some people like to talk out loud, and some people prefer to write to express their ideas. This guide has suggestions, but you can always change the method suggested. You can share your ideas using discussions, acting, signing, telling stories, recording your voice, writing by hand, typing on a computer, drawing, or another way you choose. Think about the way you and your team learn best together. Including everyone on the team is important.

Safety Tips

This guide asks you to do and think about things that may seem unfamiliar. You will notice physical and emotional safety tips in the guide. These will help you stay safe and supported during the activities. Make sure you follow your teacher's directions about staying safe.

Guide Structure

There are eight parts in this guide. Most parts have two tasks. Each task has three activities. The activities are called ***Discover***, ***Understand***, and ***Act***. In the ***Discover*** activities you will focus on thinking about information you and your team already know. In the ***Understand*** activities you will investigate to find out new information. In the ***Act*** activities you will put your existing and new knowledge into action by applying it and making decisions. Words that may be unfamiliar will be in **bold** the first time they are used. Then at the end of each part a glossary lists the definitions of these words.

Investigations

You are the one doing the research in this guide. This means often you will develop your own questions and determine the best way to answer them. Developing and answering questions is how scientists find out new information about the world around them. As an action researcher, you need to think like a scientist to discover what you need to know, investigate to find out more information, and think about the meaning of what you found out.

Keeping Organized

In this guide you will have some papers you will need to keep so you can look at them later. You may want to have a folder, notebook, or science journal to help you stay organized.

Teams

You will be working with other classmates as part of a research team. Your team will conduct investigations and make decisions together. When conducting research, there may be many things to figure out as a team. You will need to be creative. There will not always be a clear right and wrong answer. Sometimes the team might not agree. This is okay. Just make sure to respect your teammates. There is no one right answer to the problems faced by your community. There is just the right answer for you and your team.

Getting Started

You will be thinking about complex problems. Sometimes this can feel difficult. Be patient. You will be guided to consider different parts of the problem. By the time you are making big decisions, you should have lots of information. Always remember, your work is important. Decisions you make can change your community. You are an important part of making your local and global communities better.

Thank you for working to make your community better.

The Smithsonian Science for Global Goals team
Smithsonian Science Education Center
Smithsonian Institution

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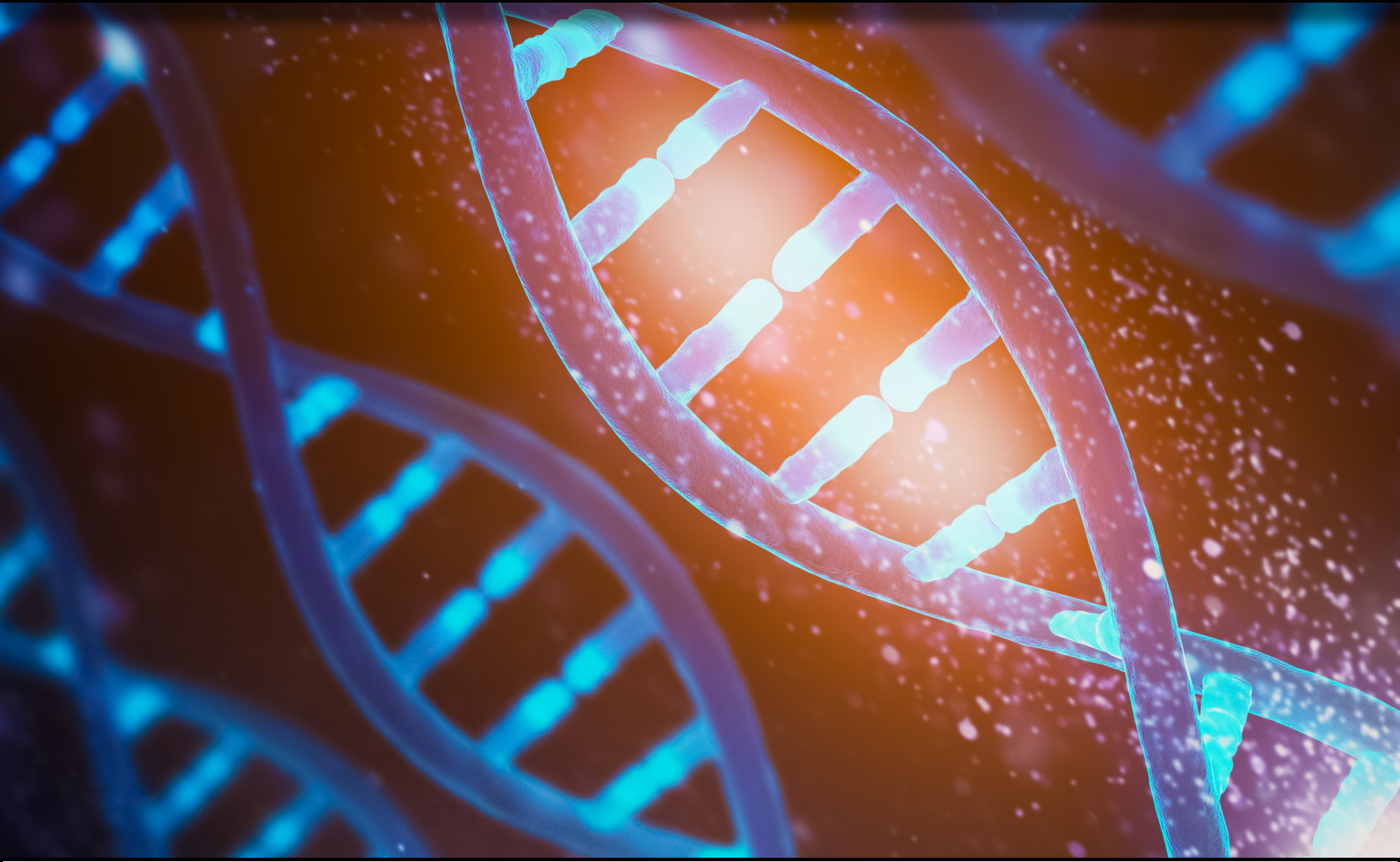
BIOTECHNOLOGY!

Part 1: Introduction to Biotechnology



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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 1. 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.

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Part 1

PART 1: INTRODUCTION TO BIOTECHNOLOGY

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: What is a sustainable future?					
Discover	Develop a personal identity map showing the different parts of who you are and create a futures mood board showing your ideas about the future.	• Paper • Pens or pencils • Objects that represent you (optional) • Class board or poster paper • Photos or magazines (optional)		25 minutes	7
Understand	Survey your community to discover different perspectives on a sustainable future.	• Paper • Pens or pencils		25 minutes + survey time	12
Act	Examine the Sustainable Development Goals, consider how biotechnology can play a role in a sustainable future, and pick the guide parts you want to use.	• Paper • Pens or pencils	*Futures Mood Board*	25 minutes	17

Part 1 Planner

Activity	Description	Materials and Technology	Additional Materials	Approximate Timing	Page Number
Task 2: How can biotechnology help create a sustainable future?					
Discover	Explore what biotechnology is and how it plays a role in your life.	• Paper • Pens or pencils		25 minutes	20
Understand	Extract DNA and investigate different ways DNA can be used or changed.	• Alcohol • DNA source, fruit or other • Containers • Fork or spoon • Water • Salt • Detergent • Filter • Skewer or toothpick		45 minutes	27
Act	Consider different perspectives on using biotechnology for a sustainable future and create a list of ethical concerns.	• Paper • Pens or pencils	*Futures Mood Board*	25 minutes	35

Part 1 Planner

Biotechnology! How can we ethically create a sustainable future for all using biotechnology?

Biotechnology can be an important tool to help reach a **sustainable** future for ourselves and our planet, but there are also risks and concerns. In this guide you will learn more about the potential of biotechnology while considering your ideas about the best way to navigate those risks and concerns.

While using the guide you will become an **action researcher** to identify and help solve problems in your community. Action researchers first ***discover*** their own existing knowledge, then they investigate to ***understand*** problems, and finally they ***act*** on what they have learned to make local and global communities better.

You will create and keep several sheets of paper or digital documents to help you record and remember information. You may want to use a notebook or folder to help organize the sheets you will use in the guide.

Remember: *In this guide you and your team are in charge. You can always change the instructions in the steps to make them work better for you and your team.*

Task 1: What is a sustainable future?

Who we are affects the way we think about and view the world around us. In this task you will first ***discover*** more about your own identity and perspectives about the future. Then you will ***understand*** more about biotechnology and related knowledge and perspectives of your community. Finally, you will ***act*** to decide what you want to investigate and think about further.

Part 1 Task 1

Discover: *What is my identity and what are my hopes for the future?*

Our different experiences, backgrounds, and ideas give each of us a unique identity. Your **identity** is what makes you you. Our different identities often lead to different **perspectives**. Perspectives are the way we think about the world around us. Understanding your own identity and perspectives can help you understand other perspectives. This activity will help you think about your own identity.

1. Take out a piece of paper and title it "Identity Map." If you prefer, you can make an identity map using objects or digital tools. There are more details about how to do that in step 6.
2. On the paper, write your name in the center of the page or draw a small picture of yourself.
3. Draw a circle around your name or picture.
4. Answer the question, "Who am I?" or, "What describes me?" The list below can give you some ideas to consider, but you choose what you want to include. You can also include things that are not on the list. Record anything you can think of that is important to who you are.
   - Age
   - School or class
   - Race and/or ethnicity
   - Gender
   - Country or place where you live
   - Country or place that is important to you or your family
   - Ideas or beliefs that are important to you
   - Topics or subjects that interest you

- Hobbies or things you like to do for fun
- Physical traits (such as tall, black hair, blue eyes, wears glasses)
- Personality traits (such as loud, funny, sad, kind)
- Roles you have in your household (such as big sister, helper, cousin)
- Groups you belong to

5. Write each answer on the page around your name. Draw a line between your name and each answer. Figure 1-1 is an example of a written identity map. You can put your answers at the end of each line.

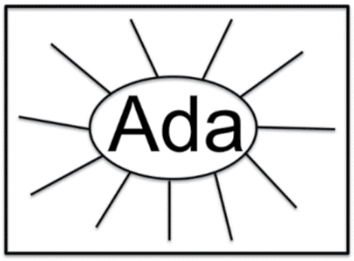

Figure 1-1: Example of a written identity map.

6. If you prefer, you can use objects around your home or class to create your map. To keep your map, you can take a picture or just remember it. Figure 1-2 is an example of an identity map using objects. You could also make a digital map using recordings or photos.

Figure 1-2: Example of an identity map using objects.

7. Now form a team. As action researchers you will work together with your team, made up of your classmates, for the rest of this guide. You will work together to understand your local area and make it better. Your team may be your whole class, or it may be a smaller group. Either is fine.

8. Share your *Identity Map* with the members of your team to find out what you have in common. Try to find matching identities with your teammates. For example, if you like to read for fun, see if you can find someone else who likes to read for fun. Find a few matching identities. Then move on to the next step.

> **⚠ Emotional Safety Tip**
>
> Sharing your identity with someone else can help build trust between you and that person. But it can be hard to share your personal identity with someone else. Only share parts of your *Identity Map* that you feel comfortable talking about.

9. Now try to find teammates who have different identities from you. Find a few people who have different identities. Then return to your place.
10. Think quietly to yourself about the different identities you found in your team. Everyone on your team is unique. Having a team that includes people with different identities means everyone has different information to share and different perspectives. As action researchers, you will work together as a team to find the best way to take action on the problems you identify. The different identities and experiences of each member of your team will help you make better decisions. For example, if you were born in the place where you live now but your teammate was born somewhere else, you each may know different things, which leads to different perspectives.
11. Read *Our Identities, Our Perspectives, Our Future*.

Our Identities, Our Perspectives, Our Future

Different people may have different perspectives on what they want the future to be like. Sometimes these perspectives are related to identities or personal experiences. Our identities can affect what we know about or what we think is important.

If there is something that is important to you now, you may want it to be part of your future. For example, maybe on your *Identity Map* you said you liked being outside. Then you might want easy access to the outdoors as part of your future.

Often books, films, or other media present ideas about what could happen in the future. These ideas can also help you imagine what kind of future you would want or not want.

In this guide you will be thinking about how you believe biotechnology can be a part of a sustainable future. But first you must think about what a sustainable future is.

An approach that balances different perspectives and can keep working for a long time is called sustainable. A **sustainable future** balances social, economic, environmental, and ethical concerns in a way that works well for people and the planet.

Your perspective about what a sustainable future should include is valuable. Other people may have different perspectives. Their perspectives are also valuable. Thinking about all these different perspectives together can help you envision a sustainable future that works for everyone, not just you.

12. Think quietly to yourself about what you want a sustainable future to include. You can use your own original ideas or ideas from other places. Use ideas from your experiences, books, movies, or other media, or conversations you have had to help you think about these questions.
    a. How would you want the future to be different than life now?
    b. Are there things you would like to remain the same?
13. Now take a piece of paper or open a digital document and divide it into two sections. Label one section "Hopes" and the other "Concerns."
14. In the *Hopes* section record your ideas by writing, drawing, or using digital images to represent your hopes for the future for you, your area, the people around you, and the whole world. Do not feel like your ideas have to be possible today—dream big!

15. As you think about your hopes for a sustainable future, you may also start to think about things that concern or worry you about the future. Record these ideas in the *Concerns* section.

> ⚠ **Emotional Safety Tip**
>
> When thinking about the future it is okay to be worried or concerned. These feelings are natural, especially when the future feels uncertain. By thinking about your fears, you can make choices to try to make sure your fears don't happen.

16. Label a class board, a large piece of poster paper, or a shared digital document "Futures Mood Board." A **mood board** is a tool to help gather ideas, concepts, and styles to design something. In this case, you are designing the future.
    a. On one half of the mood board write "Hopes." Fill this half with words, drawings, pictures, or other ways to represent each person's hopes for a sustainable future.
    b. On the other half of the mood board write "Concerns." Fill this half with words, drawings, pictures, or other ways to represent each person's worries, fears, or concerns about the future for people and the planet.

> ⚠ **Emotional Safety Tip**
>
> Sometimes you may want to keep hopes and concerns for the future private. Only share what you feel comfortable sharing.

17. Examine your *Futures Mood Board*.
    a. Do you notice things that surprise you about the hopes and concerns of your other team members?
    b. Do you notice any hopes and concerns that you have in common?
18. Read *Guidelines for Team Discussion*.

Part 1 Task 1

Guidelines for Team Discussion

- Remember, listening to many different perspectives and viewpoints is good.
- Open yourself to new ideas.
- Differences in your team can be useful. People with different identities can bring new knowledge and ideas.
- Be an active listener by facing the person and show them you are paying attention.
- Be respectful and expect respect. People may have different ideas, and that does not mean their ideas are wrong. Creating a team where all ideas are welcome is an important step toward making sustainable decisions.

⚠ Emotional Safety Tip

Sometimes your team members may have different perspectives than you. That's okay. Listen respectfully but remember that just because someone else believes something does not mean you need to believe it. It is okay to pause a conversation if you are uncomfortable or upset.

19. As a team, discuss:
    a. Do you think a person with a different identity, like someone from somewhere else or who is much older, might have different hopes and concerns about the future?
    b. If so, why might it be important to include those ideas about the future when thinking about a sustainable future?

Understand: *What does my community know and think about the future and biotechnology?*

As an action researcher on the future and biotechnology, one of your jobs is to find out more about what other people in your **community** think about the future and how biotechnology might help create a sustainable future. Understanding perspectives in your community can be an important part of considering what is sustainable and what actions you want to take. Helping your community starts by considering who is in the community and how they feel. You can investigate this using a survey.

1. First consider which community you want to focus on. A community is a group of people who share something, for example, your family, your classmates, your teachers, or your neighbors. A community can share space, like a local, national, or global community. Or a community can share an identity, like a religion, ethnicity, or common interest. If you think back to your identity map, you will probably realize you are part of many communities. Which community's perspective on biotechnology and the future would you like to understand? Discuss with your team and decide on a community you all belong to.
2. With your team, consider what would be important to know about the hopes and concerns your community has for the future. Write down a few questions you might like to ask.
3. Read *What Is Biotechnology?* and think quietly to yourself whether there are any ways you might use biotechnology in your life right now.

What Is Biotechnology?

Biotechnology is using living things, parts of living things, or things produced by living things to meet people's needs and improve their lives. It includes using parts of cells, whole organisms, or even ecosystems to meet our needs. It also includes making changes to parts of cells, organisms, or ecosystems to make them better fit people's needs.

4. In this guide you will be thinking about biotechnology and the future. You may want to start by asking people in your community general questions about the future to help you understand their perspectives, hopes, and concerns. Remember what you thought about that was related to your future hopes and concerns. Write down any questions you might want to ask your community. For example:
   a. What will be most important for our community in the future?
   b. What is the biggest threat to our community in the future?

5. You may also want to ask questions related specifically to biotechnology. Write down any questions you might want to ask. For example:
    a. What do you think biotechnology means?
    b. Are there things that excite you about biotechnology in the future?
    c. Are there things that scare you about biotechnology in the future?
    d. Or any other questions you would like to ask.
6. Read the *Survey Instructions* for more information about how to give a survey and pick your questions.

Survey Instructions

You can use a survey to understand the people in your community better. A survey is a list of simple questions you can ask of a group of people.

Choosing people to survey

a. Think about the categories in your identity map. Use those categories to try to pick a diverse group of people to survey, to get a more accurate idea of what your community thinks and feels. For example, you may want to survey people of many different ages or of more than one gender.

Ways you could give a survey

a. Talk to people in person, on the phone, or using a virtual meeting.
b. Have people answer questions using paper, email, or an online survey.
c. Collect responses using a social media post.

Picking questions

a. Consider open-ended or close-ended questions. An example of an open-ended question is, "What would be part of a sustainable future?" An example of a close-ended question is, "Is limiting global temperature rise part of a sustainable future?" You usually can get more information from an open-ended question, but if you have a lot of answers, it can be difficult to keep track of all the different ideas. Using a close-ended question is quicker, but you may miss some ideas from your community.

b. Try to make your questions neutral. That means you are not trying to put your opinion in the question. For example, "Do you agree that biotechnology should be used to help create a sustainable future?" would not be neutral. The person answering the question might assume you want them to answer "yes." A more neutral question might be, "Do you think biotechnology can be part of a sustainable future?"

Tips for giving a survey

a. Make sure your questions are easy to understand and specific, such as, "What worries you about the future?" instead of, "What worries you?"
b. Think about the best method for the survey. Is there a safe and easy way to gather the opinions of a wide variety of people in your community?
c. Think about the best way to survey your community. For example, does everyone have access to the Internet if you want to do an online survey?
d. Some people you survey may not be familiar with the meaning of biotechnology. You may want to start off by sharing the definition of biotechnology with them before you start asking questions about biotechnology. For example, you might say, "Biotechnology is using living things or parts of living things to meet people's needs. Biotechnology can be used in lots of different ways, like to make different types of plants to eat or create new medicines."

Safety tips for giving a survey

Talk to your teacher or a trusted adult for guidelines. They will know what is safest in your community.

⚠ Physical Safety Tip

Never go out alone and always be aware of your surroundings. Pay attention to local guidance on whether it is safe to interact with people outside of your home.

Part 1 Task 1

⚠ Emotional Safety Tip

It can be hard to talk to other people in the community. You may feel shy or nervous. Someone may tell you they don't want to talk. That's okay! It doesn't have anything to do with you. It just means they don't want to share. You can show them respect by thanking them and moving on to another community member.

7. Examine the questions you listed and choose the questions you want to ask your community. You probably want to ask between five and ten questions in your survey. You may want a mix of close-ended and open-ended questions.
8. Decide on your survey methods, and choose where, who, and how you will conduct your survey.
9. Remember, including everyone is important. If you are working with a team, you may need to adjust the way you do your survey so that everyone feels safe, comfortable, and able to help. Those changes are okay! They are part of including everyone. Make sure to consider:
    a. Time: If the survey happens after school, does everyone in the team have time to do it?
    b. Comfort: If you decide to move around the community to do your survey, make sure everyone on your team feels safe and able to do this. If not, what is another way team members could help with the survey?
    c. Location: If the survey is going to happen in a specific place, how easy is it for team members to get to that place?
10. If you are working with a team, assign different jobs to people. For example, if you decide to do an online survey, decide who will type the survey, who will share it, and who will collect the results.
11. Finally, conduct your survey by yourself or with your team and record the results.

Act: *How does biotechnology relate to a sustainable future for my local and global community?*

You asked your community about their hopes and concerns about the future and biotechnology. Now you can apply what you have learned to think more about the future your community wants and how that relates to a global future.

1. Take out your *Futures Mood Board* and examine the results of your survey. Are there hopes and concerns others in your community shared that are not yet part of your mood board? If so, add those ideas now.
2. With your team, use your mood board to discuss important goals for a sustainable future. These goals might be based on your hopes, like "everyone has access to clean energy" or they might be based on your concerns, like "no more extinction of animals."
3. Read *The United Nations and the Sustainable Development Goals*.

The United Nations and the Sustainable Development Goals

Achieving a sustainable future like the one you just thought about is complex. It takes many people working together in many places to create a sustainable future. When many people are working together it helps to have someone organizing. The United Nations, also called the UN, is a global organization designed to help governments and people around the world collaborate.

A few years ago, the UN asked countries and people around the world to imagine a better world and a better future. They worked together to determine a list of goals. Then the countries of the UN came to **consensus** on the most important goals needed to get to a better world. These goals for the global community are called the UN **Sustainable Development Goals**, or SDGs.

Part 1 Task 1

Figure 1-3: United Nations Sustainable Development Goals.

4. Examine the different SDGs. Are there SDGs you think are important for a sustainable future that your team didn't discuss? Do you think those goals are also important? If so, add those ideas to your *Futures Mood Board*.
5. Parts 2 through 7 of this guide will help you explore how biotechnology can be a part of a sustainable future in different ways. Each of these parts will show the possibilities of using biotechnology and will support you to think about the risks. You and your team will try to balance these ideas and determine when biotechnology should be used. Parts 2 through 7 are about:
   a. Part 2: Biotechnology and Food Systems: Exploring how biotechnology can and should help create an equitable, sustainable agriculture and food system.
   b. Part 3: Biotechnology and Materials: Using biotechnology to create new materials, like sustainable building materials, plastic alternatives, and organs for transplant.
   c. Part 4: Biotechnology and Human Health: Diagnosing and treating medical issues using biotechnology.

d. Part 5: Biotechnology and Genetic Data: Examining the genetic data being collected and considering how and when it should be used.

e. Part 6: Biotechnology and the Environment: Using biotechnology to help fix issues like pollution and biodiversity loss. **Biodiversity loss** is a decrease in the variety of the many different living things on Earth.

f. Part 7: Biotechnology and Security: Investigating when you can and should use biotechnology to make your world more secure.

6. Figure out how much time you have to complete the parts of this guide. For example, your teacher may say you only have time to do one part, just a few parts, or maybe all of them.
7. If you do not have time for all the parts, discuss with your team and pick the parts that are most closely related to hopes or concerns from your *Futures Mood Board*. After the next task, you can start working on the parts you have picked.

Task 2: How can biotechnology help create a sustainable future?

Biotechnology is rapidly changing the things people can do or even imagine doing. In this task you will ***discover*** ways you are already using biotechnology and think more about how it could be used in the future. You will investigate to ***understand*** more about new tools in biotechnology and how they can be used. Then you will ***act*** on this information to start thinking about **ethics** and how biotechnology should be used.

Discover: *How do I use biotechnology now and how could I use it in the future?*

Technology is the materials and methods used to solve people's problems and meet their needs. For example, a long time ago people developed the method of using different materials to create wheels, which helped solve a transportation problem. Wheels are an example of technology. Biotechnology is using living things, parts of living things, or things produced by living things to solve people's problems and meet their needs. Although new biotechnologies are being developed every day, there are ways people have used biotechnology for thousands of years. We will start this activity by thinking about biotechnology in your life.

1. Think quietly to yourself. What do you think of when you think about a living thing? The first thing many people think of is an animal. Do you think animals have been changed over time to better meet human needs? Discuss your ideas with your team.
2. Read *Domestication and Selective Breeding* to find out more.

Domestication and Selective Breeding

Within any **species**, or specific type of living thing, there is a lot of **variation**, or differences. For example, think of the differences in the way people appear, their abilities, the behaviors they have, and the things that interest them.

Even before they understood how the process worked, people noticed the fact of **inheritance—**that some **traits** or characteristics of parents were often passed on to their children, or **offspring**. Inheritance occurs in humans and in other living things. For example, the offspring of a fast-running horse is likely to be a fast runner. The offspring of a sheep that has very fine wool is likely to have fine wool. Animals that are friendly to humans are more likely to have offspring that will be friendly to humans.

Thousands of years ago people began to use the idea of inheritance to **domesticate** animals, which is the process of changing a species from its wild state to make it more useful for a specific purpose. People would breed two animals that had traits they wanted to encourage, in the hope that their offspring would have the same traits. This process is known as **selective breeding**.

Figure 1-4: Gray wolf.

The first domesticated animal was the dog. Its wild ancestor was closer to a wolf, but people used selective breeding and the resulting new species was friendlier to humans and could be used as a hunting assistant. Many other animal and plant species were domesticated over time, often developing traits quite different from their wild ancestors. Even within a domesticated species, humans have selectively bred plants and animals for different traits, such as size, color, or the ability to run long distances. Dogs are a good example of the wide diversity created by selective breeding within a species.

Part 1 Task 2

Figure 1-5 Variety of dogs.

Domestication and selective breeding are examples of biotechnology. Selective breeding produced many of the differences among the dogs shown in Figure 1-5.

3. Discuss with your team. What domesticated animals are you familiar with? List animals that people use as companions, as food, to produce products like milk or wool, or for labor, like carrying people or pulling loads. For each animal you list, try to think of what traits people may have been selecting for as they domesticated the animal. Write your answers on a class board or just discuss.
4. With your team, consider the pictures in Figure 1-6. Sometimes within one species (such as a cow) people have chosen different traits to select for. This results in different **breeds** or types within the species. In Figure 1-6, one of the cows is used to produce milk to sell. The other is used for its meat.
   a. What traits do you notice that are different between the two cows?
   b. Which traits might be important for milk or meat production?
   c. Which cow do you think is used to produce milk?

Figure 1-6: Dairy cow (left) and beef cow (right).

5. Examine the pictures in Figure 1-7. People have domesticated plants using selective breeding. Often, they tried to change wild plants so they produce more of their edible or desirable part, and are easier to grow and easier to harvest. Try to match the domesticated plant on the top with its wild ancestor on the bottom.

Carrots

Rice

Corn or Maize

Teosinte

Queen Anne's Lace

Rufipogon

Figure 1-7: Domesticated plants and their wild ancestors.

6. Compare your answers with the ones listed below. How did you choose which ones to match? What do you notice about changes to each plant during domestication?

a. Carrots match with Queen Anne's lace.

b. Rice matches with rufipogon.

c. Corn/maize matches with teosinte.

7. Examine the wild cabbage plant in Figure 1-8. Just like animal breeders, plant breeders sometimes focus on specific parts of the plant to change. Which part do you think breeders selected for to produce the edible vegetables shown in Figure 1-9? Match each wild cabbage part to a specific vegetable.

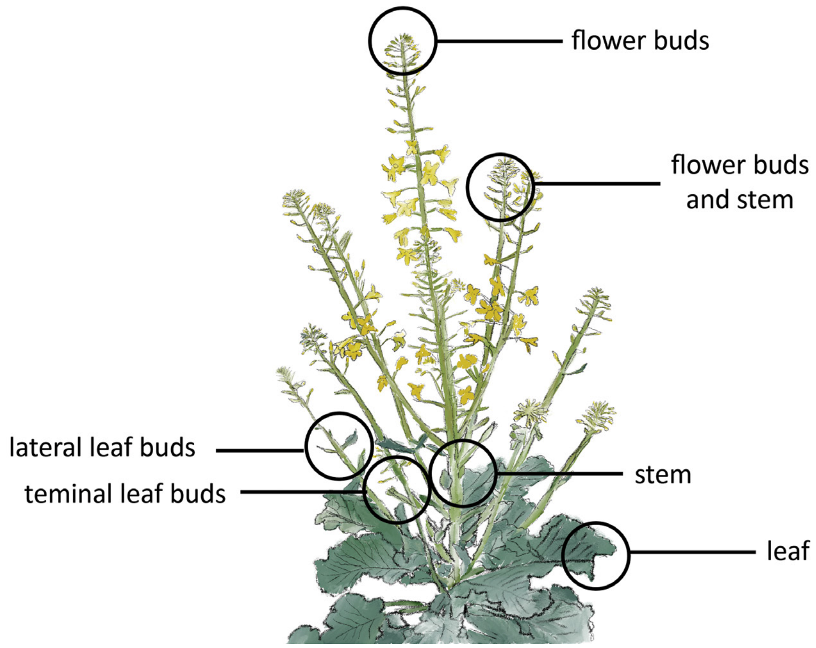

Figure 1-8: Wild cabbage plant.

Figure 1-9: Cauliflower, cabbage, kohlrabi, kale, Brussels sprouts, and broccoli (left to right).

8. Check your answers.

a. Selecting for the flower buds created cauliflower.

b. Selecting for the terminal leaf buds created cabbage.

c. Selecting for the stem created kohlrabi.

d. Selecting for the leaf created kale.
e. Selecting for the lateral leaf buds created Brussels sprouts.
f. Selecting for the flower buds and stems created broccoli.

9. Discuss with your team the way people use plants in addition to eating them, such as using them for clothing or building materials. Do you think people may have also used selective breeding to domesticate plants used in those ways?
10. In addition to plants and animals, did you know that people around the world often eat living things that are too small to see, called **microorganisms**? Discuss with your team. Do you think you eat any foods with microorganisms in them?
11. Read *Microorganisms and Food Preparation* to find out more.

Microorganisms and Food Preparation

People have been making bread and producing beer for thousands of years. What do these two processes have in common? They both use a microorganism, yeast, to create something to eat or drink. In baked goods like breads, yeast eats the carbohydrates (flours and sugars) in the bread dough and produces carbon dioxide gas. This carbon dioxide gas gets trapped in the bread dough and causes it to rise. When making beer, yeast eats the carbohydrates (sugars) in grain and produces carbon dioxide gas, which causes the beer bubbles, and alcohol.

Figure 1-10: Rising bread dough and baked bread.

Fermentation is a food preparation technique that adds microorganisms to food or encourages naturally occurring microorganisms to develop. Fermenting microorganisms eat carbohydrates and usually produce gases like carbon dioxide, acids, and/or alcohols. Many different types of food are the result of fermentation. Often more than one type of microorganism is part of the process. Fungi, like yeasts and molds, and different types of helpful bacteria are used to ferment foods and drinks in many places around the world.

For example, specific bacteria added to milk produces yogurt and cheese. Some cheeses also have types of molds added to them. Sometimes grains are fermented, like for sourdough bread or injera. Fermented vegetable and fruit products such as kimchi, miso, sauerkraut, chicha morada, and vinegar are common in many places.

Figure 1-11: Examples of fermented foods: kimchi, pickled cabbage, miso soup (top, left to right), yogurt, fermented pickles, sauerkraut (bottom, left to right).

Fermenting food often makes it easier to digest and introduces helpful bacteria to your digestive system. Fermentation can also preserve food. Using microorganisms in food preparation is an example of biotechnology. If you are interested in learning more about biotechnology and food, you can visit the *Biotechnology!* StoryMap to link to the Smithsonian's community research guide *Food!*.

12. With your team, list any ways you can think of that fermentation is used to produce things to eat and drink in your community. You may never have realized before that a food or drink was fermented, so here are some identification clues:
    a. How does it taste? Food with microorganisms often tastes yeasty, sour (from the acid produced), or alcoholic (from the alcohol produced).
    b. Are there bubbles created during the preparation? Bubbles can be a sign that gases are being produced by microorganisms. Think carefully, though, not all food or drink that is bubbly uses fermentation. For example, sodas have carbon dioxide added by the producers to create the bubbles.
    c. Is the food or drink mixed and then left to sit for a while? Microorganisms need time to grow. Fermented foods and drinks often are left to develop anywhere from a few hours to many years!
    d. Does the food or drink use cultures or starters in the process? Cultures and starters often contain the microorganisms needed to start fermentation.
13. Think quietly to yourself about how biotechnologies such as domestication, selective breeding, and fermentation have affected you and your life. How do you think human history would be different without the ways people have used and changed animals, plants, and microorganisms?
14. Think of a story about the impact on you of something produced using biotechnology—for example, the story of a pet, a favorite food, or plants you are familiar with. Share this story with a partner, your team, or write or draw it.

Understand: *What are some of the genetic tools of biotechnology?*

Domestication and selective breeding rely on the idea that offspring inherit traits from their parents. For many years, although people understood this idea of inheritance from parents, they didn't know how it worked. Finally, they realized **genetic data** is passed from parent to offspring. Genetic data is a set of instructions in each cell about how to build and maintain a living thing. Living things with a mother and a father receive a copy of the genetic data from both parents. However, it was not until the 1950s that scientists discovered the structure of the genetic data. A molecule, known as **DNA**, transfers and stores genetic data.

Discovering and understanding the structure of DNA changed biotechnology forever. It provided a new way to understand living things. Researchers also learned that by changing DNA, scientists could change the genetic data and traits of living things. Because DNA is so important to biotechnology, in this activity you will learn more about its structure and how it works. This will help you complete the rest of the guide.

1. Think quietly to yourself about these questions.
   a. What things around you do you think have DNA?
   b. What could you learn or do if you had access to that DNA?
2. Read *DNA Extraction Instructions* and carry out a DNA extraction.

DNA Extraction Instructions

DNA contains a huge amount of information and it is found in every living thing. Breaking cells apart and pulling something out, or **extracting** the DNA is often the first step in biotechnology research and applications. In this experiment, you will complete a DNA extraction yourself.

What you will need

- Alcohol: At least 70% concentration of rubbing (isopropyl) alcohol or ethanol. You can buy this at a chemist, drugstore, or places where first aid items are sold. Do NOT use alcoholic beverages; the experiment will not work.
- DNA source: You can choose your source—strawberries, bananas, peas (fresh, dried, or frozen) all work well, as do many fruits and seeds. Choose something that is easily available for you.
- Containers: A plastic bag, a bowl, or a cup. You will use this to hold the DNA source while you are mashing it. You'll also need another container to mix some ingredients.
- Fork or spoon: To mash your DNA source.
- Water: Use any clean water you have available.
- Salt: Everyday cooking salt is fine.
- Detergent: Dish soap or shampoo both work well.
- Filter: Any coffee filter will do. If one is not available you can use a paper towel, a very fine sieve, or even an old T-shirt.

- Clear container: A glass or plastic cup works best, but you can use a bowl if that is what you have.
- Skewer or toothpick

Directions

a. Put your alcohol in a freezer for 24 hours before you start.
b. Put your DNA source in a container and mash or grind it so it forms a paste. You need about 100 ml (1/2 cup) of the DNA source. You can place it in a plastic bag, like in Figure 1-12, or put it in a bowl or cup and use a fork or spoon to mash it. This process breaks up the cell walls in the plants.

Figure 1-12: Smashed strawberries in a plastic bag.

c. In another cup or bowl combine around 100 ml (1/2 cup) water, 5 g (1 teaspoon) salt, and 10 ml (2 teaspoons) detergent. Mix thoroughly.

Figure 1-13: Salt, water, and detergent mixture.

d. Add about 10 ml (2 teaspoons) of this water mixture to your mashed-up DNA source. Mix gently. The detergent will help break up the lipids (fats) in the cell membranes and release the DNA. The salt helps make the DNA easier to extract.
e. Strain the mixture through the filter into the clear container.

Figure 1-14: Filtering the strawberry mixture.

f. Take your alcohol out of the freezer and pour it gently down the side of your clear container. Pour about as much alcohol as you have DNA source mixture.
g. Watch carefully. The alcohol will sit in a layer on top of your DNA source mixture. However, DNA will begin to **precipitate**, or come out of solution, in the alcohol. Cloudy white wisps will start to appear in the alcohol as the DNA precipitates. Let your mixture sit for 5 to 15 minutes to get the most DNA.
h. You can twirl a skewer or toothpick in the alcohol layer to pick up the DNA. It will be sticky and a little slimy. This visible substance is the DNA from many cells that is stuck together.

Figure 1-15: Toothpick showing DNA extracted from strawberries.

Going further

Now that you have extracted the DNA from one source, try another source. DNA is part of every living thing. However, it can be tricky to extract it from the roots, leaves, and stems of plants. You can also extract DNA from animal products, like chicken liver. For some things you may need a blender to break up the cells rather than just mashing them by hand.

You can extract DNA in everything from seed pods you collect from plants to your own saliva (spit)! What can you find around you to use as a DNA source?

3. Discuss the results of your experiment with your team.
    a. Were you able to extract DNA?
    b. What do you think you could do with DNA once it is extracted?
4. Read *DNA: Instructions for Life*.

DNA: Instructions for Life

The information in DNA is stored in **bases**. There are four types of bases: adenine (A), cytosine (C), guanine (G), and thymine (T). The bases form a long sequence that stores information about how to make different proteins.

Each base type pairs with one other type, so A always pairs with T and C always pairs with G. These matches are known as **base pairs**. You may know that DNA is a double helix molecule. Each side contains a sequence of bases paired with the other matching set of base pairs, as shown in Figure 1-16.

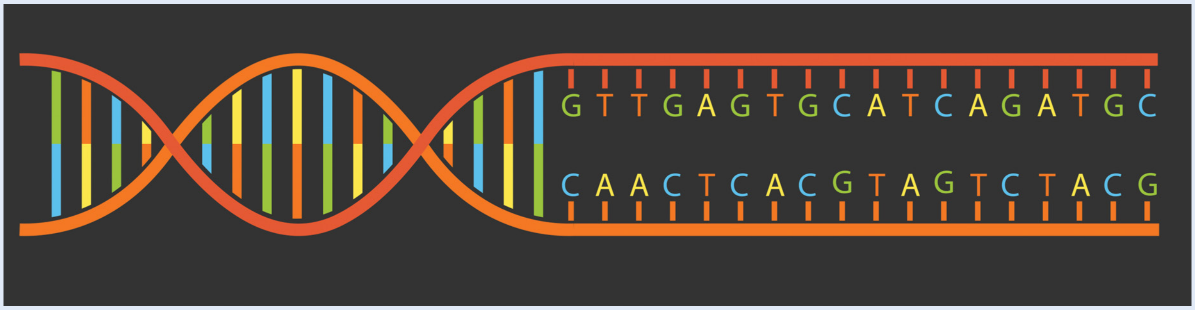

Figure 1-16: Illustration of a double helix with matching base pairs.

If you want to make sure you understand, you can use the sequence here and fill in the matching base pairs. The first few matches are done in red for you.

A T A C C G C A T T A T C G C G G A A A T C T C G A T
T A T G

In 1990, scientists around the world decided it was important to determine the entire human **genome**, or sequence of DNA, which is around 3 billion base pairs in total. Researchers from 20 institutions in six countries worked together as part of the Human Genome Project and in 2001 they published the sequence of almost the entire human genome. Researchers continued to improve their knowledge and in 2022 filled in the final gaps. The first human genome sequence produced in 2001 cost about US$1 billion to produce. Today, sequencing an entire human genome costs less than US$1,000, and the cost continues to go down.

5. Discuss with your team:
    a. Why do you think it was useful to sequence the whole human genome?
    b. The genomes of different humans are 99.9% the same. Why do you think there is still a need to sequence individual human genomes?
    c. Researchers have also been sequencing the genomes of other living things. What might they hope to learn from that information?
6. Read *Gene Expression and Variation*.

Gene Expression and Variation

You know that genetic data is carried by the molecule DNA and copies of a parents' DNA are given to their offspring. But how does this genetic data create different traits? Long strands of DNA are organized into smaller sections called **genes**. Genes can be copied and used by a cell to produce proteins. Cells "read" the sequence of bases pairs in a gene to find out how to form a specific protein. Producing these proteins is called **gene expression**.

Part 1 Task 2

Genes code for specific proteins that create specific traits. Some traits, like whether a person has a detached earlobe or can roll their tongue, are determined by a single gene. Other traits, such as a person's height and skin color, are determined by multiple genes.

Even small changes in the sequence of the base pairs in a gene can create big changes in the protein.

Let's use an **analogy** to explain. Imagine rather than the four letters (a, c, g, and t) representing the bases of DNA, the DNA instructions used the letters of the alphabet to share information.

Take out a piece of paper and something to write with. You will model a cell "reading" a gene of its DNA. For each bolded sentence, follow the instructions. In this analogy an initial gene might be read like this:

Start here: Read this sentence then draw a box.

As part of the model analogy, you probably just drew a box.

However, sometimes when DNA is copied the cell might make a mistake and copy one letter wrong. Genes with one or more differences like that are called **variants**. In this analogy, the mistake might be quite small but will change the meaning. Follow the instructions in the sentence below.

Start here: Read this sentence and then draw a fox.

How is what you drew this time different? In the example, the "b" from box changed to an "f" which changed the meaning of the sentence.

Sometimes small changes like this do not create a problem. However, sometimes they can mean the person with the variant is unable to make a certain protein properly. Diseases like Tay-Sachs, cystic fibrosis, and sickle cell anemia are caused by variants like this.

In the past, once a problematic variant occurred, there was no way to fix it. However, in 2012 scientists began using a new biotechnology tool called **CRISPR-Cas9.** CRISPR is sometimes called "DNA scissors" because it can snip DNA in very specific places to add, delete, or change base pair sequences.

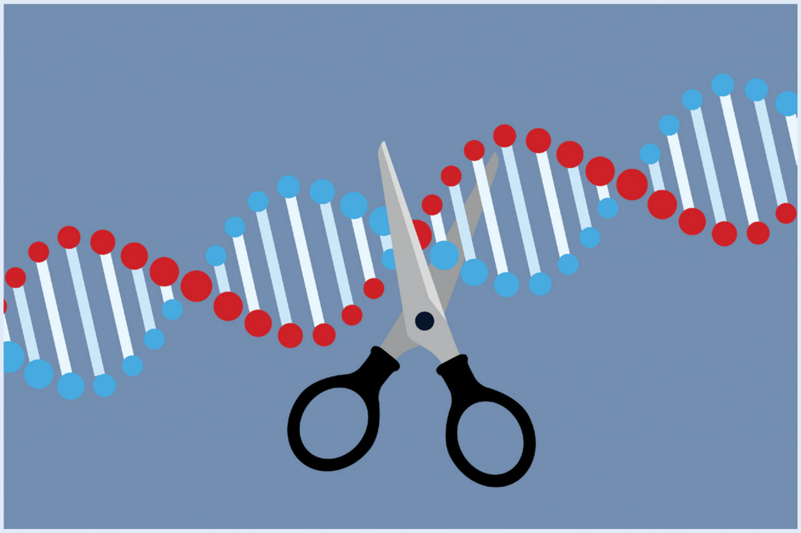

Figure 1-17: Illustration of CRISPR-Cas9, sometimes known as DNA scissors.

The development of these techniques means it is easier than ever before for people to change genes in very specific ways—a process called **gene editing**. For example, in this analogy, by using CRISPR the word "fox" could be changed back to the original word "box."

Or by using CRISPR, new instructions could be added. Continue modeling a cell reading a gene and follow the instructions below:

Start here: Read this sentence and then draw a box and a rainbow.

Or by using CRISPR, scientists can take a piece of the gene out. Here's an example of that using the sentence analogy. Follow the instructions in the bold sentence.

Start here: Read this sentence.

Or by using CRISPR, scientists can take a piece of the gene out and replace it with another base pair sequence. Follow the instructions in the bold sentence to model an example of that.

Start here: Read this sentence and then think of a box.

Or by using CRISPR or other techniques, scientists can stop genes from being expressed. This is called **gene silencing**. Follow the instructions in the bold sentence to model an example of that.

Part 1 Task 2

Stop here: Read this sentence and then draw a box.

Examine what you drew on your paper. Did you get different instructions after the gene was edited?

CRISPR and other similar gene editing tools mean it is possible to change specific parts of the genome of any living thing.

Using gene editing tools, gene expression can change in many ways. By changing the DNA in genes, the proteins they code for can be changed. Mistakes in gene copying can be fixed and new instructions can be added. Using gene silencing, a gene that is causing a problem can be "turned off."

If you would like more information about how gene expression and editing works within a cell, you can find more resources in the *Biotechnology!* StoryMap.

Parts 2 through 7 share more details about how gene editing and other biotechnology tools have opened up many new possibilities for human health, the environment, and many other areas.

7. Discuss with your team:
    a. Can you think of a specific way or ways a gene editing tool could be used to help people or the planet?
    b. If you can't, don't worry, you will be learning more during the rest of the guide.

Act: *What concerns do I have about using biotechnology sustainably?*

Biotechnology tools can change the world around us in dramatic ways. However, just because things can be done does not mean they should be done. In this activity you will start to consider how and when you think biotechnology should be used.

1. As a team, take out a piece of blank paper or use a section of a class board. Divide your paper or the board into four sections and draw a circle in the middle, as shown in Figure 1-18. In one section write "Social," in one write "Economic," in one write "Environmental," and in one write "Ethical."

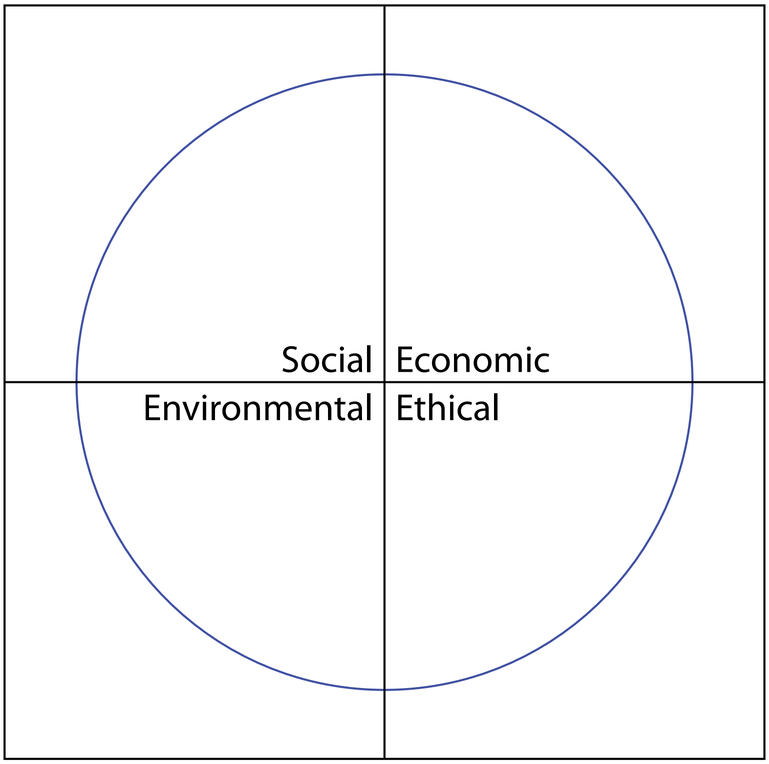

Figure 1-18: Perspectives sheet.

2. Read *Different Perspectives* and think about what the different perspectives mean. Write words or draw pictures within each section of the circle to help you remember the concerns of people thinking about each perspective.

Different Perspectives

People may have different perspectives. Often a person's perspective may be related to parts of their own identity or experiences.

Considering different perspectives can help uncover solutions for a sustainable future. Sustainable means balancing the needs of different people and other living things over the long term. When thinking about sustainability, it is important to consider four types of perspectives: social, economic, environmental, and ethical.

- **Social** is about the interaction of people in a community. The health, education, and well-being of people are the most important things from this perspective.
- **Economic** is about money, income, and use of wealth. Economic growth, including making sure people have jobs and enough money, is the most important thing from this perspective.

- **Environmental** is about the natural world. Protecting the Earth and its natural systems are the most important things from this perspective.
- **Ethical** means that something is fair. Doing what is right and having a just community where everyone is treated fairly are the most important things from this perspective.

3. Now read the *Biotechnology Scenarios*. In each section of your *Perspectives Sheet*, draw pictures or write words that show ways this situation might be helpful from that particular perspective. Also draw or write ways that you think the scenario might concern or worry people thinking from this perspective.

Biotechnology Scenarios

Scenario 1: A researcher modifies the DNA of a human egg cell by editing a gene to makes the cell more resistant to disease.

Scenario 2: Plant biologists use CRISPR to modify the DNA of a rice plant to insert a gene that makes the plant need less water to grow. Next year they will start to use this modified plant in local farms.

Scenario 3: A gene therapy treatment that inserts new DNA sequences into targeted body cells helps cure a rare disease. The treatment is only available at a few hospitals and costs US$450,000.

Scenario 4: A company collects and sequences DNA samples, which enables clients to better understand their family heritage and risk of specific diseases. This data could potentially be used by employers or insurance companies to make decisions about whether to hire or insure people. However, right now the company's privacy policy currently states the data will only be used by the company itself.

Scenario 5: A mosquito species carries and infects people with the disease Zika. A team of researchers introduces a genetic modification to that species of mosquito. The genetic modification will slowly destroy the population of mosquitoes over time by limiting their ability to reproduce. The researchers hope this will stop the spread of Zika. The team plans to release the modified mosquito into the wild.

4. Examine all the concerns from the *Perspectives Sheet* with your team. Are there specific **themes**, or main ideas, that you notice? If so, make a note of these themes.
5. Several **themes** often emerge when thinking about using biotechnology ethically. Examine the themes that follow and make a note if they are reflected in some of the things you thought about from a social, economic, environmental, and ethical perspective.
   a. Access: Who gets to use and benefit from biotechnology?
   b. Privacy: What personal data is available and how can it be used?
   c. Unbalanced ecosystems: Natural systems are **interdependent,** which means different parts of the system depend on one another. Will the biotechnology unbalance the system in an unanticipated way?
   d. Persistence: Will the modification remain in the body of a living thing or in larger natural systems? Will the modification spread uncontrollably?
   e. Decision-making: Who should get to decide these issues? How do the decisions of one person or group affect others?
   f. Safety: What is the potential for harm?
6. Discuss with your team which ethical themes you think are most important to keep in mind as you consider whether biotechnologies should be used.
7. Pick some or all of the themes listed here, as well as any other themes you think are important. Create a list, chart, infographic, piece of artwork, or other method to help you remember these themes. Keep this *Ethical Concerns List*; you will need it in other Parts of this guide. If it is a visual reminder, you may want to post it somewhere in your classroom.
8. Go back and examine your *Futures Mood Board*. Think quietly to yourself or share with your team:
   a. In your hopes for the future, could some hopes be threatened by the ethical themes you identified?
   b. In your concerns about the future, could some concerns become more likely due to the themes you identified?

Congratulations!

You have finished Part 1.

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.

Action researcher: A person who works with their community to discover, understand, and act on local and global problems they learn about

Analogy: Comparing two things to help provide clarification

Base pairs: The matches that DNA bases form with one another**:** A always pairs with T and C always pairs with G

Bases: The four types of DNA units that store information: adenine (A), cytosine (C), guanine (G), and thymine (T)

Biodiversity loss: A decrease in the variety of the many different living things on Earth

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

Breeds: Different types within one species, for example two breeds of dogs

Community: A group of people who share something in common, such as a space or an identity

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

CRISPR-Cas9: A biotechnology tool that cuts DNA in very specific places to add, delete, or change base pair sequences

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

Domesticate: The process of changing a species from its wild state to make it more useful for a specific purpose

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

Environmental: About the natural world

Ethical: Something that is fair

Ethics: The fairness of something

Extract: Pulling out a part from within a larger thing

Fermentation: A food preparation technique that adds microorganisms to food or encourages naturally occurring microorganisms to develop

Gene editing: Changing genes in very specific and targeted ways

Gene expression: Producing a specific protein from a gene

Gene silencing: A process in which scientists stop genes from being expressed

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

Genetic data: The set of instructions within a cell on how to build and maintain a living thing

Genome: The complete sequence of DNA of a living thing

Identity: The characteristics that make you y ou

Inheritance: The process in which traits or characteristics of parents are passed on to their children

Interdependent: When different things, people, or parts of a system depend on one another

Microorganisms: Living things that are too small to see without magnification

Mood board: A tool to help gather ideas, concepts, and styles to design something

Offspring: The children of parents

Perspectives: The different ways we think about the world around us

Precipitate: When part of a solution turns into a solid

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

Social: Relating to the interaction of people in a community

Species: A specific type of living thing, like a human or a dog or a coconut tree

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

Sustainable Development Goals (SDGs): Seventeen goals for a better world created by the countries of the United Nations

Sustainable future: A future that balances social, economic, environmental, and ethical concerns and that works well for people and the planet

Technology: Materials and methods used to solve people's problems and fill their needs

Themes: Main ideas

Traits: Characteristics

Variants: Genes with one or more differences from the original

Variation: Differences in living things

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SCIENCE
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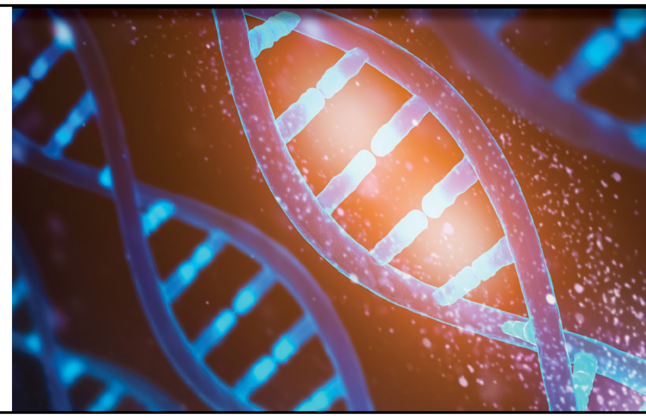
BIOTECHNOLOGY!



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

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PART 2 BIOTECHNOLOGY AND FOOD SYSTEMS

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

Part 2 Planner

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

Part 2 Planner

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.

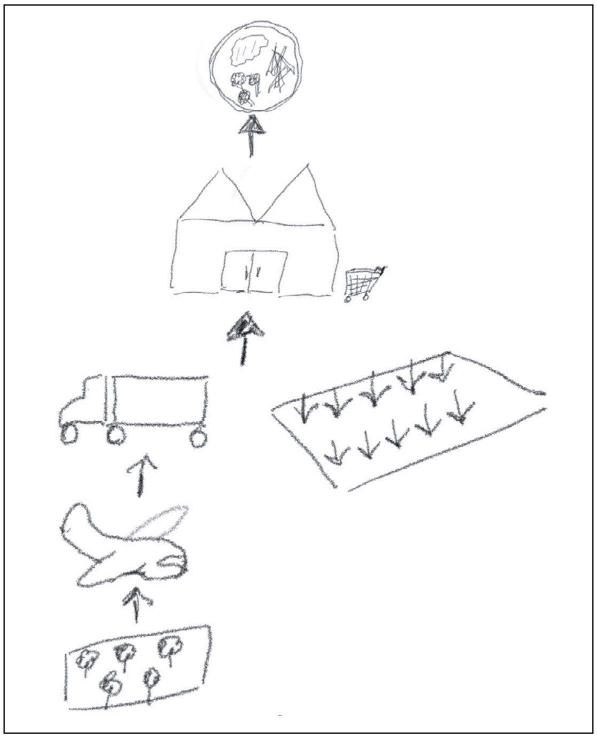

Figure 2-1: Example of a food system drawing.

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.

Part 2 Task 1

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.

Part 2 Task 1

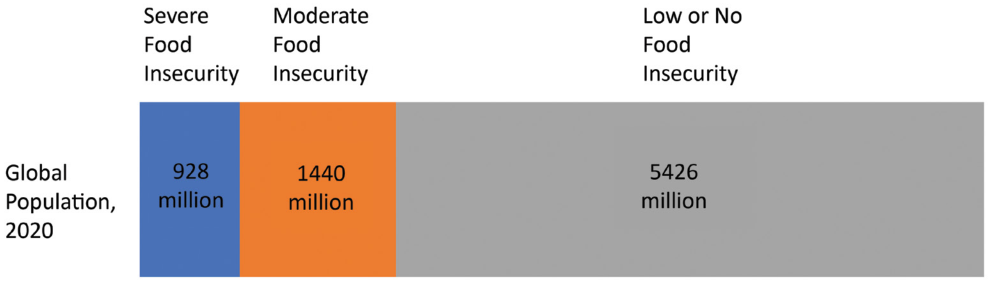

Figure 2-2: Global food insecurity, 2020[1].

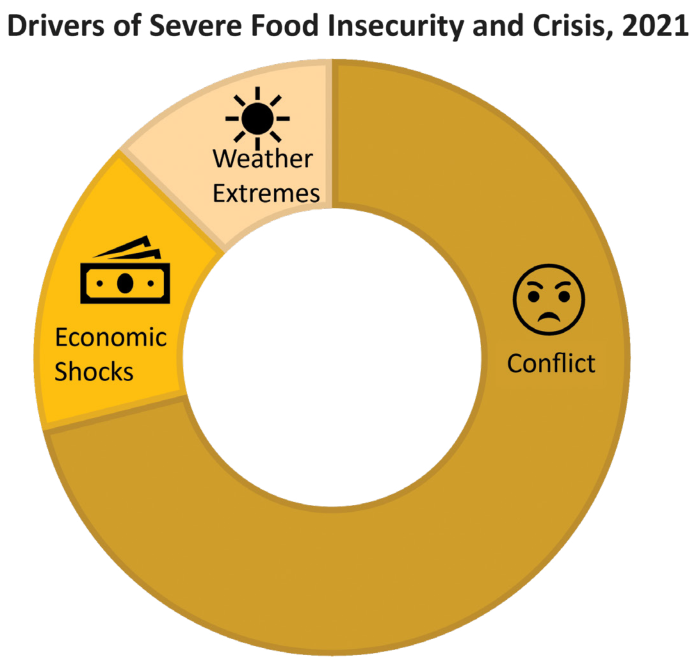

Figure 2-3: Drivers of severe food insecurity and crisis, 2021[2].

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.

Part 2 Task 1

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.

Part 2 Task 1

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.

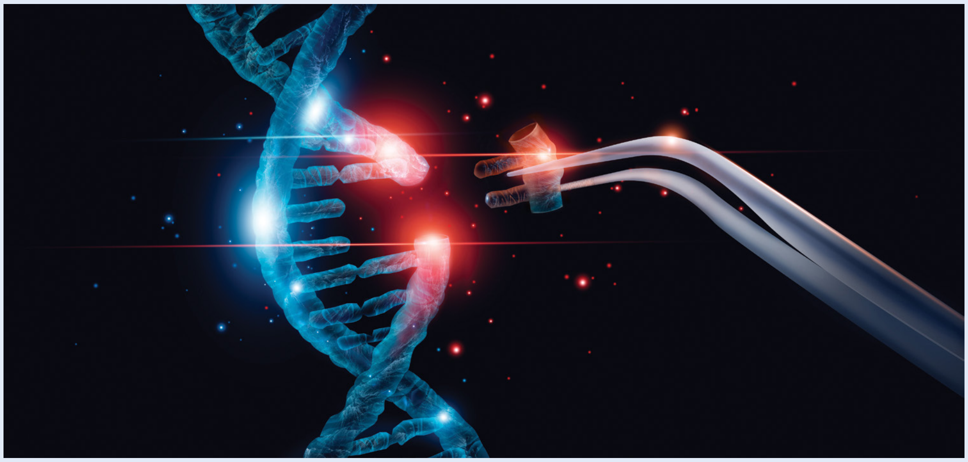

Figure 2-5: Representation of small changes to DNA such as those that might be made using CRISPR.

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.

Part 2 Task 1

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 crtl: 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.

Part 2 Task 1

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.

Part 2 Task 2

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.

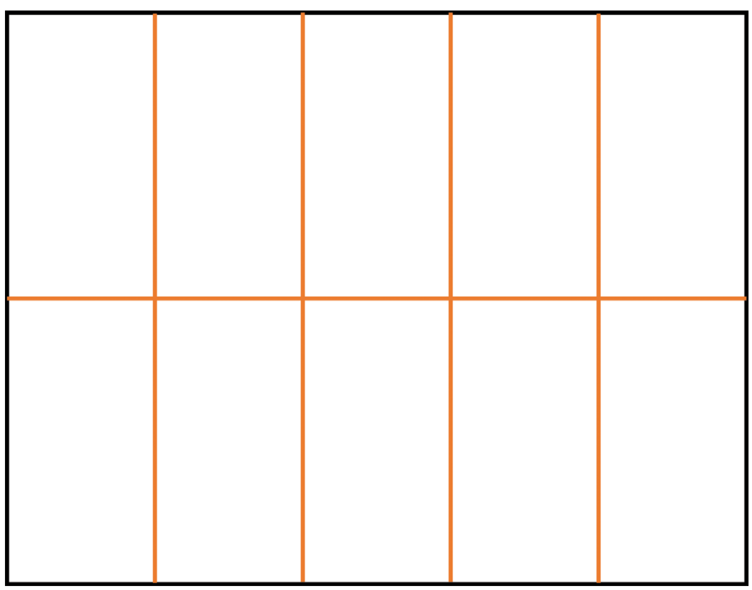

Figure 2-7: A paper model can be used to represent Earth's surface.

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.

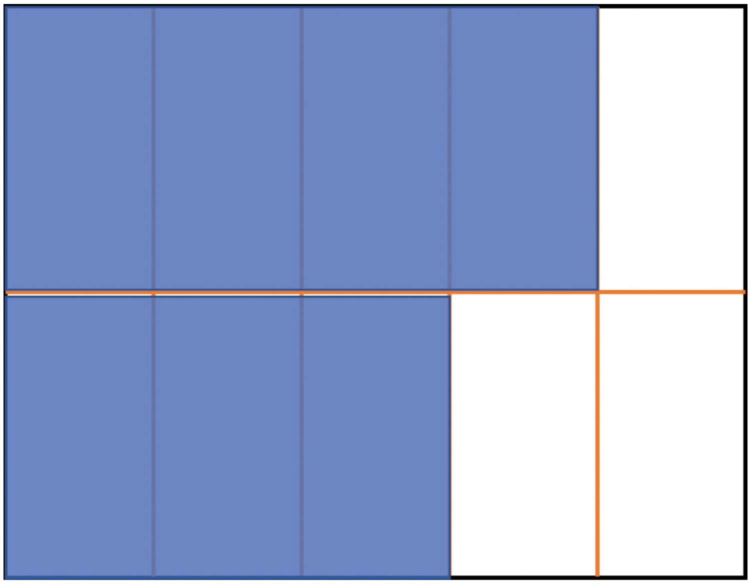

Figure 2-8: A paper model of Earth's surface with the ocean marked out.

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.

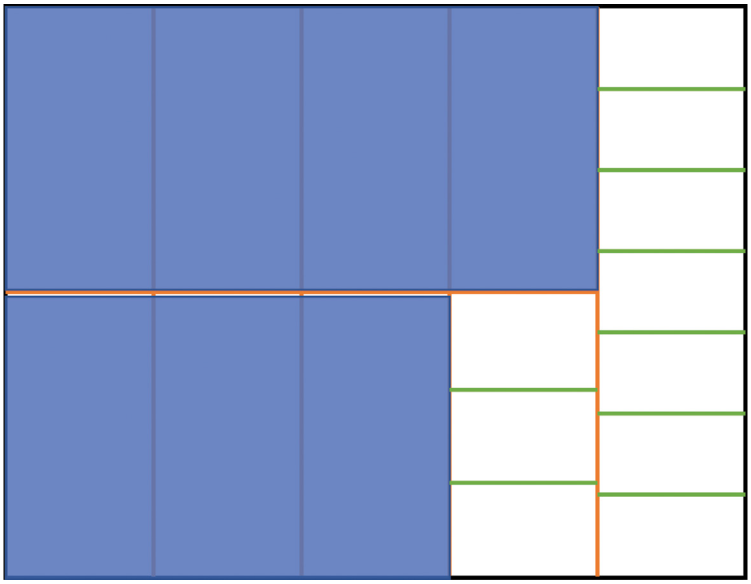

Figure 2-9: A paper model of Earth's surface with the land divided into 10 parts.

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.

Part 2 Task 2

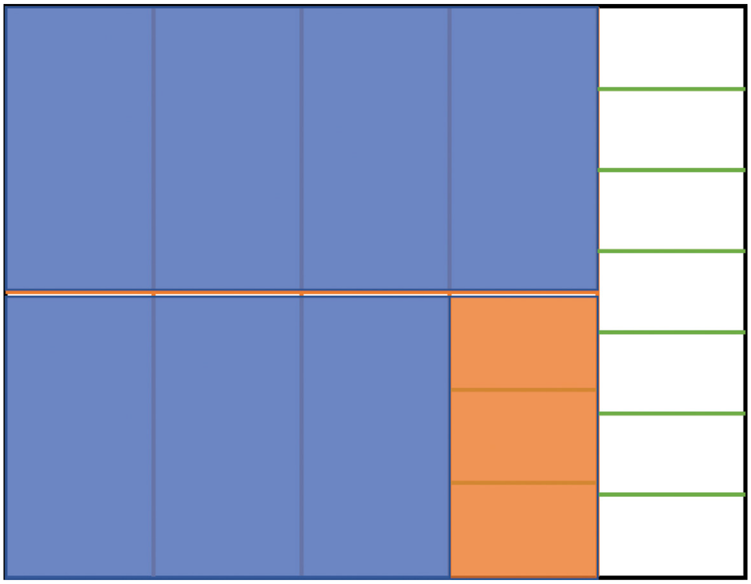

Figure 2-10: A paper model of Earth's surface with only the habitable surface remaining.

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.

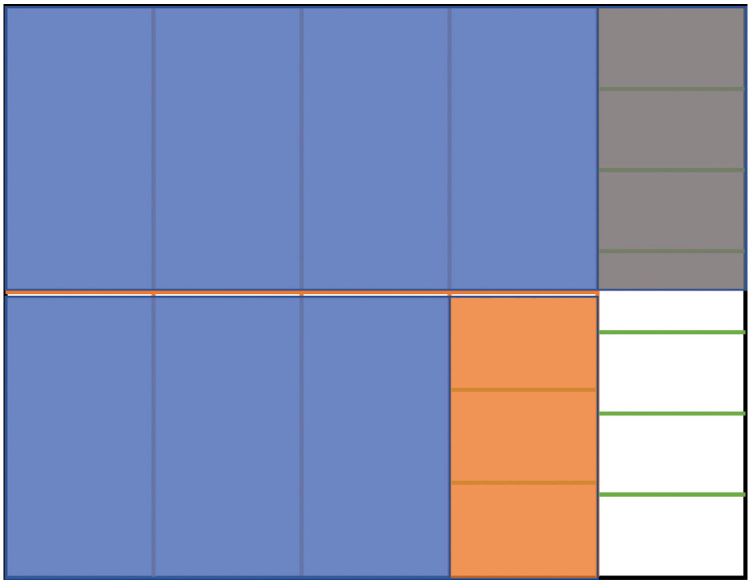

Figure 2-11: A paper model of Earth's surface showing the part that is used for producing food.

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.

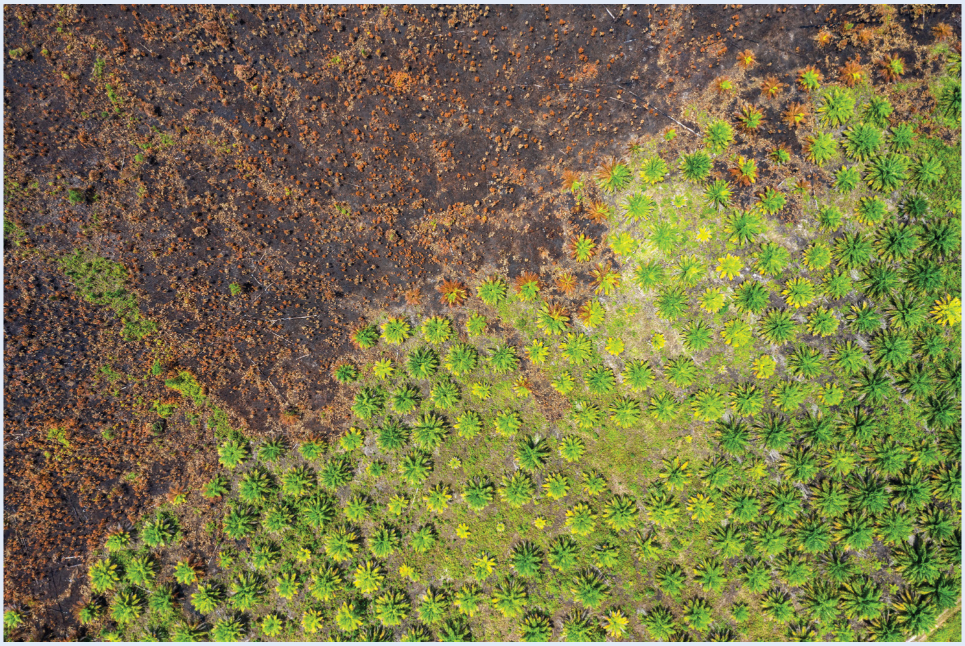

Figure 2-13: The dark area in this photograph is where the forest has been burned to make more room for a palm oil plantation (the green plants).

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.

Part 2 Task 2

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.

Part 2 Task 2

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.

Part 2 Task 2

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.

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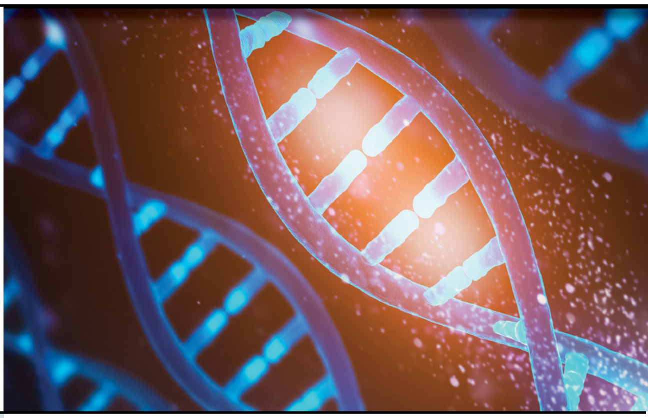
BIOTECHNOLOGY!



Part 3:

Biotechnology and Materials

SUSTAINABLE DEVELOPMENT GOALS

developed by Smithsonian Science Education Center

in collaboration with iap SCIENCE HEALTH POLICY the interacademy partnership

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PART 3: BIOTECHNOLOGY AND MATERIALS

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: How can biotechnology change the materials we use?					
Discover	Explore materials and sustainability and create profiles for materials in your own environment.	• Paper or class board • Pens or pencils		45 minutes + investigation time	93
Understand	Investigate biotechnology and sustainable materials and make your own bioplastic.	• Microwave-safe container • Cornstarch • Cooking oil • Pipette or eyedropper (optional) • Water • Food coloring (optional) • Spoon • Microwave or other heat source, such as a stovetop	*Sustainability Profile* for plastic water bottle (Discover activity)	60 minutes	99
Act	Consider the impact of innovative materials and share a new material with your community.		*Ethical Concerns List* (Part 1)	40 minutes + action time	106

Part 3 Planner

Activity	Description	Materials and Technology	Additional Materials	Approximate Timing	Page Number
Task 2: Can we create the materials we need using cells and biotechnology?					
Discover	Discover ways scientists are using living things to create new materials.	• Paper or class board • Pens or pencils		30 minutes	109
Understand	Investigate the need for 3-D bioprinting, create a model, and consider challenges and the future of the field.	• Paper or class board • Pens or pencils • Circular sprinkles (nonpareils, couscous, sand, or other small, round granules) • Peanut butter, toothpaste, or a gel-like material • Sandwich or plastic bags	Printouts of Figures 3-17 (1 copy) and 3-18 (4 copies) (optional)	65 minutes	113
Act	Think about ethical concerns about using biotechnology to create materials and share them with others.	• Paper • Pens or pencils	*Ethical Concerns List* (Part 1) *Futures Mood Board* (Part 1)	20 minutes	122

Part 3 Planner

Task 1: How can biotechnology change the materials we use?

We each use materials every day. A **material** is any substance that makes up an object. The places we live, our furniture, our clothes, our food, the products we use, our means of transportation all require materials. Where do these materials come from and is the way we are using them **sustainable**? What alternatives exist? In this task you will first ***discover*** more about your own use of materials and whether it is sustainable. Then you will investigate to ***understand*** more about sustainable materials created using **biotechnology**. Finally, you will ***act*** on this information and decide how this will affect your use of materials in the future.

Meet Your Research Mentor

Meet Dr. Young Kim. Young (pronounced YUHNG) is one of the many researchers around the world trying to use biotechnology to make materials more sustainable.

Young is an associate professor of sustainable biomaterials at Virginia Tech University in the United States. He has a PhD in packaging science. However, he also has knowledge and perspectives that came from other parts of his identity. Since Young is now working with you, it is important to understand who he is.

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

- 52 years old
- Received PhD from Clemson University, class of 2005
- Asian (South Korean)
- Male
- Lives in Blacksburg, Virginia, USA
- Strong ties to South Korea and the USA
- Interested in how to use bioplastics more efficiently and economically
- Likes video games and golf

- Wears glasses and short hair, "like soldier style"
- Believes in always having a positive mindset
- Money-maker of the household
- Part of Packaging Systems and Design Group housed in the Department of Sustainable Biomaterials at Virginia Tech

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

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

Throughout this task you will notice Young 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.

Part 3 Task 1

Discover: *What are the sustainability issues with the materials we use?*

Every day we are all using different materials. Some materials are natural, like wood, stone, and sand. Some materials, such as plastic, steel, and concrete, are created by people. Scientists believe the mass of human-made materials is now greater than the mass of all living things on Earth. In this task you will be thinking about the consequences of using and creating different types of materials. How sustainable are the materials around you?

1. With your team, sit in a circle.
2. Have each person on your team try to name a material used in each of the following categories. For example, for buildings someone might say "wood." You can say a natural material such as "stone" or a human-made material such as "bricks." You may not know all the materials that are part of a category. That's okay, just do your best. When someone can't think of an answer, move on to the next category.

   a. Buildings and construction
   b. Household goods (furniture, appliances, utensils, etc.)
   c. Clothing
   d. Packaging (of food; beauty, medical, personal and household products; transported items, etc.)
   e. Infrastructure (roads, bridges, etc.)
3. Pick one item you or your teammates listed and think quietly to yourself:
   a. Where does that material come from? For example, is it dug out of the Earth?
   b. What happens to it when it is no longer being used? For example, does it get recycled? Does it go into a landfill? Does it go into the air? Does it enter the waterways? Does it get burned?
   c. What do you think makes a material sustainable? Read Young's ideas.

Young says . . .

There are many different parts to a material being sustainable. Is the source of the material sustainable? Does the material create high carbon emissions, polluting the atmosphere?

There are many ways to increase the sustainability of materials—for example, improving the processing technology to consume less energy, reusing the material, and recycling. Thinking about where the material comes from and what happens to it when it is thrown away is an important part of sustainability.

4. As a team, discuss, what does it mean for a material to be sustainable? For example:
   a. Are sustainable materials made from resources that are **renewable**, meaning easily replenished? Often this means they're based on something that could grow back quickly, like a fast-growing plant, fungus, or bacteria. This is sometimes called **biobased**.
   b. Are sustainable materials **biodegradable**, meaning able to break down relatively quickly in a natural environment? For example, would they decompose quickly in a compost heap or if they reached a waterway?

Part 3 Task 1

c. Are sustainable materials **affordable**, meaning inexpensive?

d. Are sustainable materials **durable**, meaning able to be reused many times or have their materials easily recycled?

e. Are sustainable materials **low-resource**, meaning made without needing a great deal of energy or water or other natural resources?

f. Are sustainable materials **clean**, meaning they add only minimal **greenhouse gases** or other types of pollution to the natural environment?

5. With your team, use a piece of paper or the board to create a *Sustainability Profile* chart like the one in Figure 3-1.

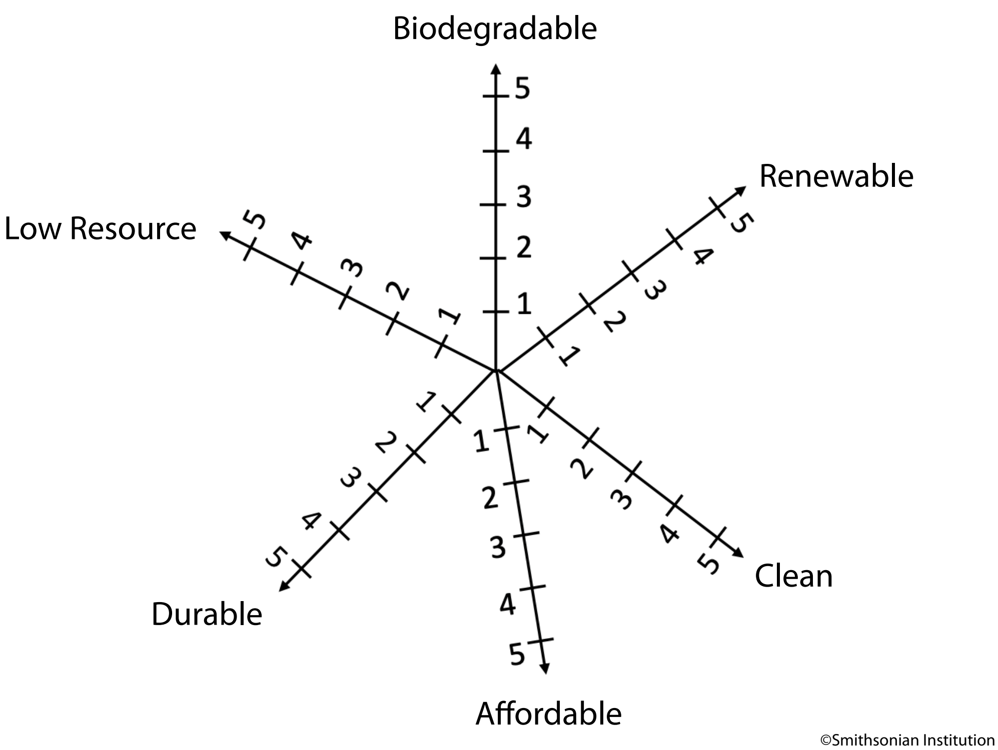


Figure 3-1: Sample Sustainability Profile chart.

6. Read *The Life Cycle of a Plastic Water Bottle* and search for information about whether the material used to create the plastic water bottle is renewable, biodegradable, affordable, durable, low-resource, and clean.

The Life Cycle of a Plastic Water Bottle

Millions of years ago, living things in the ocean like algae and zooplankton died, sank to the sea floor, and were buried in sediment. Over time, the bodies of these living things were compressed deep into the Earth. That compression changed them into a fossil fuel known as crude oil.

Then in recent times workers drilled deep into the Earth to reach the crude oil. They pumped the oil out of the Earth and sent it through a pipeline to be **refined**. At the refinery other workers heated and distilled the crude oil to separate it into different parts. One part was heated at high temperatures to break it into short molecules. Some of these molecules were combined into long strings called **polymers** with a process that uses heat, water, and other chemicals. The resulting plastic is called PET. The PET was formed into small pellets and shipped to a plastic bottle factory.

Once the PET pellets reached the factory they were melted down and had air blown inside them while pushing the molten PET against a mold to form a bottle. The bottles were filled with water, capped, packed, and shipped to a store.

At the store, the water bottle was inexpensive. A person bought it, drank the water, and got rid of the bottle.

Figure 3-2: Plastic bottles after use.

The rest of the story could go in many different directions. Sometimes, the bottle is thrown away and ends up in a landfill where it will not degrade for hundreds of years. Or the bottle could be burned with other trash for fuel, releasing carbon into the atmosphere. Or the bottle could be recycled into other products, such as another bottle or a T-shirt. But plastic is usually only recycled a few times before the quality decreases, and it is no longer usable. Or someone could litter or bottles could be washed out of a landfill. Then a bottle could enter the waterway and make its way to the ocean, where it will float, slowly breaking into smaller pieces for hundreds of years. These plastics and microplastics can cause problems for sea life and human health. In fact, by weight, plastic bottles are the most littered items on beaches around the world.

7. Fill out the *Sustainability Profile* for a plastic bottle, based on *The Life Cycle of a Plastic Water Bottle*. For each characteristic, such as biodegradable, rank the plastic bottle from very bad (1) to very good (5) and draw a dot at that number along the line. Don't worry if you don't have a good answer to one or more of the characteristics. Just do your best. Connect the dots between the lines. You now have the plastic bottle's sustainability profile. Figure 3-3 shows an example.

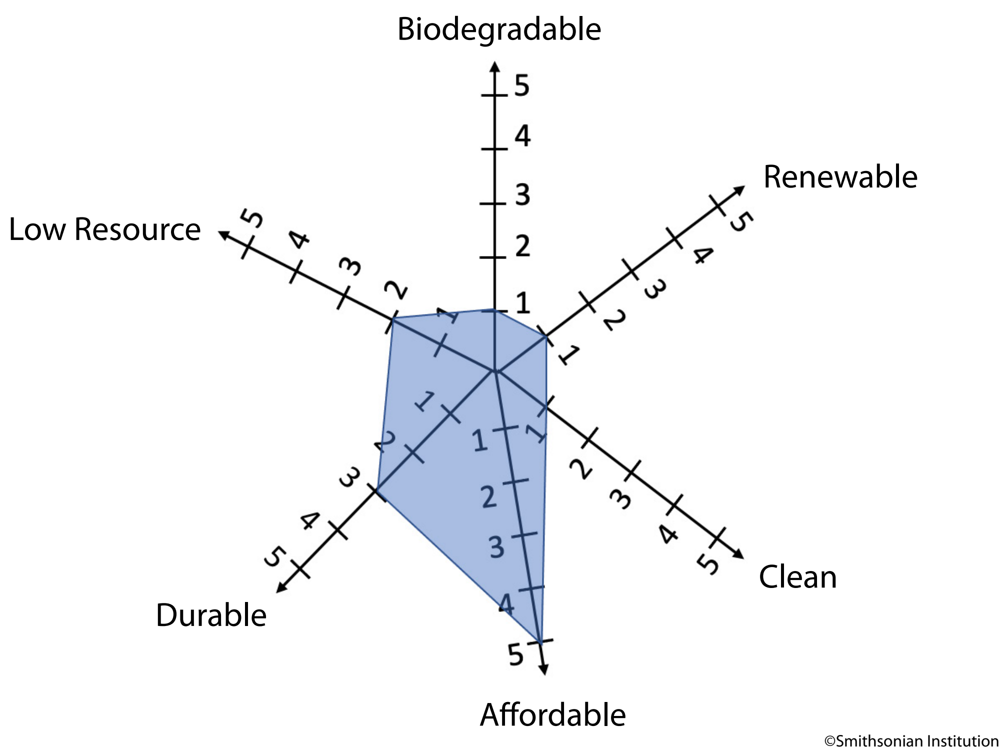


Figure 3-3: Example of a typical plastic water bottle's sustainability profile.

8. Think quietly to yourself: Can you think of a material that might have a better sustainability profile than a plastic bottle?
9. Read *Materials and Sustainability Search Instructions* and carry out the instructions on your own.

Materials and Sustainability Search Instructions

Location

Move around your classroom, your school, home, or the space where you are learning.

Materials

Search for items that are in the categories you listed in step 2. For example, maybe you find a wooden table in your classroom or the sidewalk outside your home is made of concrete. Pick one item to investigate.

Decide on sustainability

Create a new *Sustainability Profile* chart like the one shown in Figure 3-1. Label the chart with the name of your item. Examine your item. For each characteristic on the sustainability profile, decide on a number between 1 (very bad) and 5 (very good) for your item and plot the number on the chart. If you are not sure, you can use the Internet, the library, or another source to help you decide. If you cannot find out the information, just take your best guess. When you have finished, connect the numbers.

10. Share your *Sustainability Profile* chart with your team.
11. Examine your teammates' sustainability profiles. What do you notice?
12. As a team, discuss:
    a. What were the most and least sustainable materials you found?
    b. What often made materials not sustainable? For example, was it that they were not biodegradable or were not reusable or were made from materials that were not renewable?

***Understand:** How could biotechnology help create more sustainable materials?*

Creating more sustainable materials is important. Biotechnology can help with this process. Sometimes biotechnology can help by using living things to create items we need. Sometimes biotechnology can help by recycling waste products into usable materials. Sometimes biotechnology can help create and use proteins called **enzymes**, which speed up and encourage specific chemical reactions. In this task you will learn more about how biotechnology can help make plastics more sustainable. Then you will think about how biotechnology can change the sustainability profile of other materials.

1. Examine your *Sustainability Profile* for the plastic water bottle from the Discover activity. Read each of the innovations Young shares and discuss with your team how the new technique might change the sustainability profile of the plastic bottle.

Young says . . .

You may be familiar with poly-lactic acid (PLA). It is one of the most common bioplastics. To create PLA, you have cornstarch or another food source for bacteria, bacteria eat it, and produce lactic acid. Then we polymerize the lactic acid and get PLA plastic. PLA is biobased and **compostable** in some situations.

   a. As Young explained, scientists have created polymers using materials such as cornstarch and the waste from sugarcane. These are sometimes called **bioplastics**. How would using cornstarch or sugarcane waste to create the materials used to make the plastic change the sustainability profile of a plastic bottle?

Part 3 Task 1

Young says . . .

We have another type of plastic called PHA that is biodegradable in the ocean. This is important because although PLA is sometimes compostable, it does not biodegrade in the ocean and we know a lot of plastic ends up in the ocean.

b. How would the ability to biodegrade in the ocean change the sustainability profile of a plastic bottle?

Young says . . .

There is also the question of what the bacteria are eating as they produce the chemicals to make bioplastic. For example, some scientists are engineering bacteria so they will eat waste plastic and then produce the chemicals needed to make ocean-biodegradable plastic.

c. If producing an ocean-biodegradable plastic could decrease the amount of plastic waste, as Young describes, how would that change the sustainability profile of a plastic bottle?

2. Use the *Bioplastic Instructions* to create your own bioplastic.

Bioplastic Instructions

Materials to gather

- Microwave-safe or heat-safe container
- 15 g (1 tablespoon) cornstarch (also called corn flour)
- 4 drops cooking oil
- Pipette or eyedropper (optional, you can also use your finger)
- 22 g (1.5 tablespoons) water
- Food coloring (optional)

- Spoon
- Microwave or other heat source, such as a stovetop

Steps to follow

a. Put the cornstarch in a microwave-safe or heat-safe container.
b. Add four drops of cooking oil using a pipette or eyedropper, or letting the drops fall off the tip of your finger.
c. Add the water.
d. Add the food coloring (optional).
e. Use the spoon to stir until the mixture is smooth.
f. Heat in the microwave on medium heat for 30 to 90 seconds. Check it after every 30 seconds. Your bioplastic should be clearer and dry to the touch. The thicker the bioplastic, the longer it will take in the microwave.
g. If you are using a stovetop, stir the bioplastic over low heat until it turns clearer and becomes thick.
h. Your container now has a flexible bioplastic! Wait until it cools a little bit and then remove it from the container. If you want it in a particular shape, mold it into that shape and leave it to cool completely.
i. If you want more plastic, use the same proportions and increase the amount of each ingredient.

Figure 3-4: An example of homemade bioplastic.

⚠ Physical Safety Tip

Materials heated in the microwave can be hot! Be careful as you remove your bioplastic from the microwave and wait for it to cool before you touch it.

More about bioplastics

- This plastic can be molded into many different shapes.
- It is biodegradable; if you buried it in the soil or put it in a composter, it would decompose.
- Although your homemade bioplastic may be fragile, scientists are able to make bioplastic that is quite durable, just like the plastic you are used to.

For other bioplastic recipes and more about bioplastic production, visit the *Biotechnology!* StoryMap.

3. Discuss with your team:
   a. What went well with making bioplastic?
   b. What was a challenge?
   c. What types of things would need to change for bioplastics to be used more commonly?
4. Recall the categories of materials from the Discover activity. You have already thought about plastic in packaging materials. What other types of sustainability issues with materials can biotechnology help solve? The charts in Figures 3-5 through 3-8 show sustainability profiles for a common material in each category you considered in step 2 of the Discover activity. Examine each sustainability profile carefully. Does anything concern you? What do you wish would change?

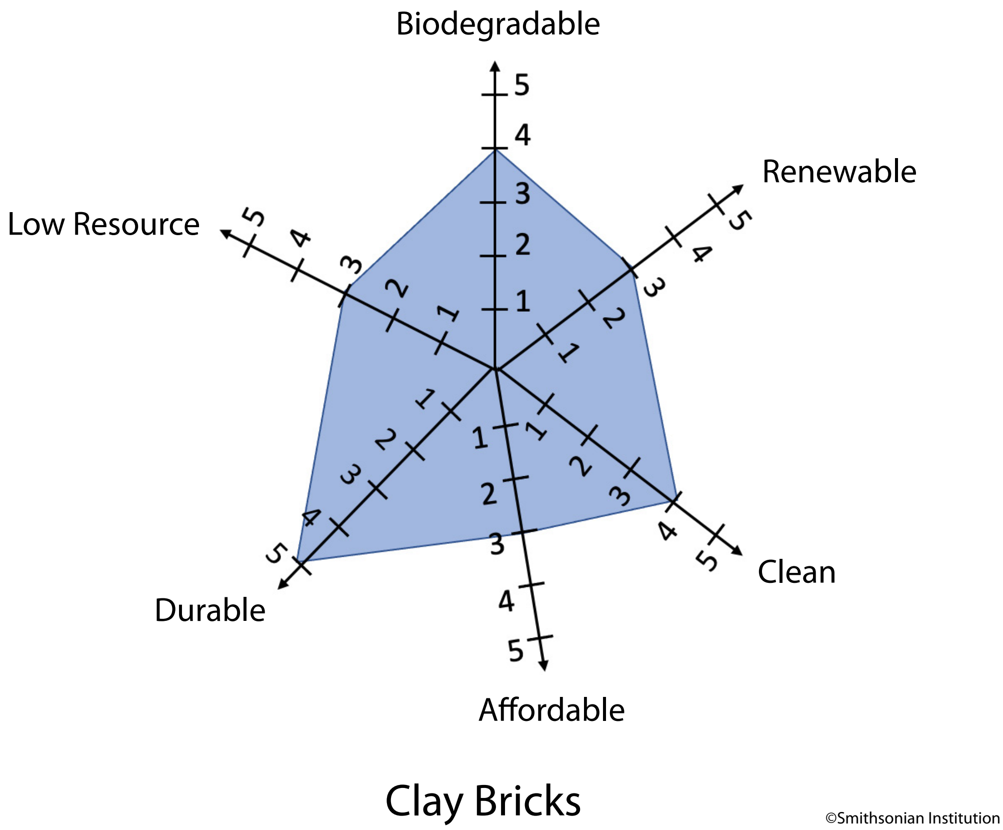


Figure 3-5: Sustainability profile of clay bricks.

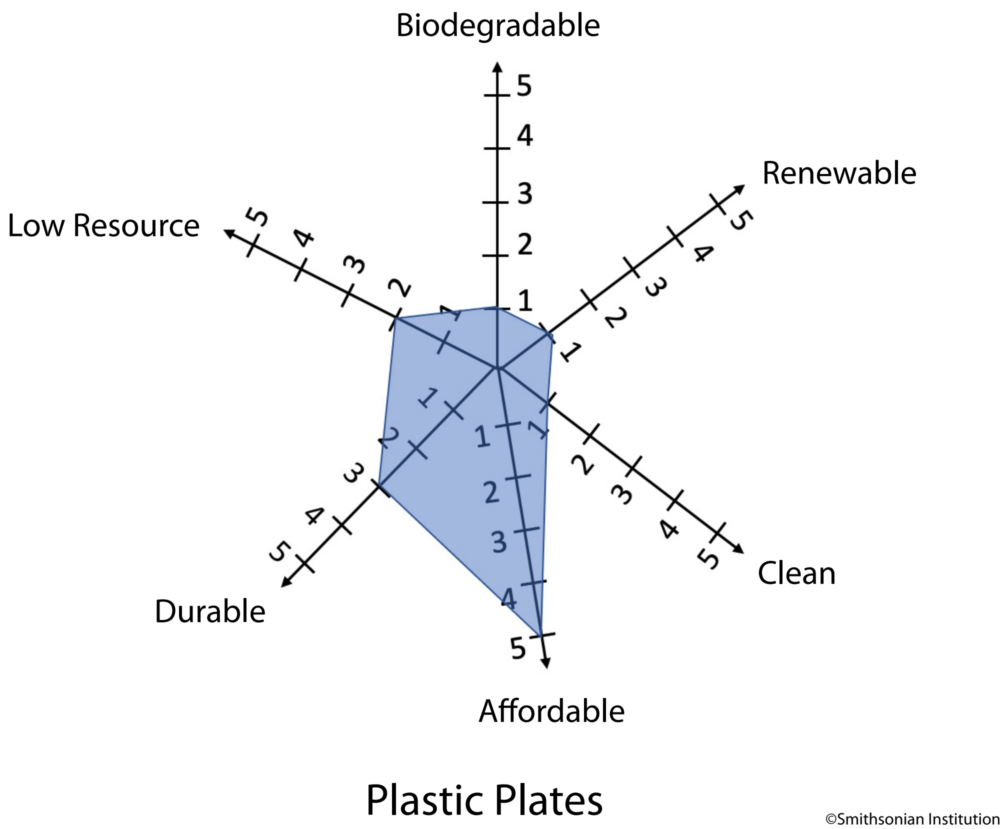


Figure 3-6: Sustainability profile of plastic plates.

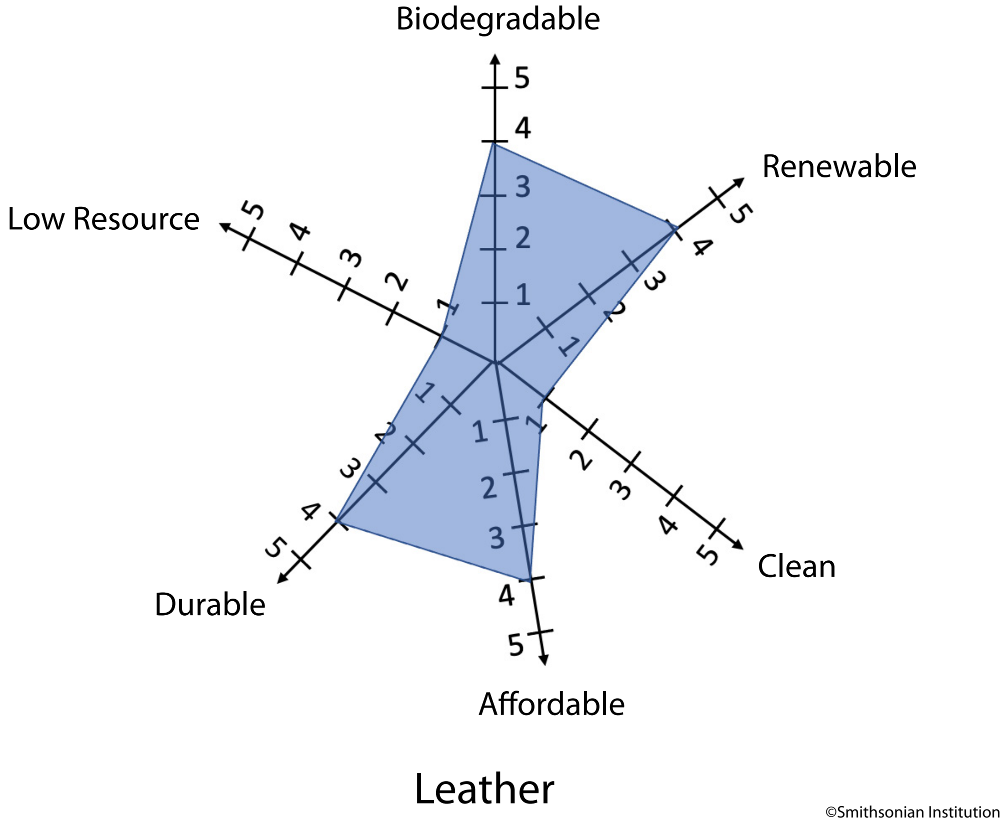


Figure 3-7: Sustainability profile of leather.

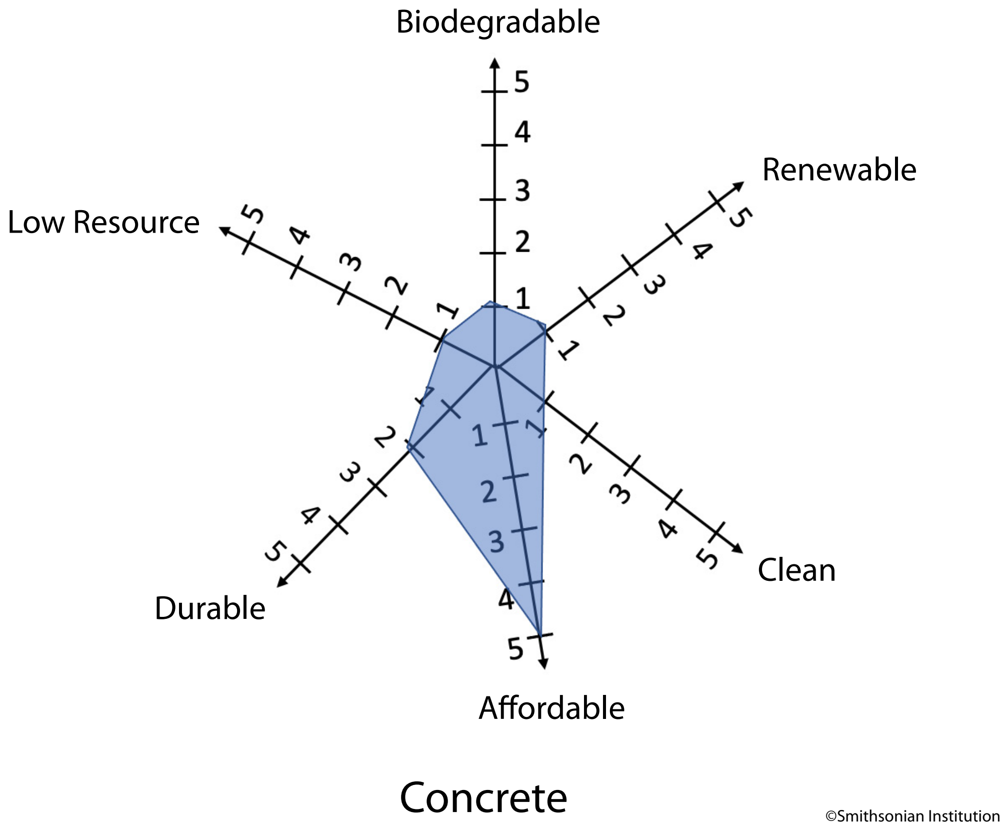


Figure 3-8: Sustainability profile of concrete.

5. Read *Sustainable Material Innovations*. For each innovation, match it with an existing material from Figures 3-5 through 3-8. How do you think the innovation changes the sustainability profile of the existing material?

Sustainable Material Innovations

Self-healing concrete has bacteria embedded into the concrete. These bacteria can create concrete-like structures. So if a crack develops in the concrete, the bacteria will react to the air and water in the crack and fill it. This means the concrete can last much longer without having to be replaced.

Mango leather is made from mango waste. It does not need the toxic chemicals used when making leather from cow hide. Mango leather avoids the greenhouse gases and deforestation caused by the cattle farming that is necessary to produce the cow hides.

Figure3-9: Leather made from mango waste.

Mushroom bricks are grown from fungi. They can grow into many different shapes and do not need high heat and energy to fire them, unlike clay bricks. When they are no longer being used, they can easily biodegrade.

Part 3 Task 1

Figure 3-10: Stacked mushroom bricks.

Sugarcane plates can be made out of sugarcane waste. Sugarcane plates biodegrade in only three months, but plastic plates can take hundreds of years to biodegrade. Unlike the need to **extract** oil or gas from the Earth, sugarcane plates are produced from a waste produce of sugar production.

6. Discuss with your team:
    a. Which material out of the ones you have explored seems most exciting to you?

Act: *How should we use biomaterials?*

Many people would like to use sustainable materials, but there are reasons they are not able to do so. In this activity you will decide what aspects of sustainability you think are most important for materials. You will consider whether there are **ethical** concerns about using some of the new materials created using biotechnology. Then you will craft a message to share about the material you want others to use.

1. Think about the new, more sustainable materials you learned about in the Understand activity. Pick the material that excited you the most. Sometimes even

though a material can seem sustainable from one perspective, it can create a problem from another perspective. Are there concerns about this material you can think of from one of the four perspectives? Discuss with your team concerns from different perspectives for each of the materials.

a. From a **social** perspective, is using the less sustainable material an important part of your culture or part of keeping people healthy?

b. From an **economic** perspective, is the new material more expensive to produce? Could it be produced using existing production facilities, like factories?

c. From an **environmental** perspective, is there an impact on wildlife or the atmosphere created by using the new material? For example, maybe farming mushrooms, mangoes, or sugarcane to use in sustainable materials will take land away from wild areas or will use a lot of pesticides.

d. From an ethical perspective, will using this material make things more unfair, such as by increasing inequality between people?

2. Examine the *Sustainability Profile* chart shown in Figure 3-1. Think quietly to yourself: Do you think all characteristics of a sustainability profile are equally valuable or are some more important? If you think some are more important, which ones?

3. Discuss your ideas with your teams and try to come to **consensus** on the material you would be most excited to share information about with the rest of your community. Consensus is not competing to win or lose. Coming to consensus means working together to find a balanced decision that works for everyone.

   a. Are there certain perspectives you think are really important to consider?

   b. Are there some sustainability profile characteristics that everyone thinks are important?

   c. If people disagree, think back to your identity map and what you learned about perspectives. How is your opinion related to your identity and past experiences?

4. With your team, think about what made you start using new or different materials in the past. Could you be part of changing how other people are using materials?

5. Develop a way to communicate about the material your team agreed on with others in your community. For example:
   a. Could you start using this material yourself and become an example to others?
   b. Can you create this material yourself and show others?
   c. Could you gather information and create an infographic to help people understand why this material is a better choice?
   d. Is there another way you would like to communicate?
6. Decide what you will do. Make sure your plan can include everyone on your team.
7. Use your communication technique to share information about the material you chose with your community.

Task 2: Can we create the materials we need using cells and biotechnology?

Imagine a world in which you could create the materials you need using biotechnology. A world where engineered yeast and bacteria become the new factories, where people needing a heart transplant receive a heart printed out of their own cells. In this task you will ***discover*** more about your connection to ways scientists are already using living things to create new products. Then you will investigate to ***understand*** how advances in using human cells for bioprinting are creating new opportunities. Finally, you will consider the possibilities and ***act*** to create the future you want.

Discover: *Could cells become the new factories?*

You learned in Part 1 how biotechnology has used **microorganisms** like yeast and bacteria to create things like bread and yogurt. Those microorganisms use their natural processes to produce carbon dioxide that makes bread rise or the lactic acid that makes yogurt sour. However, what if you were able to change the natural processes of microorganisms to produce different materials? Scientists are creating whole new processes to create materials using biotechnology tools, like **CRISPR**. Scientists now also have the ability to create entirely new sequences of **DNA**, known as **synthetic DNA**.

1. Remember, a material is any substance that makes up an object. If you think about it, your body is composed of materials. With a partner, think about some of the materials that are part of your body—for example, your hair, nails, bones, or stomach acid. Discuss with each other:
    a. Where do these materials come from?
    b. How are cells involved in making materials in your body?
    c. Are cells sometimes part of the materials themselves?
    d. Can you think of any materials produced by cells in other living things?
2. Read *The Many Functions of the Cell*.

The Many Functions of the Cell

Cells are the original production facilities. Each cell is busy, from tiny single-celled organisms like bacteria and algae to each one of the massive number of cells in a multicellular organism like a whale or a redwood tree. Cells use the instructions found in DNA to carry out many activities, such as:

- Producing materials
- Processing waste
- Using energy from the sun to create sugar from water and carbon dioxide in a process called photosynthesis, which removes carbon from the air and releases oxygen
- Growing and dividing

Cells produce many things and perform functions that are useful to themselves and the organisms of which they are a part.

People have used existing products and processes from cells for thousands of years, like when fermenting foods and creating beer, as you learned in Part 1. We use these existing products and functions to fill some of our needs. But we have always been limited by what the DNA in cells naturally produces or does. We fill other needs using chemical processes.

However, we now have an easy-to-use set of tools to edit DNA. Using CRISPR or other biotechnology tools, we can change the DNA in cells to have a different or additional set of instructions that will tell the cells to do different things.

3. With your partner, think together of what types of materials you wish cells could be modified to make. For example:
   a. Materials that might replace ones that are not sustainable
   b. Materials that are currently difficult or expensive to find or produce
   c. Natural materials that can not or should not be harvested from nature

4. Use drawings or words to capture your ideas and share with the rest of your team.
5. Read *Biotransformation and Design*.

Biotransformation and Design

When a cell makes a material, there are often several steps involved. Material A is transformed into Material B, which is transformed into Material C. This process is called **biotransformation**.

Biotransformation often uses enzymes to transform one material into another. For example, in plants the biotransformation process of photosynthesis uses certain enzymes to transform carbon dioxide and water into sugar.

When scientists want to use a living thing to make a material, they need to design the biotransformative pathway. They figure out the steps to create the material they want and what enzymes are needed. Each enzyme is coded for by a specific **gene** within the DNA. Scientists can find or even create a gene to code for each enzyme they need, and insert that gene into the cell they are using.

6. Now you will have an opportunity to become a bioengineer and design your own biotransformative pathway. Here are some details:
   a. Your goal is to make artemisinic acid. Artemisinic acid can be used to make the best treatment we have for malaria. It occurs naturally in a plant, but in very small amounts, so it is expensive. As a bioengineer, you would like to make artemisinic acid easier to make so it becomes cheaper.
   b. You can do this by inserting genes for different enzymes into your cell. If the cell has all the right genes for specific enzymes, it can transform a molecule called FPP into artemisinic acid.
   c. Right now you have FPP, Material A.
   d. You want to get artemisinic acid, Material E.
   e. There are four intermediate steps.

f. Use the chart in Figure 3-11 to design which enzymes you will use to get from Material A (FPP) to Material E (artemisinic acid).

g. You can use any of the enzymes in your enzyme library in Figure 3-12, but you will not need to use them all. Use Figure 3-11 to fill in which enzymes and materials you need to use, in which order.

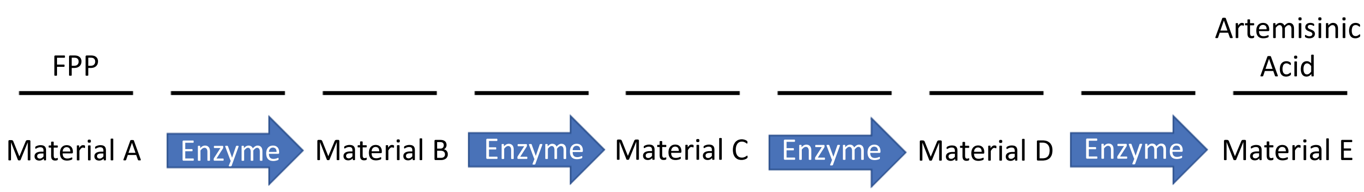


Figure 3-11: The biotransformative pathway from FPP to artemisinic acid.

Enzymes	Materials	
	Takes in (or converts)	**Puts out (or produces)**
AaALDH1	Artemisinic aldehyde	Artemisinic acid
CYP71AV1	Amorphadiene	Artemisinic alcohol
CY3A4	HPTP	HPP+
ADS	FPP	Amorphadiene
Lactate dehydrogenase	Pyruvate	Lactate
AaADH1	Artemisinic alcohol	Artemisinic aldehyde

Figure 3-12: Enzyme library.

7. Compare your answers to your teammates'. Did everyone design the same pathway? Use Figure 3-13 to check your answers.

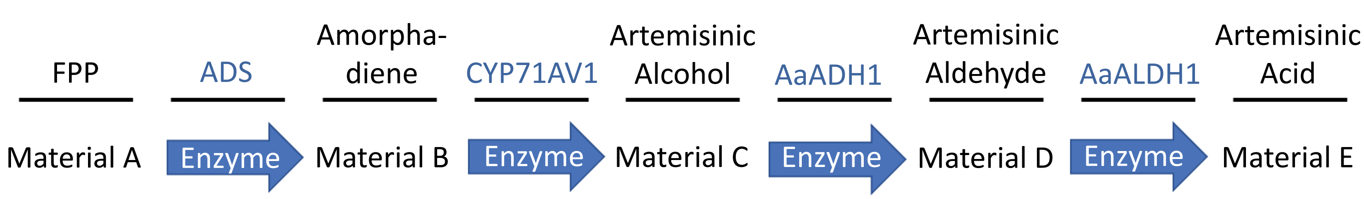


Figure 3-13: Correct biotransformative pathway from FPP to artemisinic acid.

8. Right now, scientists around the world are working on developing different biotransformative pathways to create different products. Many pharmaceuticals, flavorings, fragrances, new bioplastics, and parts of beauty products are already being produced this way. What do you think will be next?

Understand: *Could we print organs using cells?*

Cells can produce amazing things all by themselves. However, in a multicellular organism, like a human, cells do not work alone. They group together with other cells of the same type to form **tissues**, such as muscle or nerve tissues. Different tissues combine to form **organs**, such as the heart, lungs, skin, and liver. Organs are more complex and generally are very important to the body.

1. Think quietly to yourself about the organs you know you have. The things you may think of as "parts of the body" like your brain, kidney, and lungs are all organs.
   a. Why do you think each organ is important?
   b. What would your life be like if one of your organs was damaged or destroyed?
   c. If your organ fails or is no longer working, right now the best thing to do is replace it. Starting in the 1950s, doctors have been doing **transplants**—taking an organ or part of an organ out of one person and putting it into another person. How many organs do you think were transplanted worldwide in 2020? Share your guess with your team.
2. Discuss with your team: In 2020 there were 129,681 transplants performed around the world. However, many people needed a transplant who could not get one. What can you think of that might prevent someone from getting a transplant?
3. Examine the chart of organ transplants in the United States in 2021, shown in Figure 3-14. Discuss with your team:
   a. What problem do you notice?
   b. Can you think of anything that would help fix the problem?
   c. What questions do you have?

⚠ Emotional Safety Tip

You may know someone waiting for an organ transplant and it can be upsetting to think about how long they may need to wait. If you need to pause or take a break, that's okay.

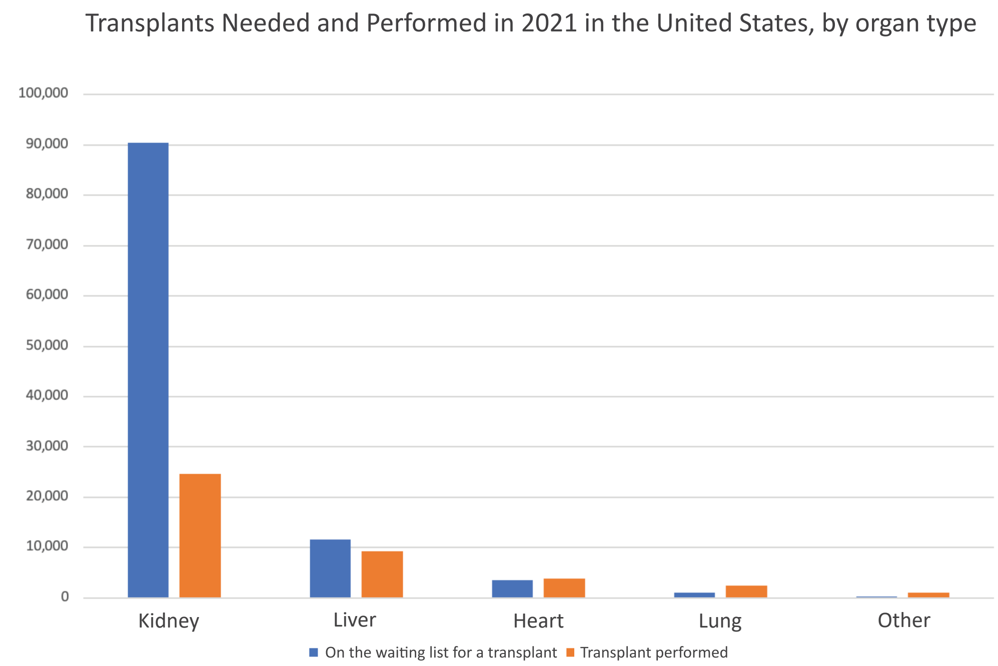


Figure 3-14: Transplants needed and performed in 2021 in the United States, by organ type.[1]

4. What is the transplant situation like in your country? Do people have to wait a long time before they receive a transplant? Do they have to travel to another place to receive a transplant? Which organ is transplanted most often? If you want to explore more about types of transplants or wait times in your country, you can use the *Biotechnology!* StoryMap.
5. Think to yourself: Imagine if people who needed organs did not need to get them from someone else. What if the organs could be grown from their own cells? How do you think that could change the situation shown in Figure 3-14?
6. Now consider quietly: Another problem with transplants is that your body's immune system reacts to cells from other people and sometimes can attack transplanted organs. How would this situation change if organs could be grown from your own cells?

Part 3 Task 2

7. With your team, use a board, a piece of paper, or another way of recording your ideas.
    a. If you were a team of scientists trying to grow organs from cells, what kind of challenges do you think you would face?
    b. Why do you think it might it be better to use tissue from the living thing to replace organs, rather than another material like a metal or plastic?
8. Read *Cell Culture*.

Cell Culture

Before you can get the cells in tissues to grow in specific ways, such as to form an organ, first you need them to grow!

In the early 1950s, scientists were working hard to find ways to **culture** human cells. A cell culture means growing cells outside the body in a lab. There are many challenges when culturing human cells. Usually human cells have nutrients, molecules, and oxygen provided by the rest of the body. It was difficult to replace these things and keep human cells growing for a long time outside the body.

Scientists were struggling to keep human cell cultures alive, until they got a sample of cancerous cells from Henrietta Lacks, an African American woman living in Baltimore, in the United States. Doctors collected the cell sample to diagnose Henrietta, but they also sent some of the sample to a scientist trying to culture cells. However, the doctors and researchers did not even ask Henrietta's permission to culture her cells or tell her they would use them for research!

Henrietta's cells did well in the laboratory. They kept living and dividing. They became the first immortal human **cell line**, known as HeLa cells. HeLa cells are still used by scientists today, more than 70 years after they were taken from Henrietta. Many medical advances, from polio vaccines to artificial insemination, used HeLa cells in their development. Companies have used research conducted on HeLa cells to create profitable products and techniques. However, the money these companies made was not shared with Henrietta or her family. You can find out more about Henrietta Lacks and her story in the *Biotechnology!* StoryMap.

⚠ Emotional Safety Tip

It may make you feel sad or angry that Henrietta Lacks had her cells used without her consent. It is okay to have these feelings. Sometimes when you feel sad or angry it can be a good way of noticing things you think are unjust and need to change.

Scientists now have found out a lot about growing cells. They can now grow cells that were taken from your own body. This means a tissue culture in your body could be used to test things specific to you. For example, your tissue culture could be tested with certain treatments to see how the tissues in your body would react. Since each person is unique, this might help to match the right treatment to the right person. It also could allow new treatments to be tested on a tissue culture rather than on animals.

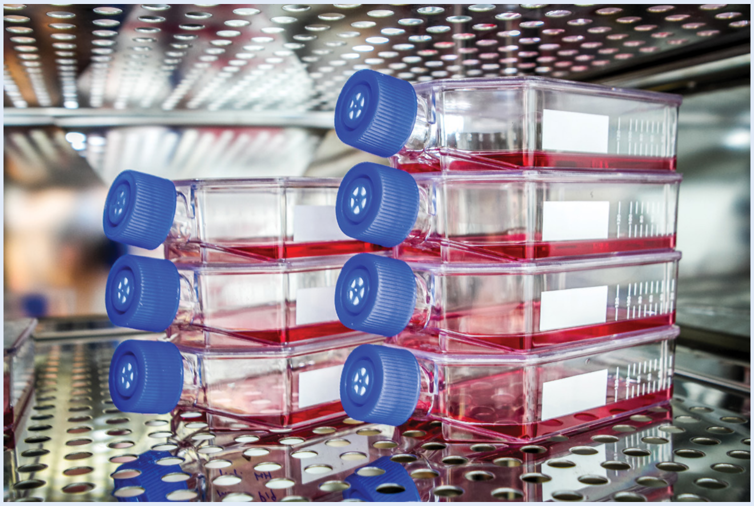


Figure 3-15: Tissue culture flasks in a laboratory.

Culturing tissues from your body is also an important step when using those tissues to form an organ, if you need one. Scientists are now beginning to use cells from tissue cultures in **3-D bioprinting**. You will find out more about that in the next model experiment.

9. One of the methods scientists are using to make tissues now is 3-D bioprinting. Discuss with your team:
    a. Have you ever been around a 3-D printer? Do you know how it works?
    b. Most 3-D printers lay down materials such as plastics in thin layers, slowly building up the item over time. How do think this could work with cells?
10. Read *Modeling 3-D Bioprinting* and follow the instructions.

Modeling 3-D Bioprinting

Scientists are still working on how to 3-D print organs. In this activity you will be using materials to help you understand how this process might work.

Materials

Circular sprinkles (nonpareils), couscous, sand, or other small, round granules: These represent the cells that are printed into tissue. The cells are mixed with the bioink and go through the nozzle to create the 3-D printed organ. Often, the cells come from the patient themselves! Other times, they come from a donor. Either way, a few collected cells are cultured to produce the high number required for tissue printing.

Peanut butter, toothpaste, or a gel-like material of similar consistency: This material will represent the bioink. Bioink is a gel that contains water, polymers, and often other materials to help the printed object keep its shape.

Sandwich or plastic bags: You can use any thicker plastic bag, but one that seals might work best. The tip of the bag will represent the nozzle of a 3-D bioprinter. The nozzle is where the bioink comes out.

Instructions

a. Draw a kidney shape on a piece of paper or paper plate. Figure 3-16 has an example of what a kidney shape is. Remember Figure 3-14 and the need for kidneys to transplant? You will be modeling what it might be like to 3-D print a kidney.
b. To prepare your materials, add your cells (round granules) into your bioink (gel material).

c. Load your bioink and cell mixture into the bag. You're modeling loading the cell-containing bioink into a 3-D bioprinter.

d. Cut a very small hole in one corner of your sandwich bag. It should be only a few millimeters wide. This represents the nozzle of a 3-D bioprinter, so only a thin stream of bioink should be able to come out.

e. Plan how you will create the kidney, keeping in mind that 3-D bioprinters deposit ink layer by layer. You may find it helpful to draw a sketch of the layers you plan to print. Figure 3-16 shows an example.

Figure 3-16: Sample model of the 3-D bioprinted kidney activity.

f. Use your loaded sandwich bag to print your organ! Remember to work in layers, from bottom to top.

11. Discuss with a partner:
    a. What went well with trying to create your 3-D printed kidney model?
    b. What was difficult about the materials you were using?
    c. What do you think the challenges would be with developing the materials used for actual 3-D bioprinting with real cells?
    d. How would creating a real kidney using 3-D printing be different from the modeling activity?

⚠ Emotional Safety Tip

Scientists are working on how to 3-D bioprint kidneys and other organs, but they have not yet succeeded with this goal. Every day they are learning more, but if you know someone who needs a new organ, you may feel impatient for this scientific process to progress. It okay to feel frustrated, angry, or sad. Pause and take a break if you need to.

12. Read *Bioprinting Challenge* and follow the instructions.

Bioprinting Challenge

Prepare

If you want, you can print out and cut up one copy of the Organ Cards from Figure 3-17 and four of the Challenge Cards from Figure 3-18. Or you can just examine the cards. If you do not print them, you will need a way to record the scores for the Challenge Cards.

Instructions

a. Gather in a circle with up to four teammates. You will be exploring some of the other challenges scientists face when trying to use 3-D bioprinting to create organs.

b. Each Organ Card describes three types of challenges:
   - Cell types: how many different types of cells are part of the organ
   - Structure: how big or complex the organ is
   - Blood vessels: getting blood into and out of the organ to keep all the cells alive and healthy (**arteries** carry blood to an organ, **veins** carry it away)

c. Have one person pick an Organ Card from Figure 3-17 or the pile of printed cards. The card will give you a profile of a commonly transplanted organ.

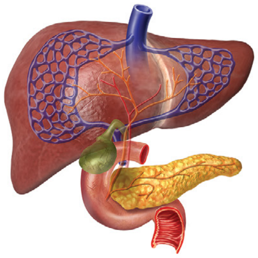
Organ Card: Kidney

Cell types: More than 20 cell types

Structure: Around 10 to 12 cm in adults and contains about 1 million mini filtering units

Blood vessels: Kidneys have large arteries the branch into smaller arteries. They contain many blood vessels.

Organ Card: Liver

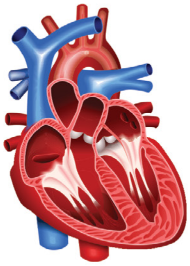


Cell types: 4 cell types

Structure: Around 14 cm in diameter, split into two main parts; each part contains around 8,000 smaller areas

Blood vessels: A large vein drains blood out of the liver. It does not contain many small blood vessels.

Organ Card: Heart



Cell types: 4 major cell types

Structure: Around the size of a fist, divided into four chambers; each chamber is surrounded by a muscular wall

Blood vessels: Blood is pumped through each of the four chambers, as well as through branching arteries and veins.

Organ Card: Lung

Cell types: More than 40 cell types

Structure: The main entrance branches into two areas, each of which divide many times into tiny sections

Blood vessels: Lungs are covered with arteries and veins that branch into many smaller blood vessels.

Figure 3-17: Organ Cards.

d. Fill in a Challenge Card based on the information on the Organ Card. For each category, assign a difficulty score from 1 (not a difficult challenge for this organ) to 5 (a very difficult challenge for this organ). Add the three scores to get the overall difficulty score.

Challenge Card for: ____________ Difficulty score

Cell complexity:
Does this organ contain many different types of cells? ______

Structural complexity:
Is the organ structure complex? Is it large? ______

Blood vessels:
Would many blood vessels need to be printed? ______

Overall difficulty (add difficulty scores):

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Figure 3-18: Challenge Card.

e. Repeat for the remaining three organs. When you've assessed all four, rank them from most to least challenging, based on the overall difficulty scores you assigned on your Challenge Cards.
f. Discuss with your group: Were there challenges you did not expect?
g. Scientists are working to create bioprinted organs. What do you think will be the biggest challenge?
h. Do you think 3-D printed organs will be common one day?

Act: *When do you think cells should be used to create materials?*

There have been tremendous advances over the past decade in using cells in different ways. Companies are now using cells to produce pharmaceuticals, beauty products, flavorings, biodegradable plastic, and other materials. Scientists can currently print skin, bone, blood vessels, **corneas** (the outermost layer of the eye), ears and other cartilage, and even miniature, semi-functional versions of organs (including hearts, kidneys, and livers).

The technology is moving fast. In this activity however, your job is to slow down and think about any concerns you or others in your community might have about using any of these technologies. You can use this information to help your community think about these new technologies.

1. Take out your *Ethical Concerns List* from Part 1.
2. Consider what you learned about using cells in different ways during the Discover and Understand activities. Recent advances in biotechnology mean certain things that were impossible in the past may be possible or close to possible now. Just because things can be done does not mean they should be done. Does the use of biotransformation, cell culture, or bioprinting raise any of your ethical concerns?
3. Read *Five Whys Instructions*.

Five Whys Instructions

- Break into pairs.
- Sit facing your partner.
- Read out one of the prompts from step 4 and have one partner respond with how they feel about it.
- The other partner should ask them why.
- The first partner should respond with why they feel this way.
- Then the other partner should ask why about their explanation.
- Repeat until the other partner has asked "why" five times.

4. Use these prompts for your Five Whys exercise. For prompt, have one partner share their opinion about the following situations and have the other partner ask why.
   a. Tissues taken from animals such as cows, pigs, and chickens can be cultured, just like the tissue cultures you learned about in the Understand activity. The meat harvested from these tissue cultures is composed of the same type of cells as meat from the animal itself, but it is grown in a lab.
   b. Cells used to create products, such as the ones you learned about in the Discover activity, do not need to only be single-celled organisms like yeast or bacteria. Plants can be modified to make specific medicines, for example. These plants can be grown in large quantities on farms and then have the target product extracted.
   c. One scientist decided to change the DNA in human cells. Before birth, human DNA was modified to create a person more resistant to disease. Theoretically, modifications to DNA could create people who were stronger, faster, smarter, or any one of many **traits**.
   d. Producing materials that are more sustainable is important, but people also may need to shift to consuming fewer materials in general. Some people worry that if more sustainable materials become common, then people will not be motivated to change how much they consume.
5. Remember your *Futures Mood Board* from Part 1? Add to or create a new mood board about the use of cells to create things in the future.
   a. What are some amazing things that you hope might happen?
   b. What are some things that you are concerned might happen?
6. Pick one thing you think is either exciting or concerning. Tell another person about it. Do they share your perspective? Have a respectful conversation where you encourage them to think about why they think the way they do. What do they hope will happen with cells and biotechnology in the future?

Congratulations!

You have finished Part 3.

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.

3-D bioprinting: Using a printer to lay down cells and other related substances in layers to build up a tissue

Affordable: Inexpensive

Arteries: Blood vessels that carry blood to an organ

Biobased: Composed of materials from a living thing, such as a plant, fungus, or bacteria

Biodegradable: Able to break down relatively quickly in a natural environment

Biotransformation: The use of natural substances that include enzymes to speed up a desired chemical reaction

Bioplastic: A substance made from polymers of organic materials, as opposed to regular plastic materials, which are generally made from fossil fuels

Biotechnology: The use of biology, natural processes, and natural materials to solve problems and make technology

Cell line: A population of cells that can be grown and is uniform in its functionality and appearance

Clean: Adds only minimal greenhouse gases or other types of pollution to the natural environment

Compostable: Able to be easily and relatively quickly decomposed by living things such as bacteria, fungi, and worms in the soil

Consensus: A balanced agreement that works for everyone

Cornea: The outermost layer of the eye

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

Culture: The process of incubating or growing microorganisms in the laboratory; these can be microorganisms such as bacteria, or human, plant, or animal cells

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

Durable: Able to be reused many times or have materials be easily recycled

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

Environmental: About the natural world

Enzymes: A protein that helps speed up the process of a chemical reaction; an enzyme can be used over and over and is never used up

Ethical: The fairness of something

Extract: Pulling out a part from within a larger thing

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

Greenhouse gases: Gases such as carbon dioxide or methane that cause the atmosphere to get warmer

Low-resource: Made without needed a great deal of energy, water, or other natural resources

Material: Any substance that makes up an object

Microorganisms: Living things that are too small to see without magnification

Organs: Composed of tissues, organs are specialized to perform a particular function; for example, the heart is specialized to pump oxygenated blood to the rest of the body

Polymer: A chemical compound made of repeating molecular building blocks called monomers

Refine: To eat and distill a substance, such as crude oil, to separate it into purer parts

Renewable: Easily replenished

Social: Relating to the interaction of people in a community

Sustainable: The ability to conserve natural resources and not result in a negative impact on the environment

Synthetic DNA: Entirely new DNA that does not exist naturally in nature and has been created by humans

Tissues: A group of cells with similar structure and function that make a larger subunit

Traits: Characteristics

Transplants: The transfer of a healthy organ from one person into another person whose organ has failed or was injured

Veins: Blood vessels that carry blood away from an organ

End Note

1. Health Resources & Services Administration. 2022. *Figure 1: Patients on the waiting List vs. Transplants Performed by Organ (2021)*. Data collected February 2022. Retrieved from https://www.organdonor.gov/learn/organ-donation-statistics/detailed-description#fig1.

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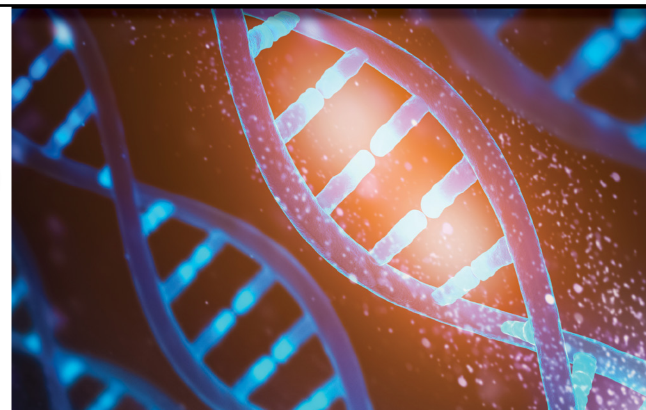

Part 4:

Biotechnology and Human Health

SUSTAINABLE DEVELOPMENT GOALS

developed by

Smithsonian
Science Education Center

in collaboration with

iap SCIENCE HEALTH POLICY
the interacademy partnership

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PART 4: BIOTECHNOLOGY AND HUMAN HEALTH

Part 4

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: How can we diagnose diseases using biotechnology?					
Discover	Explore what you know about diagnosing disease and how this relates to genetic variants.			20 minutes	135
Understand	Determine which disease is causing a patient's symptoms and identify the genetic variant. Consider the risks of genetic diseases related to ancestry.			30 minutes	141
Act	Take on the role of genetic counselor and share with others ethical and personal considerations related to genetic testing.		*Ethical Concerns List* (Part 1)	20 minutes	145
Task 2: How can we fix genetic diseases using biotechnology?					
Discover	Consider what you know about disease treatment. Use an analogy to explore the stages of diagnosis, design, and delivery of gene therapy.	• Paper or class board • Pens or pencils		20 minutes	150
Understand	Model gene therapy options and investigate ongoing gene therapy clinical trials.	• Paper • Pens or pencils		30 minutes	154
Act	Develop a communication plan to share more about the diagnosis, design, and delivery of gene therapy with your community.		*Futures Mood Board* (Part 1) *Ethical Concerns List* (Part 1)	20 minutes + action time	160

Task 1: How can we diagnose diseases using biotechnology?

Knowing the cause of a medical problem can be an important step in figuring out how to treat or cure it. In this task, you will ***discover*** more about the way **biotechnology** is used to help **diagnose** or identify a disease. You will ***understand*** how diagnosing disease works by modeling how diseases can be detected using genetic data. Finally, you will ***act*** on this information and consider when genetic diseases should be diagnosed.

Meet Your Research Mentor

Meet Dr. Filippo Pinto e Vairo. Filippo (pronounced FIH-lee-po) is one of the many researchers around the world trying to use biotechnology to improve human health and create a healthier future. As action researchers you are also trying to improve health in the future. Filippo will be your research mentor to help you understand more about the role biotechnology can play in diagnosing disease.

Filippo is a clinical geneticist and associate professor at the Mayo Clinic in Minnesota, United States. He has a master's degree in medical sciences and a PhD in genetics and molecular biology, and completed a postdoctoral fellowship in individualized medicine as well as a specialization in data science. However, he also has knowledge and perspectives that came from other parts of his identity. Since Filippo is now working with you, it is important to understand who he is.

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

- Physician for 15 years, geneticist for 12 years
- Huge sports (of any kind) fan
- Enjoys walking, loves traveling
- Lives in Rochester, Minnesota, USA
- Born in north Brazil, but lived for 30 years in south Brazil
- 39 years old

Part 4 Task 1

- Male and uses he/his/him pronouns
- Black hair ("When I had it!"), black eyes, average height
- Optimistic, good-tempered, curious
- Speaks Portuguese, English, a little Spanish, and French
- Interested in genomic and translational medicine
- Life goal: help diagnose individuals with undiagnosed diseases using state-of-the-art technologies
- Father of a unique, wonderful daughter
- Son of a physician and a lawyer

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

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

Throughout this task you will notice Filippo 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 do I know about diagnosing disease?*

You may think diagnosing diseases is something only doctors do, but really many of us diagnose common diseases all the time. In this part we will be talking about two different types of diseases.

One type is **infectious disease**, which means you catch a disease from someone or something. Viruses and bacteria are two common types of microorganisms that can cause infectious disease. For example, when someone who is infected with a virus coughs, sometimes that cough pushes small pieces of virus out of their body and into the air, and someone else can be infected by breathing in those small pieces.

Another type of disease is **genetic disease**. Genetic disease occurs when a **variation** within a person's **genome** causes the disease. You cannot catch a genetic disease.

Sometimes you **inherit**, or are born with, the genetic variation that causes the disease. One example of an inherited genetic disease is sickle cell disease. Sometimes you **acquire**, or develop the genetic variation over time, as you grow and your cells divide. Cancer is one example of an acquired type of genetic disease.

1. Imagine you and your friends share a meal. Not long afterwards everyone who ate together begins to feel sick and starts vomiting. Would you have an idea of what might have caused the disease? If so, congratulations! You just made a possible diagnosis. It is very likely you all ate some food that had a harmful microorganism that your body wanted to get rid of, so you started vomiting. This is an example of an infectious disease.
2. Now think about another infectious disease, COVID-19. Share with your team what you know about COVID-19 **symptoms**, or signs that you might be sick. Which COVID-19 symptoms are you familiar with?
3. Many of the common symptoms of COVID-19 can also be caused by other infectious diseases. For example, many infectious diseases cause a runny nose, coughing, and fever. With your team, discuss, how you could find out for sure whether someone with these symptoms has COVID-19 or another illness.
4. After you have discussed how to diagnose someone with COVID-19 symptoms, read *Testing for COVID*.

Testing for COVID

There are two common types of tests to diagnose someone with COVID-19.

One is called an **antigen** test. The antigen test is often taken at home. Sometimes it is called a rapid test because it can give results in around 15 minutes. The COVID-19 virus has specific antigens, or proteins, that are unique to the virus. The COVID-19 antigen test contains a substance that reacts when the antigen is present. So if enough of the virus is in your body, it reacts with the substance in the test and often signals the presence of the antigen by turning a color. Figure 4-1 shows an example.

Figure 4-1: This is a positive antigen COVID-19 test. A line at the C (control) shows the test is working. A line at the T (test) shows the test is positive and the protein antigen of COVID-19 is present.

The other common COVID-19 test is called a **PCR** test. PCR is a biotechnology technique that creates many copies of existing genetic material. The PCR technique can be used in many ways. In the case of the COVID-19 PCR test, if the COVID-19 viral genetic materials are present, the PCR creates many copies, so they are easy to detect.

⚠ Emotional Safety Tip

The COVID-19 pandemic has affected people's health and lives. You may have been sick yourself or have had friends or family who were sick or died from COVID-19. Thinking about this may be upsetting. If you need to pause and take a break, that is okay.

5. Have you or someone else you know ever been tested for COVID -19? If you feel comfortable doing so, share that experience with your teammates.
   a. Which type of test do you think was used?
   b. Was it useful to have the results of the test? Why or why not?
   c. Have you ever known anyone who had trouble having their disease diagnosed?

Filippo says . . .

Diagnosis is so important. For example, if a newborn is very sick, it could be an infection. But it could be a genetic disease. And if you can diagnose this child, you can offer the right treatment, the right medicine, the right diet. You can save lives, and we are doing this. When you sequence the genome of a newborn that is ill in the intensive care unit, you find a genetic answer 50% to 60% of the time.

6. Read *Genetic Variation and Diseases*.

Genetic Variation and Diseases

As you read before, infectious diseases like COVID-19 are only one type of disease. Another type of disease is genetic. When cells grow and divide, the **DNA** in the cells is copied. During this copying process there is a chance of making errors. These errors may delete, insert, or change a portion of DNA. These errors are sometimes called **mutations**. These mutations create genetic **variants**, or **genes** with one or more differences from the original.

You inherit some genetic variants from your parents when you are born. You also continue to acquire genetic variants throughout your life as your DNA is copied when your cells divide. Other things can also cause mutations and genetic variants, like exposure to tobacco, certain chemicals, radiation, ultraviolet light, and certain viruses.

Not all mutations are harmful; many do not have any effect at all. Your body has many ways of identifying and getting rid of cells that do have harmful mutations.

However, sometimes people inherit DNA that has harmful variants. Often this matters more in some cells than in others. For example, in the genetic disease cystic fibrosis, the genetic variant is in all the person's cells, but is particularly harmful in cells in the lungs and intestines.

Part 4 Task 1

People also acquire harmful variants. If a cell that has harmful variants is not identified and removed by the body, it can continue to divide. This means all the cells that come from those cell divisions will almost always also have the harmful variants. This uncontrolled growth of cells with harmful variants is called cancer. Cancers usually start in one area of the body, like the liver, brain, or stomach.

⚠ Emotional Safety Tip

You or someone you care about may suffer from an inherited or acquired genetic disease. This is not your or their fault. It is okay to feel sad, frustrated, or upset. If you need to pause and take a break, that is okay.

Filippo says . . .

There is no such thing as a normal genome. Everyone has genetic variants when compared to a so-called **reference genome**. I am different from you in part because we have genetic variants. What clinicians and researchers do is to find out if there are specific genetic variants that are causing a patient's symptoms.

7. Now, with a partner, think about genetic disease. Often these diseases are caused by just one small variation in the base pair DNA sequence of a gene. For example, if an A base changes to a C base, this variation can create problems building the protein for which the gene usually codes. How could you diagnose this disease? Consider the biotechnology tools you have learned about here and in Part 1 (they are listed below). Pick the tool or tools you think might be useful to diagnose an inherited genetic disease. Explain to your partner how you think that might work.
    a. **Genome sequencing**, a tool that allows you to find out the order of all the DNA **bases** in the cell
    b. **CRISPR**, a tool that allows you to change specific parts of a DNA sequence in a cell

Part 4 Task 1

c. Antigen test, a tool that reacts to specific proteins

d. PCR test, a tool that makes lots of copies of a specific part of DNA

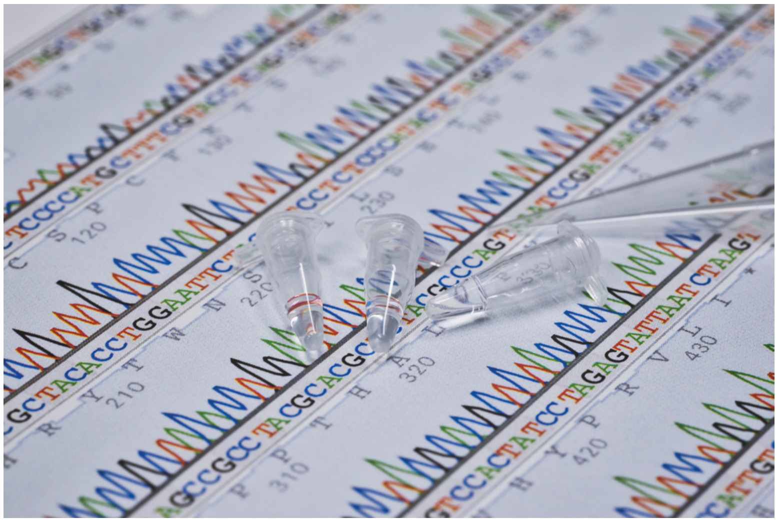

Figure 4-2: A genome sequencing result.

8. One common way genetic diseases are diagnosed is through genome sequencing. There are certain genetic variations that are known to be linked to genetic disease. If you have one of these variations and you have the symptoms of the disease, it is likely the genetic variation is causing the disease. As you learned in Part 1, genome sequencing is getting more inexpensive all the time. Discuss with your teammates:

   a. What are the advantages to having affordable and available genome sequencing?

   b. Are there any disadvantages?

Filippo says . . .

Many patients have been searching for a diagnosis for a long time. Even when you give them news that is not good, it can be helpful. They can get some closure. They can start to find other similar patients and think about their options. When you are in the dark [without a diagnosis] it is just difficult to do anything.

Understand: *How can biotechnology determine the specific causes of disease?*

Genome sequencing can help medical researchers find out more about whether a genetic disease is causing specific symptoms. Though everyone is born with dozens to hundreds of new variants, many of these variants do not create problems. But some specific variants of human genes have already been identified as often leading to disease. The difficulty is in determining which variants may be causing the symptoms of a genetic disease.

1. Clinicians and medical researchers are like disease detectives. They are trying to work backwards from the symptoms to the cause of a disease. Sometimes they can do this by looking at things people with specific symptoms have in common. One of the things people may have in common is the same genetic variant.
2. Read and follow the *Disease Detective Instructions* to become a disease detective yourself.

Disease Detective Instructions

These are the steps clinicians and medical researchers use when they are trying to find the cause of a disease.

a. **Examine the symptoms:** When searching for a genetic cause of a disease, the first thing researchers usually examine is a person's symptoms. If others have similar symptoms and a genetic cause is known, that genetic cause might be the first place to investigate.

b. **Decide which part of the genome to sequence:** If a specific genetic variation is suspected to be the cause of the disease, sometimes only one gene is sequenced. However, as genetic sequencing is becoming more affordable, researchers often will sequence a person's whole genome.

c. **Analyze the genome:** Researchers have created something called a reference genome using the most common DNA sequences they collected. They use computers to compare the DNA sequences of the patient with sequences from the reference genome. They analyze large amounts of data to identify variants. Variants can be due to several causes.

- Deletion: A variant can have one or more base pairs deleted. For example, if the reference sequence was ACTAGAG but the patient had the sequence AAGAG, the base pairs CT were deleted.
- Insertion: A variant can have one or more base pairs **inserted**, or added. For example, if the reference sequence was ACTAGAG and the patient had the sequence ATCTAGAG, the base pair T was inserted right after the first A.
- Substitution: A variant can have one or more base pairs substituted. For example, if the reference sequence was ACTAGAG and the patient had the sequence CCTAGAG, the base pair C was substituted for the first base pair A.

d. **Match the variant to the disease:** If other people in the population have the same variant and the same symptoms, that is a good clue that the variant may be causing the disease.

3. Now you can try to be a disease detective yourself, using the same steps.

> ⚠ **Emotional Safety Tip**
>
> There has been a lot of progress in diagnosing and treating genetic diseases, but still, if you know someone with one of these diseases you may be worried about them. Even if you don't know someone personally, learning about diseases can feel hard and scary. It is okay to pause and take a break if you need to.

4. Examine the symptoms: Use the clues in the following steps to help identify the cause of the patient's symptoms.
   a. Patient A symptoms: persistent coughing, frequent respiratory infections, wheezing, salty-tasting skin
5. Decide which part of the genome to sequence: Figure 4-3 shows four common genetic diseases and the genes that have been linked to those diseases. Which gene do you think you should sequence for Patient A?

Tay-Sachs Disease	Sickle Cell Disease
Symptoms: weakness, difficulty swallowing, loss of hearing or vision **Linked gene:** *HEXA* (hexosaminidase A)	**Symptoms:** anemia (lack of red blood cells), periods of pain, swelling of hands and feet, delayed growth **Linked gene:** *HBB* (hemoglobin-beta-locus)
Cystic Fibrosis	**Hemochromatosis**
Symptoms: frequent coughing and lung infections, shortness of breath and wheezing, poor growth, salty skin **Linked gene:** *CFTR* (cystic fibrosis transmembrance conductance regulator)	**Symptoms:** feeling tired, pain in joints, darkening of skin **Linked gene:** *HFE* (homeostatic iron regulator)

Figure 4-3: Symptoms and linked genes of four genetic diseases.

6. Analyze the genome: Let's assume you decided to sequence the CFTR gene that is linked with cystic fibrosis. The CFTR gene has almost 200,000 base pairs. A computer gives you another clue and identifies one place in the CFTR gene in Patient A that is variant, meaning it is different than the reference sequence.
   a. Can you find the variant in patient A? Remember, the variant could be a deletion of one or more base pairs, an insertion of one or more base pairs, or a substitution of one or more base pairs.

      Reference *CFTR* partial sequence: AAAATATCATCTTTGGTGTTT
      Patient A *CFTR* partial sequence: AAAATATCATTGGTGTTT

7. Match the variant to the disease: The CFTR gene codes for the CFTR protein, which is usually part of the cell membrane. The CFTR protein helps maintain the balance between salt and water within and outside of cells. There are many variants that can cause a problem with the CFTR protein, and those variants can cause cystic fibrosis. Figure 4-4 shows three common CFTR variants.
   a. Which variant do you think Patient A has?
   b. Would you diagnose Patient A with cystic fibrosis?

CFTR Variant Name	CFTR Variant Description
P.Phe508del	This variant is the deletion of three base pairs (CTT), which results in a protein missing one amino acid. This protein does not get properly folded and so is not usable.
P.Gly542*	This variant is caused by a substitution of a G for a T. This substitution stops the protein from adding the remaining amino acids and the protein is not usable.
p.Asn1303Lys	This variant is caused by the substitution of a C for a G. This changes the amino acid asparagine to the amino acid lysine. The stops the protein from functioning correctly.

Figure 4-4: Three common CFTR variants and their effects in the body.[1]

8. Read *Patient A Diagnosis* to find out if you diagnosed Patient A correctly.

Patient A Diagnosis

If you thought the symptoms of patient A matched the symptoms of cystic fibrosis and so you should test the CFTR gene, you are right.

The reference sequence had three base pairs (shown in bold) that were deleted in Patient A's CFTR gene: AAAATATCAT**CTT**TGGTGTTTGG.

The scientific name of this variant is P.Phe508del and it is the most common cause of cystic fibrosis globally. Once the variant is identified, scientists can start thinking about how to fix the genetic problem. You will learn more about this in Task 2.

Because cystic fibrosis is an inherited disease, certain variants can be more or less common among different populations. For example, in many parts of Europe more than 70% of cystic fibrosis patients have the P.Phe 508del variant. However, in Turkey only around 20% of cystic fibrosis patients have this variant. Your genetic **inheritance** from your biological parents, grandparents, and so on is called your **ancestry**. Your ancestry is important when thinking about genetic diseases.

9. Most reference sequences were built by gathering DNA from people with European ancestry and finding their most common base pair sequences. Discuss with your team:
   a. Why might that be a problem for identifying whether a variant is causing a disease if the patient does not have European ancestry?
   b. How could gathering reference sequences from people with other ancestries help scientists better diagnose disease?
10. Not all genetic diseases are caused by a problem with just one gene. Read what Filippo has to say. How might having multiple genes that cause a disease change what you need to do to diagnose it?

Filippo says . . .

With some diseases it is a single gene causing a single disease. This is straightforward. But this is not always the case. For example, with epilepsy there are multiple genes involved. Every single day we are discovering new genes that cause epilepsy. The sequencing technology has developed a lot. With next-generation sequencing we can sequence the entire genome more quickly and affordably. Then we can search for variants in thousands of genes at a time—even ones we didn't know caused epilepsy, for example.

Act: *How can we use this information ethically and wisely?*

Not everyone wants to know everything about their health. It is the nature of genetics that when a person finds out things about their health, they sometimes find out information they did not want to know. They may also find out about potential health problems of their relatives. Often before a genetic test is done, a **genetic counselor** will help people think through what it will mean to have this knowledge. In this activity you will think about the questions you might raise if you were a genetic counselor.

1. Imagine you are a genetic counselor. What are some of the things you think might be very important to think about before being tested for a genetic variant?
2. Write down questions you might like to ask or topics to raise with someone making this choice. What should they think about?
3. Examine your *Ethical Concerns List* from Part 1. If anything on the list reminds you of any questions you might like to ask or ideas you would want the patient to think about, write down those ideas now.

Filippo says . . .

We are now using genetic testing in all sorts of different ways. We are testing people who are healthy who want to know if they are likely to develop a genetic disease or if they might pass a genetic disease on to their children. So we are now using genome testing not just for diagnosis, but also to help people plan and make decisions.

4. With a partner, read *Situation One*.

Situation One

People with certain genetic variants in the *BRCA1* gene have a higher risk of developing breast cancer. This is true for men and women. Just because you have a *BRCA1* variant does not mean you will develop breast cancer; it is just more likely.

Others in your family have had breast cancer. You are considering testing for *BRCA1* variants. However, your sister does not want to know whether she has a *BRCA1* variant. Although her genetic results could be different, if you tested positive, it would mean she could have as much as a 50% chance of testing positive as well. Do you want to have a *BRCA1* genetic test?

5. Assign one partner to be a genetic counselor and the other to be a patient in Situation One.
    a. As the genetic counselor, use the questions you wrote down and any others you can think of to encourage the patient to think about the potential consequences of their decision. Your role is not to judge them or make them decide a certain way; it is to help them consider all the different parts and consequences of their decision. For example, you might ask, "Why are you considering getting the *BRCA1* genetic test?"
    b. As the patient, think about how you might feel if you were in Situation One. Try to answer the genetic counselor's questions. If the information is not provided, for example if there are questions about why your sister does not want to know, you can just use your imagination to make up realistic information. For example, you could say, "I am thinking about getting the test because I just had a friend who was diagnosed late with breast cancer and it has been hard to treat" or, "I am thinking about getting the test because I believe it is better to know than not know," or another reason that you decide.
6. Now switch. The partner who was the genetic counselor becomes the patient. The partner who was the patient becomes the genetic counselor. Use the information in Situation Two to role play another discussion, the same way you did in step 5.

Situation Two

Your parent had a genetic disease that affects the brain called Huntington's disease. A person is born with the variant that causes the disease, but the symptoms do not develop until middle age. People with symptoms usually have problems with thinking, behavior, and movement that get worse over a period of 10 to 25 years.

There is currently no cure for this disease. If your parent had it, you have a 50% chance of inheriting this disease. Do you want to have a genetic test to find out whether you inherited Huntington's disease?

⚠ Emotional Safety Tip

Having conversations about whether you would or would not test for a disease can feel emotional, especially if you know someone with a genetic disease. There are no right or wrong answers, and every person and situation is unique. If you need to pause and take a break, that is okay.

7. Discuss with your team:
   a. Why might it be important to have conversations like those you modeled with the genetic counselor before testing?
   b. As testing becomes more common, are there things you think people need to be talking about more frequently?
   c. Some people are able to access genetic testing. Others may not be in a location that offers genetic testing or genetic testing may be too expensive for them. How do you feel about that?
8. Write or draw the important things you want to remember and share about diagnosing genetic disease. Be sure to include:
   a. How it works
   b. The types of diseases can be diagnosed
   c. What is useful about testing to diagnose genetic diseases
   d. What are the potential concerns
   e. Why this might be important to your community
9. Share this information with a classmate, friend, or family member. Discuss with them why it might be important to know this information.

Task 2: How can we fix genetic diseases using biotechnology?

In Task 1, you explored how to diagnose genetic diseases. **Gene therapy** is one type of treatment to fix genetic problems. Using gene therapy, genes can be added or changed to treat genetic diseases. Today the dream of gene therapy is rapidly becoming a reality. In this task you will ***discover*** the need for targeted treatments to fix genetic problems. Then you will investigate to ***understand*** how biotechnology is helping to deliver personalized treatments. Finally, you will ***act*** by integrating what you now know into community dialogues about treating disease.

Meet Your Research Mentor

Meet Dr. Nicole Paulk. Nicole (pronounced nih-COLE) is one of the many researchers around the world trying to use biotechnology to improve human health and create a healthier future. As action researchers you are also trying to improve health in the future. Nicole will be your research mentor to help you understand more about the role biotechnology can play in treating disease.

Nicole is a professor of biochemistry and biophysics at the University of California, San Francisco, in the United States. She has a PhD in viral gene therapy and completed a postdoctoral fellowship in human gene therapy. However, she also has knowledge and perspectives that came from other parts of her identity. Since Nicole is now working with you, it is important to understand who she is.

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

- Lives in San Francisco, California
- 38 years old
- White/Caucasian female
- Interested in viruses, gene therapy, and genome engineering
- Likes to snowboard, cycle, go on adventure vacations, and go white-water rafting

Part 4 Task 2

- "Tall, hazel eyes, long straight brown hair that won't curl no matter WHAT I do to it, huge smile"
- Loud voice, goofy, detail-oriented
- Daughter of a lumberjack and a secretary, sister to an electrician
- Life goal: help discover treatments for diseases that have no therapies, particularly for diseases in kids

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

- Are there things you have in common with Nicole?
- Are there ways in which you are different from Nicole?
- Can you see anything about Nicole's identity, in addition to her university degrees, that would help her understand different perspectives or ideas about human health?

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

Discover: *How can we treat genetic diseases?*

DNA is like an instruction manual for your cells. When there are errors with the instructions, there can be problems with your cells and your body. In Task 1 you learned about how researchers are diagnosing these errors. In this activity you will start thinking about treatments to fix these errors.

1. Use a class board or a piece of paper to list diseases you know about. These can be diseases you or others you know have had or just diseases you have heard about. If you have time, you can ask others you know, like your family or friends, for additional ideas.
2. Now list any treatments you know next to each disease. Treatments might include pills, injections, surgery, or other methods.

3. With your team, discuss:
    a. Do these treatments fix the cause of the problem or just make someone feel better for a while? It is okay if you do not know the answer to this question. Just do your best.
    b. Are these treatments targeted to one specific place in the body or do they go all over the body?
    c. How do the treatments reach the part of the body they are trying to treat?
4. Examine your list of diseases and treatments. Circle the diseases you think might be caused by problems with your genes. Next you will be thinking about the way gene therapy tries to treat genetic problems.
5. Read this **analogy**, then answer the questions with your team.
6. You know that a cell uses the instructions in DNA to build proteins. Let's imagine you are like a cell and are trying to build something. In this analogy you are trying to build a chair just like the one in Figure 4-5. What would you need?

Figure 4-5: The chair you are trying to build in the analogy.

7. You might think you need materials to build the chair and instructions on how to build it. This is true for a cell as well when it is building a protein. It needs materials to build the protein, and it also needs instructions. Where does the cell get its instructions?
8. The cell gets its instructions from DNA, just like you might get your instructions from an instruction manual. Imagine the instructions have an error. Maybe a sentence or a whole page is missing. Or perhaps the instructions were printed

Part 4 Task 2

wrong and tell you to attach a piece backwards. Or maybe there are extra steps printed that should not be there.

   a. With your team, think about how an error in your instruction manual might be an analogy for an error with the DNA instructions in a cell.
   b. Are there different types of errors possible in DNA, just as there were with your instruction manual?
   c. What do you think might happen when building a protein if there was an error in the DNA that codes for it?

9. Read *DNA Instructions and disease*.

DNA Instructions and Disease

Without all the correct instructions, you might not be able to build the chair so that it is usable. And without all the correct base pairs in a gene, a cell might not be able to build a usable protein. When a cell cannot build a usable protein, this can cause a disease. Diagnosing the problem means finding the place in the instructions that is creating the problem. You learned about this in Task 1. Now you will think about how to fix this problem.

10. Continue thinking about the chair analogy. If there was an error with the instruction manual, how could it be fixed? For example, if you had a whole new instruction book that was correct, you would know how to build the chair. Or if you had a correct copy of just the missing step, you would know how to build the chair.
    a. How could fixing the chair instructions be an analogy for designing a gene therapy?
    b. With your team, think about what you know about different biotechnology techniques. Are there any techniques you can think of that might be used to fix problems with a gene? Read *Gene Therapy Types* to learn more.

Part 4 Task 2

Gene Therapy Types

There are different approaches to treating genetic diseases.

Sometimes, a whole new copy of an existing gene is added to a cell and then usable proteins can be made, along with the unusable ones from the existing variant gene. This would be like having a whole new set of instructions delivered so you could build the chair. This is called **gene replacement therapy**.

Genes can also be directly edited within the genome, using a tool like CRISPR. This would be like someone arriving at your home and using a pen to fix the error in your instruction manual. This is called **gene editing therapy**.

Sometimes, a gene that is supposed to be switched off and not make proteins gets switched on by a variant. This would be like if you had an additional step in your instruction manual. Someone could come to your home and use a marker to cross out the extra step. In the case of gene therapy, a gene that blocks that variant gene from building proteins might be introduced. This is called **gene inhibition therapy**.

Nicole says . . .

A genetic medicine can either be something that's permanent or something that's temporary. It can be something where we edit your genome. For example, if you were born with a mutation in one of your really important genes, we could actually go in and fix that mutation in place so you wouldn't have that mutation anymore. Or we could give you a whole functional copy of a gene.

11. Delivering the gene therapy is another challenge. Think again about the analogy. Even though the correct instructions for the chair may exist, that doesn't help you unless you have them at your home. Imagine you need a physical copy of the correct instruction manual to build the chair. Someone reading it to you over the phone or sending you an electronic copy will not do. The company that produces

the guide is far away, but they do have correct copies. How could you get a copy of the missing step at your home?

   a. When something is delivered to your home, what kind of information do you think is necessary so the delivery person can get it to you—not to your neighbor, a person across the country, or a person across the world?
   b. Why do you think it might be important to target the delivery of a gene therapy to a specific cell (or cells)?

Nicole says . . .

The delivery of the gene therapy needs to be specific, just like a delivery truck delivers to a specific place, not just go to your country or your state. The delivery has to go to your street, to your building, right to your door.

12. Examine your list of circled genetic diseases and treatments from steps 1 and 2. Discuss with your team:
    a. Which disease would you be most excited to have a gene therapy to treat?
    b. Gene therapy targets the specific genetic problem within specific cells. How is that the same or different from the treatments you listed in step 2?

Understand: *How can biotechnology help provide targeted treatments?*

The goal of gene therapy is to target the specific problem with the gene in the specific cells where it is a problem. This can be challenging, but scientists have made tremendous progress.

1. Think about ways you could deliver gene therapy to specific cells and share your ideas with your team. You need to:
   a. Protect the genetic material you are trying to deliver
   b. Deliver genetic material to the cell

c. Make sure the genetic material enters the cell you want, also known as the **target cell**

2. Now, with your team, read Special Delivery. What natural systems already target and deliver genetic material to cells?

Special Delivery

Viruses can be very good at entering and infecting cells. Think of the virus as like the delivery vehicle from the Discover analogy. How could this be useful?

Usually, viruses contain their own genetic material that they carry into a cell when they enter it. However, imagine all the viral genetic material was removed. Only the parts needed for delivery remain. This virus delivery vehicle is called a **viral vector**. The viral vector can now deliver lots of different things. For example, you could add a gene for gene therapy to the virus and have it delivered to the cell. Viruses are not the only gene therapy delivery vehicles, but they are by far the most common. Different viruses are selected for different needs.

3. Think about a viral infection you have had (such as a cold or the flu). Did the virus tend to attack certain places in your body? Some viruses tend to infect the respiratory system, others the digestive system, others may infect other types of cells. So most viruses are already targeting specific cell types. Why might that be useful when using them as a delivery mechanism?

Nicole says . . .

People usually think of viruses as something that we treat, for example if you're sick with a virus. But in fact the vast majority of viruses on the planet don't make humans sick. They can be used as delivery tools. Different viruses tend to go different places. Viruses are already really good at getting inside of our cells, so we can use a virus to deliver the gene therapy.

We can also custom tailor viruses in all kinds of ways to make them more targeted to a particular spot in your body, or to a particular **species**, or to a particular combination of tissues or cell types.

Part 4 Task 2

4. Divide up into groups of three. Each member of the group will need a pencil and a piece of paper. Read *Modeling Gene Therapies Instructions*.

Modeling Gene Therapies Instructions

As a group you are going to model how different types of gene therapy work once they reach the target cells.

Remember when you learned that a cell can "read" DNA to build proteins? In Part 1 we used the analogy of the sentence, "Start here: Read this sentence and then draw a box" as an analogy for how DNA gives cells instructions. In this activity you will use this analogy to model how different gene therapies work.

Choose one person to model the cell, one person to model the current gene, and one person to model the gene therapy.

The cell

If you are modeling the cell, your job is to follow the instructions you receive. Cells always need to be told to start reading a piece of DNA. So, as long as you receive an instruction begins with "Start here" you will carry out the instruction. Use a piece of paper and pencil to draw anything you are told to draw.

The current gene

If you are representing the current gene, you write instructions on the top of your piece of paper. Tear off that part of the paper and give it to the cell to carry out. If the gene therapy replaces or changes your piece of paper, you should let them do it.

The gene therapy

If you are representing the gene therapy, your goal is to make sure the cell is drawing what is needed. In this model you will have three options:

a. **Gene Replacement:** Write down instructions on an additional piece of paper and give them to the cell to carry out. The current gene will then give your piece of paper to the cell.

Part 4 Task 2

b. **Gene Editing:** Take your pencil and correct a few letters that were mutated in the current gene. Have the current gene give their corrected instructions to the cell.

c. **Gene Inhibition:** Take your pencil and cross out what the current gene has written so it cannot be read. Have the current gene give their crossed-out instructions to the cell.

There will be four rounds. Have the current gene and the gene therapy read the details for each round. Hide the details from the cell. Can the gene therapy find a way to get the cell to meet the goal?

Round 1

Goal: Have the cell draw a circle.

Current gene: Begin by writing the sentence, "Start here: Read this sentence and then draw a circle" on your piece of paper. Now you will model the mutation. Erase the word "circle" and substitute in the word "line." Your paper should now read, "Start here: Read this sentence and then draw a line."

Gene therapy: Use the type of therapy you think would be best to achieve your goal of getting the cell to draw a circle.

Round 2

Goal: Have the cell draw a big triangle and then a small triangle.

Current gene: Begin by writing the sentence, "Start here: Read this sentence and then draw a big triangle and then a small triangle" on your piece of paper. Now you will model the variant. Erase the part that says, "and then a small triangle."

Gene therapy: Use the type of therapy you think would be best to achieve your goal.

Round 3

Goal: Have the cell draw nothing.

Current gene: Begin by writing the sentence "Start here: Read this sentence" on your piece of paper. Now you will model the variant. After "sentence" add the words, "and then draw squares until the paper is filled." Your paper should

Part 4 Task 2

now read: “Start here: Read this sentence and then draw squares until the paper is filled.”

Gene therapy: Use the type of therapy you think would be best to achieve your goal.

Round 4

Goal: Have the cell draw a square.

Current gene: Begin by writing the sentence, “Start here: Read this sentence and draw a square” on your piece of paper. Now you will model the variant. Erase everything between “Start” and “square.” Your paper should now read: “Start square.”

Gene therapy: Use the type of therapy you think would be best to achieve your goal.

Part 4 Task 2

5. Discuss with your group:
   a. Why were some gene therapies better than others for the different situations in the different rounds?
   b. Could you have used other ones? For example, if the gene therapy you chose was gene replacement, could you have used gene editing instead?

⚠ Emotional Safety Tip

Although scientists have made a lot of progress and the first gene therapies are starting to be available to the public, there is a long way to go. Many gene therapies are only in the testing phase and many more are still in development. It can be frustrating if you or someone you care about is suffering from a disease that might be cured or helped using gene therapy, but the therapy is not yet available. It is okay to feel sad or angry about that. By learning about how gene therapy works, you can help educate others and encourage the changes you want.

6. Read what Nicole says. How do you think gene therapy will change things in the future?

Nicole says . . .

A virus can now be a therapeutic drug to treat you for something. For example, there are kids who are unable to see because they are born with a specific type of blindness that is caused by a problem with one of their genes. We can give them a one-time infusion of a virus into their eye that gives them a functioning gene that they weren't born with—a gene they needed to see. Then, once they wake up from the surgery, they can see. And they can see forever. We can cure this form of blindness using gene therapy.

Right now a lot of the gene therapy work is on rare diseases, but work is starting on even more common ones. I think in the future there will be gene therapies for diseases like heart disease, diabetes, and cancer. If you are in middle or high school now, I feel certain that you will be eligible for a gene therapy within your lifetime. It will become a common type of treatment.

7. You have learned more about the way gene therapy works. Now choose a disease you know about in your community. You will be doing some research to investigate whether there are any ongoing **clinical trials** using gene therapy to treat that disease. A clinical trial is the final stage of developing a treatment. If a treatment appears to be working and to be safe in laboratory and other models, it usually is tested next with a small group of people. If those people have good results, it gets tested with even larger groups. If you have access to the Internet, you can go to trialsearch.who.int or clinicaltrials.gov to search for clinical trials that are happening right now. Search for the name of the disease you are investigating and gene therapy.
   a. How many clinical trials are underway?
   b. How recent are the clinical trials?
8. Compare your results with your teammates.
   a. Which disease did you find has the most gene therapy clinical trials?
   b. Are there any gene therapy clinical trials you are really excited about?

Act: *How can we ethically use gene therapy to solve medical problems?*

You have learned about gene therapy and how it is used. Now you will think about how this relates to your hopes and fears for the future. Then you will consider what other people should know about gene therapy and the future.

1. Take out your *Futures Mood Board* from Part 1.
2. What hopes do you have for the future after learning about gene therapy? If you want, add drawings, words, or photos to help represent those hopes.
3. What concerns do you have for the future after learning about gene therapy? If you want, add drawings, words, or photos to help represent those concerns. Be sure to consider anything related to your *Ethical Concerns List* from Part 1.
4. Think to yourself, what is the most important thing you learned during this task?
5. Share your thoughts with your team and listen carefully when they share their ideas with you.
6. Discuss with your team:
   a. Who are people who really need to know about the diagnosis and treatment of genetic diseases but don't know already?
7. As a team, can you come up with a way to share these important ideas with this group? For example:
   a. Could you create a visual to present to another class?
   b. Could you create a song, poem, or play to explain what gene therapy is and how it works?
   c. Do you have other ideas about how to share?
8. Plan how you want to share with the audience you identified. Make sure to find a way that includes everyone on your team. Don't forget to:
   a. List the steps you need to take.
   b. Assign different people responsibility for different steps.
   c. Put your plan into action!

Congratulations!

You have finished Part 4.

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.

Acquire: Develop over time or in response to something

Analogy: Comparing two things to help provide clarification

Ancestry: Your genetic inheritance from your biological parents, grandparents, so on

Antigen: A protein that is unique to a virus or specific type of cell; the immune system uses antigens to identify things to attack

Bases: The four types of DNA units that store information: adenine (A), cytosine (C), guanine (G), and thymine (T)

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

Clinical trial: A test of a treatment that occurs after laboratory and other models have proven successful; the treatment is usually tested with a small group of people and if those people have good results, it gets tested with even larger groups

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

Diagnose: Identify a disease

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

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 editing therapy: Changing a very specific small part of a gene in a cell to treat a disease

Gene inhibition therapy: Blocking a harmful variant gene from building proteins

Gene replacement therapy: Adding a new copy of a gene in a cell to treat a disease

Gene therapy: A type of treatment that uses functional genes to fix a genetic problem in the body

Genetic counselor: A professional who helps people think through genetic testing decisions and consider the results of that testing

Genetic disease: An illness caused by variation within the genome

Genome: The complete sequence of DNA of a living thing

Genome sequencing: A tool that allows you to find out the order of all the DNA bases in the cell

Infectious disease: An illness you catch from someone or something

Inherit: Born with, coming from your parents

Inheritance: How traits or characteristics of parents are passed on to their children

Inserted: Added into another thing, often into a specific place

Mutations: Copying errors in DNA resulting in genetic variation, now more commonly called variants

PCR: A biotechnology technique that creates many copies of a piece of existing genetic material

Reference genome: The most common gene sequences across a population

Species: A type of living thing, like a human or a dog or a coconut tree

Symptoms: Signs that you might be sick

Target cell: The specific cell a therapy is trying to treat

Variants: Genes with one or more differences

Variation: Differences in living things

Viral vector: A virus delivery vehicle for other genetic materials, such as gene therapies

End Note

1. Cystic Fibrosis Centre at the Hospital for Sick Children in Toronto. 2022. Cystic Fibrosis Mutation Database. Retrieved from http://www.genet.sickkids.on.ca/Home.html.

Part 4 End Note

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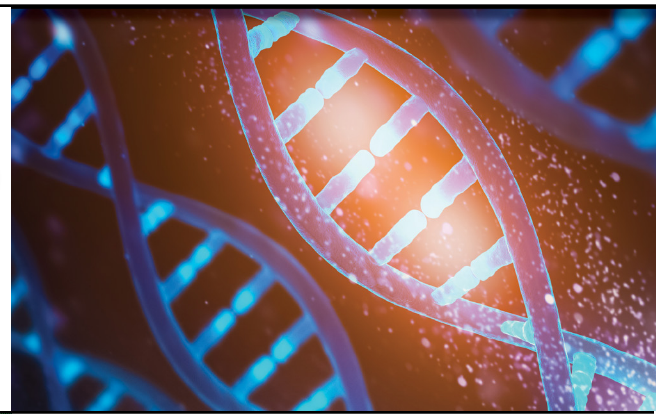

Part 5:

Biotechnology and Genetic Data

SUSTAINABLE DEVELOPMENT GOALS

developed by
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the interacademy partnership

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PART 5: BIOTECHNOLOGY AND GENETIC DATA

Part 5

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: How should we use and protect genetic data?					
Discover	Explore how genetic data relates to your identity. Discover more about how genetic data is collected and the information it contains.		*Identity Map* (Part 1)	25 minutes	171
Understand	Consider your concerns about uses of genetic data. Conduct interviews to understand community concerns.	• Pens or pencils • Paper		30 minutes + interview time	175
Act	Analyze different perspectives on the ownership and use of genetic data. Choose one perspective to share with another person or group.	• Pens or markers • Poster paper or class board		25 minutes	182
Task 2: How can environmental genetic data help identify and solve problems?					
Discover	Search for evidence of living things and find out how the evidence from eDNA can help answer questions.	• Pens or pencils • Paper		35 minutes + search and observation time	187
Understand	Analyze case studies of investigations using eDNA and design your own investigation.	• Pens or pencils • Paper		60 minutes	191
Act	Develop your ideas about the ethical considerations and other perspectives on the use of genetic data and use these ideas to modify your eDNA investigation.	• Pens or pencils • Paper	*Ethical Concerns List* (Part 1)	25 minutes	201

Part 5 Planner

Task 1: How should we use and protect genetic data?

The information in a **genome** is called **genetic data**. The genetic data of your genome can tell researchers many things about you. This is true for humans and all living things. In this task you will ***discover*** more about what we can learn from **DNA**. Then you will investigate to ***understand*** more about how people in your community feel about sharing this information. Finally, you will ***act*** to decide how you think genetic data should be protected.

Meet Your Research Mentor

Meet Dr. Kadija Ferryman. Kadija (pronounced kah-DEE-jah) is one of the many researchers around the world thinking about how to use **biotechnology** ethically.

Kadija is a professor of bioethics and health policy at Johns Hopkins University in the United States. She has a PhD in anthropology. However, she also has knowledge and perspectives that came from other parts of her identity. Since Kadija is now working with you, it is important to understand who she is.

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

- Jamaican-American, or "Jamerican"
- Both of my parents were born and raised in Jamaica, as well as all of my ancestors going back to the 1790s.
- Woman
- Native New Yorker; born and raised in New York City
- BA from Yale University, PhD from the New School for Social Research
- Interested in how we understand differences between human groups, digital technologies, justice and fairness in society
- Likes Caribbean and African diasporic dance, cooking, jogging, listening to podcasts, cycling, spending time with family and friends
- Has been wearing glasses since the fourth grade

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

- Are there things you have in common with Kadija?
- Are there ways in which you are different from Kadija?
- Can you see anything about Kadija's identity, in addition to her university degrees, that would help her understand different perspectives or ideas about the ethics of using genetic data?

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

Discover: *What can we learn from DNA?*

Every person's genome is unique. It contains information that determines parts of your identity. There are many different ways this information can be used.

1. Take out your *Identity Map* from Part 1.
2. Examine it carefully. Find any parts of your identity that you think might be related to your DNA. For example, your identity map may include physical characteristics determined by your DNA. Or your identity map may include roles you play based on shared genetic relationships, such as daughter or brother.
3. Discuss with your team:
   a. Which parts of your identity do you think could be found in your DNA?
   b. Which parts of your identity are not found in your DNA?
   c. Can your DNA tell your story? Does your DNA leave out important parts of what make you you?

Emotional Safety Tip

Your genetics can affect who you are but they do not determine all parts of your identity. Sometimes people may assume certain things about you based on your genetics. But you are the one who decides who you are.

4. Think quietly to yourself:
    a. Are there ever parts of your identity that you want to keep private?
    b. How would you feel if other people could find out that information using your DNA?
5. Gather with your team. You will be investigating more about how genetic data is collected and analyzed. Read *Collecting the Sample*.

Collecting the Sample

The first step to using genetic data is to collect a sample of DNA. DNA can be found in every cell in your body. It can be found in your hair, sweat, blood, urine (pee), feces (poop), saliva (spit), and even little flakes of your skin that you leave behind.

6. With your team, discuss:
    a. Where might you have left samples of your DNA without realizing it? Make a list of all the places you can think of.
    b. Would you be comfortable if these samples were used to find more information about you?
7. Read *Analyzing the Sample*.

Analyzing the Sample

After collection, the DNA in the sample needs to be sequenced so the genetic data can be analyzed. Researchers use chemicals to extract DNA, just as you did in Part 1. Then researchers can use a DNA sequencing machine to find out the sequence of As, Ts, Cs, and Gs. This sequence is then sent to a computer for analysis and interpretation. Figure 5-1 shows an example.

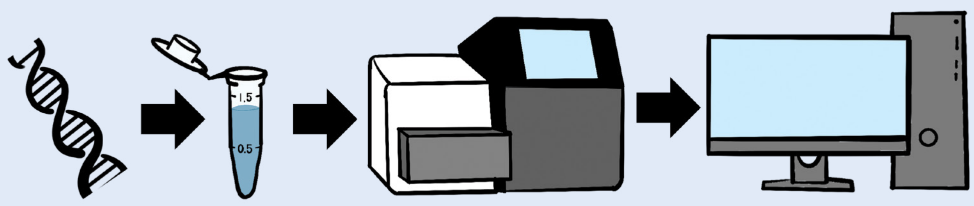

Figure 5-1: A DNA molecule is collected in a sample tube and sequenced in a machine, which then sends the data to a computer for analysis.

Part 5 Task 1

You may remember from Part 1 that scientists sequenced the whole human genome as part of the Human Genome Project. At that time, scientists had to sequence all the DNA in order, like reading a book from start to finish. It took a long time. Now scientists have found a quicker way to sequence DNA called **next-generation sequencing**. They sequence many parts of the DNA at the same time. Then they use a computer to reassemble the pieces in order. Humans share 99.9% of our DNA, so as long as there is enough of a part, it is straightforward to see where it fits into the sequence of the genome. Scientists use a **reference genome**, or an example of a living thing's genome, to help them understand the order of the DNA pieces.

8. Discuss with your team:
    a. How did the Human Genome Project make it easier to sequence genomes of other humans?
    b. There is now something called the Pan Genome Project in which scientists are trying to sequence the genomes of all living things. Why might this be useful?
9. Now that you have a DNA sequence, you need to discover what it means. Read *Using the Clues*. Can you figure out whose DNA you collected?

Using the Clues

Genetic data is often used by researchers to identify which living thing left behind a sample of their DNA. Genetic data can tell us a lot about the species or individual who left it behind. Researchers analyze the genetic data to find out more about the living thing it came from.

Who does the DNA belong to?

Imagine you are a researcher who collected a sample of DNA and wants to find out who the DNA belongs to. For this activity we will use a set of imaginary monsters. As a researcher, can you use the genetic data from genes A, B, C, and D in the collected sample to identify the monster who left it behind?

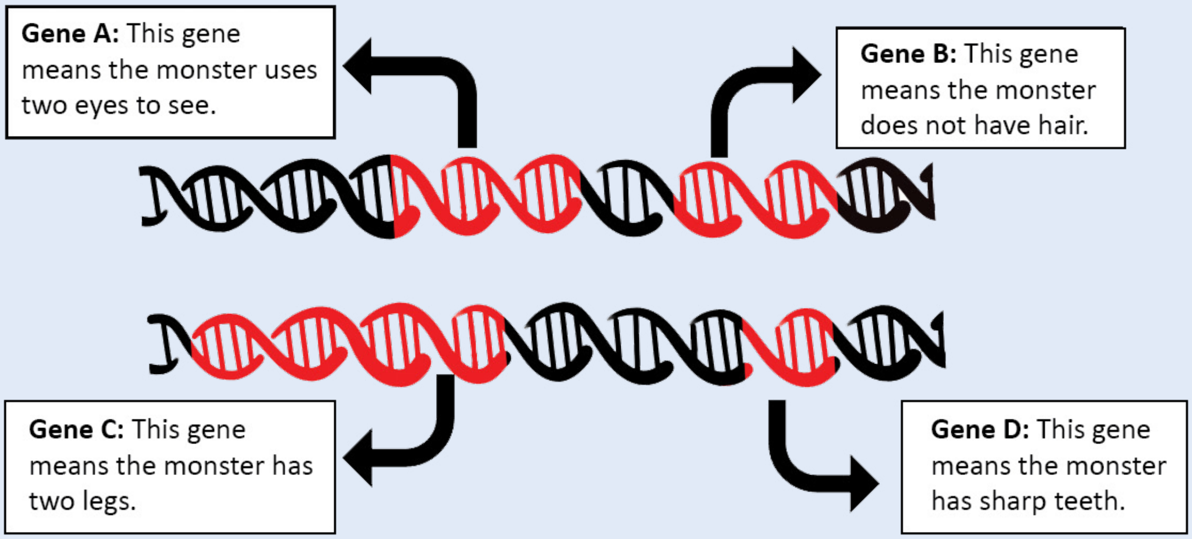

Figure 5-2: Imaginary monster genes.

Which monster did the DNA come from?

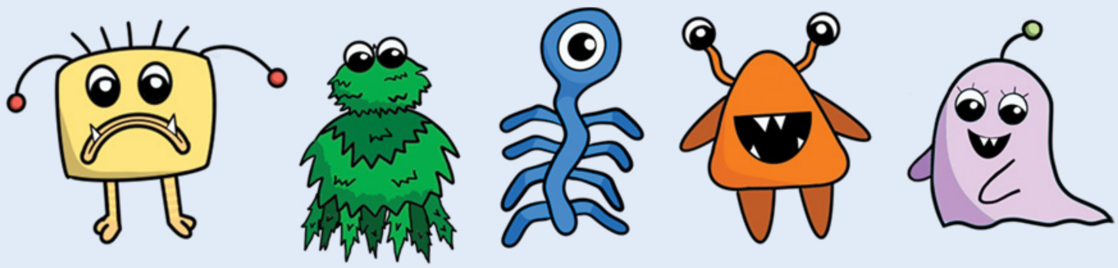

Figure 5-3: Imaginary monsters.

10. Think together with your team and discuss:
    a. Can you think of any situations in which someone might want to use genetic data from a sample to figure out which people had been in a certain place?
    b. Can you think of any situations where someone might want to use genetic data to know more about relationships between people, like whether a person is a family member?
    c. Can you think of any situations where someone might want to use genetic data to find out more about an individual's characteristics, like whether they might have DNA **variants** that are connected to disease?
11. Read what Kadija says. What do you think the similarities and differences in human DNA can tell us? Do you think it should change the way we think about people we think of as different?

Kadija says . . .

After sequencing the human genome, we found that all humans are 99.9% alike. But over the course of history, we as humans have spent a lot of time dividing ourselves up into different groups, categories, and "kinds" of people, and this has sometimes had harmful consequences. So what do we do with our 0.1% of genetic difference? Is that meaningful or not? Why or why not? Those questions really captivate me.

Understand: *How can genetic data be used?*

People's genetic data contains a lot of information that can be useful. Different groups often collect genetic data. Sometimes it is collected for research, for example to understand more about human diseases. Sometimes it is collected by companies that analyze genetic data to answer questions about ancestry and possible health outcomes. Sometimes genetic data is collected by law enforcement to try to solve crimes. In this activity, you will think more about how genetic data is used and the impacts of those decisions.

1. Read *Genetic Data Use One* through *Genetic Data Use Five* and answer the questions to consider by yourself.

Genetic Data Use One: Law Enforcement

Dutch investigators caught an art thief using DNA evidence. After an art heist, investigators found a sample of DNA left behind on a picture frame. The sample from the frame helped investigators identify several people who had contact with the stolen artwork, including a man who had previously been to jail for art theft. Authorities concluded that since this man's DNA was present at the scene of the crime, he must have been the person who stole the paintings. The accused thief says he is innocent. He says the paintings could have been stolen by any of the people whose DNA was left behind at the scene.

Questions to consider

a. If you were an investigator, how certain would you feel that you had caught the right person?
b. Are there instances you can think of when DNA evidence does not lead to a just outcome?

Genetic Data Use Two: Research

Governments, private companies, and research institutions are creating databases of genetic data they have gathered from many people. Researching the data in these databases can help answer questions about genetic diseases and potential treatments. Some of these databases are **open access**, or able to be freely accessed by other researchers. However, many databases have restrictions. Data in the databases are **deidentified**, meaning there are no names attached to genetic data. But some institutions are still concerned about privacy and so they limit access to the database or only share some genetic data. Other times, companies may want to keep ownership over data they have collected.

Kadija says . . .

One way that data can be kept private or confidential is by taking off identifying information. For some kinds of data, you can take off someone's name, address, or gender and still be able to use that information as anonymous data for a particular function. But with genomic information, that data is quite literally about you. How do you make genetic data anonymous and still use it in beneficial ways, such as for health research?

Questions to consider

a. What concerns do you have about data being open access? What advantages do you think there are?
b. Do you think a company should be able to own someone else's genetic data? If not, who should own it?
c. Review what Kadija says. Do you think it is possible to deidentify genetic data?

Genetic Data Use Three: Personalized Marketing

You can pay a company to gather the genetic data from your DNA, a process called **direct-to-consumer (DTC) testing**. Your results can show information about your **ancestry**, or what part of the world your ancestors came from. It can also show potential diseases you might be at risk for. Recently, through a partnership with a music streaming service, a direct-to-consumer testing company even created personalized music playlists based on your ancestry!

Questions to consider

a. Do you have any concerns about your genetic data being used to market things that might be interesting to you, based on your ancestry, like music or recipes?
b. What if the marketed items were based on your health information in your DNA? Is that different?

Genetic Data Use Four: Healthcare Decisions

Results from DTC companies can show if you are more likely to develop certain diseases. However, these results arrive to you virtually. There are no experienced health care professionals to help you interpret them. People may make decisions about their own behaviors, such as choosing to have children or keeping up with preventive health screenings, based on these results. They also may choose to share these results with relatives who may have similar results. DTC results are not always completely accurate or easily interpreted.

Questions to consider

a. Do you think there should be a requirement to have a health care professional talk to people who have a high risk of developing a disease, based on their DTC results?
b. What potential problems are there if people share results with their relatives when their relatives do not want to know the information?

Genetic Data Use Five: Data for Sale

DTC companies are paid by consumers to test their genetic data and share those results. However, pharmaceutical companies, research institutions, health and beauty companies, and technology startups all sometimes pay DTC genetic testing companies for access to a database of their users' deidentified genetic data. Figure 5-4 shows an example.

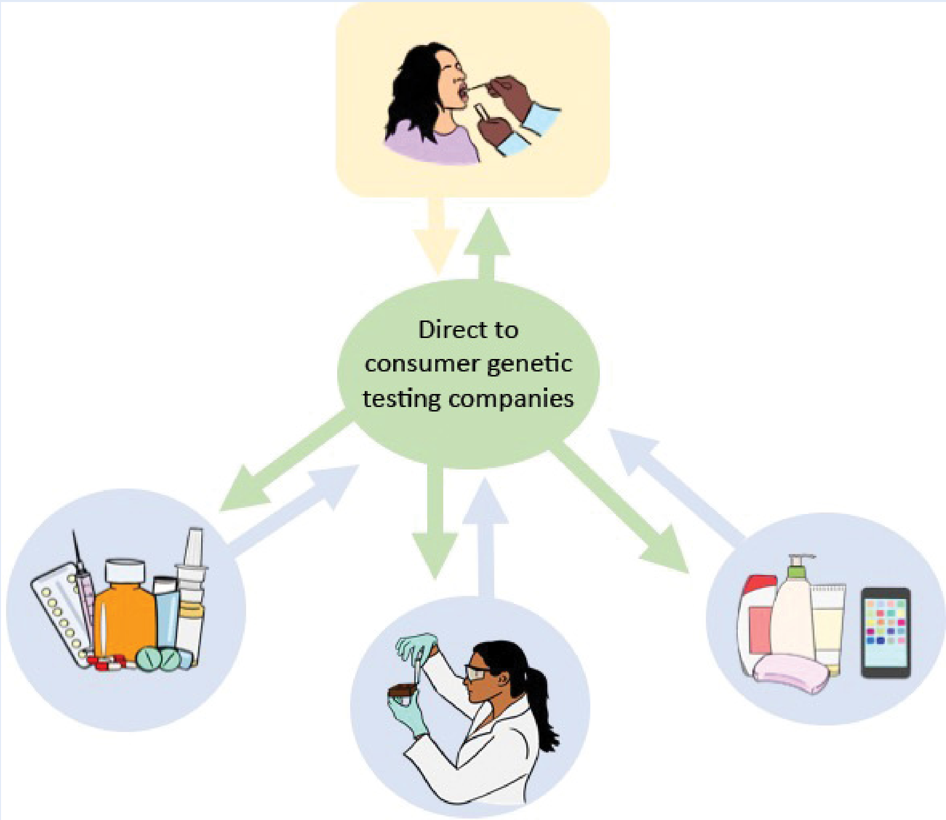

Figure 5-4: The DTC business model: Individuals share a genetic sample with DTC companies. These companies return the genetic data to the individual, but also sell it to pharmaceutical companies, research institutions, and other companies.

Part 5 Task 1

Questions to consider

a. Do you have any concerns about the way DTC companies sell genetic data?
b. What are the benefits to individuals of the DTC business model? What are the benefits to DTC companies?

2. Gather together with your team. Discuss the different examples and your answers to the questions.
   a. Did anyone in your team have different answers?
   b. How do you think others in your community might answer?
3. Read what Kadija says. What do you think is important to think about when discussing how genetic data is gathered or used?

Kadija says . . .

Genetic data in some ways is the most personal kind of information that there can be about a person. It's literally the sequence of the genetic material in your cells. We inherit our genetic data from our family members, so this information is personal to you, but some of it is also shared among your family members.

If we have access to this very personal data about an individual, how should we analyze that data? We can find out interesting things, such as what makes people sick. Genetic data is a very powerful resource, on one hand. However, we also have to think about how to use this very personal information in a way that's safe and just, and fair to individuals and to communities.

4. Now you will discuss these ideas with more people in your community. Read *Genetic Data Interview Instructions* and carry out your investigation.

Genetic Data Interview Instructions

You can interview people in your community to learn about their experience with or feelings on gathering and using genetic data. This can help you find out your community's opinions on genetic testing and the use of genetic data.

Choosing people to interview

a. Think about who might know the most about the use of genetic data. For example, it might be a teacher at your school, a person who has used a DTC test, a local scientist, people who work in health care, or leaders who make decisions for your community.
b. Every person in your community has a valuable perspective. Think back to your *Identity Map* from Part 1. Different parts of your identity help give you information. If you can, interview people from a variety of ages, genders, sexualities, jobs, incomes, religions, ethnicities, or other identities so you can get a variety of information. As a team, try to talk to people who live in all parts of your community.
c. Think about the many ways people can share information and try not to leave groups of people out. For example, some people in your community may not use your language. Try to find someone to help you translate so you can find out more about their experiences.
d. Conducting interviews can take a long time, so you may decide to interview just one person. That is okay. If everyone on your team interviews at least one person, you will have enough information to complete the activity.

Questions

With your team, develop a list of questions to ask during the interview. Think about the questions you answered as part of *Genetic Data Use One* through *Genetic Data Use Five*. Are any of those questions ones you want to ask during an interview?

Are there other questions you would like to ask your community? Be sure to include questions to help you find out about experiences or concerns you don't already know about. For example:

a. Do you have any experience with genetic data or testing?
b. Do you feel like genetic testing is safe? Is it safer to test yourself at home or at a clinic or research facility?
c. Are there any ways you or others in our community could benefit from genetic data?
d. What are the concerns about your privacy when receiving genetic testing?

Ways to record an interview

a. You can interview people many ways, such as in person, over the phone, using email, or through a social media platform.
b. You can use audio or video to record an interview.
c. You can write or draw to make a record of the ideas that are shared with you.

Tips for conducting an interview

a. Make sure to ask permission to record a person's answers.
b. Ask permission to share the interview with the rest of your team, class, or other people in the community. People might be more willing to share if their interview is anonymous.
c. If it feels as if someone didn't answer your question, don't be afraid to ask the question again in a different way.
d. Let the person you are interviewing answer the questions in the way they want. Be patient. Listen carefully. Understand that they might give answers you didn't ask for or expect.

Safety tips for interviewing people

Ask your teacher for guidelines. They will know what is safest in your community.

⚠ Physical Safety Tip

Never conduct an interview alone and always be aware of your surroundings. You might want to suggest recording the interview in a quiet public place.

⚠ Emotional Safety Tip

It can be hard to communicate with other people in the community. You may feel shy or nervous. Someone may tell you they don't want to talk. That's okay! It doesn't have anything to do with you. It just means they don't want to share. You can show them respect by thanking them and moving on to another community member.

5. Examine the results of your interviews with the rest of your team.
   a. What common responses do you notice?
   b. Did anyone say anything that surprised you?
   c. How do you think the information you collected might be useful when making decisions about genetic data?

Act: *What rights do people, scientists, and companies have to genetic data?*

Biotechnology is changing rapidly. Researchers are now able to gather and sequence many more DNA samples much more quickly. When science moves quickly, sometimes people do not have an opportunity to think about different perspectives on the way it may be used. In this activity you will explore different perspectives about genetic data ownership and use, and consider which you would like to share with others.

1. With a partner, start by discussing what it means to own something. Then discuss what it means to own genetic data.
2. Now read Kadija's thoughts. Did her ideas make you think differently about anything?

Kadija says . . .

You might be interested in science and want to give a research study access to your genomic information for the common good. But because blood relatives have some similar genetic information, you would also be giving that research project access to your family's shared genetic information. Some of your family members might not want their information used as a part of this research! But because you want to, some of their information would be included in a research study.

3. Think back to the question of ownership from *Genetic Data Use Two*. With your partner, decide which people or groups might think they have some ownership over genetic data.
4. With your partner, think about the following potential owners of DNA and answer the questions together:
   a. Individual person:
      - Genetic data is information stored in an individual person's DNA. Does an individual automatically own their own data?
      - Do you own data gathered from samples you left around, such as samples from found hair or saliva?

   b. Relatives:
      - Your genetic information is very similar to that of your family and can be used to gain a lot of information about people related to you. Does that make genetic data collectively owned?
      - Should you be consulted before your relatives test their own DNA?
      - Should you have to ask your relatives before you test your own DNA?

   c. Private companies and public research institutions:
      - Private research institutions can **patent** genes they create in a laboratory. A patent is a license from the government that means an individual or company owns an invention for a period of time. This helps make sure they can profit from their research. Can a company own genetic data?
      - Should genes be patented like other things?

5. Divide your team into three groups. These groups will consider three out of the four perspectives you learned about in Part 1. For right now, do not worry about the environmental perspective. Instead, assign each team to one of these perspectives:
    a. **Social** is about the interaction of people in a community. The health, education, and well-being of people are the most important thing from this perspective.
    b. **Economic** is about money, income, and the use of wealth. Economic growth, including making sure people have jobs and enough money, is the most important thing from this perspective.
    c. **Ethical** means the fairness of something. Doing what is right and having a just community where everyone is treated fairly is the most important thing from this perspective.
6. Have each group use a large piece of paper or the board to list their ideas from each perspective. Write or draw answers to these questions:
    a. Thinking about this perspective, how might you want to use genetic data?
    b. What are any concerns about the use of genetic data from this perspective?
    c. Who should own or be considered when thinking about genetic data from this perspective?
7. Use Kadija's thoughts to help you consider whether there is anything you missed listing on your sheets. If there is, add those ideas now.

Kadija says . . .

With genetic data, privacy can be a privilege that only some people have the right to. Some law enforcement agencies are able to collect genetic information or biological information about people who have merely been arrested, not even convicted of a particular crime. Who gets to be "genetically private" can be different in some places, depending on what social group you belong to or are associated with. If you are in a group that is sometimes targeted, sharing your genetic information may be risky.

8. If you used a piece of paper, tape it on a wall or somewhere people can examine it.
9. Move around and examine each group's work. If you think something listed is important to remember or you would want to share it with others, find a way to mark it either by drawing a star, circling it, checking it, or another method.
10. Come back together as a team and examine all the information your team thought was important from the three perspectives. What are the new perspectives that individuals, companies, researchers, or other groups should consider?
11. By yourself, pick one important perspective you would like to share or remember. Decide who you want to share this perspective with and create a way to do that. For example:
    a. If you want to remember information yourself, you might write a short reflection or draw a picture to help you remember the important perspective on genetic information.
    b. If you want to share with a family member, you might write them a letter explaining the perspective you want to share.
    c. If you want to share with a company or group of researchers, you might compose a social media post tagging them. If you feel comfortable, you can post it.
12. Keep a copy of your perspectives sheets to use in Task 2.

Task 2: How can environmental genetic data help identify and solve problems?

Just like human genetic data, genetic data in the environment can be gathered from many places and used in many ways. **Environmental DNA**, or eDNA, is a sample of all the DNA of the many living things that are present in an environment. In this task, you will ***discover*** how eDNA can help you answer questions about the living things around you. Then you will use case studies to ***understand*** how eDNA analysis can be used to research questions from public health to conservation to archaeology. Finally, you will ***act*** on this information by creating an experiment with eDNA that considers different perspectives.

Meet Your Research Mentor

Meet Dr. Irene Xagoraraki. Irene (pronounced i-REEN) is one of the many researchers around the world using biotechnology. Irene will be your research mentor to help you understand more about how biotechnology can help us learn more about the people and other living things around us.

Irene is a professor of environmental engineering at Michigan State University in the United States. She has a PhD in environmental engineering. However, she also has knowledge and perspectives that came from other parts of her identity. Since Irene is now working with you, it is important to understand who she is.

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

- 52 years old (born in 1970)
- Bachelor's degree from the University of the Aegean in Greece, and PhD from University of Wisconsin-Madison
- Greek by birth, US-Greek dual citizen
- Female
- Lives in Michigan, United States
- Crete, Greece, is an important place to her and her family
- Interested in education, science, nature, geopolitics

- Likes spending time by the water, walking in nature, hiking, gardening, photography, puzzles, live music, dancing, movies
- Brown eyes, brown hair, Mediterranean look
- Kind, down-to-earth, conscientious, funny
- Mother, wife

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

- Are there things you have in common with Irene?
- Are there ways in which you are different from Irene?
- Can you see anything about Irene's identity, in addition to her university degrees, that would help her understand different perspectives or ideas about using genetic data?

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

Part 5 Task 2

Discover: *How can we use biotechnology to learn more about our environment?*

Earth and its system of many living things is complex. Sometimes we want to make good decisions to help people and the planet, but we do not have enough information. For example, maybe we don't know which or how many living things are in a place. Sometimes eDNA can help solve this problem.

1. Read *Living Things Search Instructions* and follow the steps.

Living Things Search Instructions

Sometimes you can directly observe a living thing, for example if you see a plant or a bug. Sometimes you can use other evidence to know whether a living thing has been in a place. For example, a person might leave personal items behind like a jacket or bag. Another living thing might leave paw prints or scat (poop). In this investigation, you will be listing all the living things you can directly observe or find evidence of.

Pick a research area

Pick a place to do your research. It does not need to be very large. If you can use an outdoor location, that might be best. However, even in an indoor location there are usually many different types of living things. Find a partner and make sure you pick a place where both partners can move around easily.

Identify evidence

Think about what you might use as evidence—for example, things a living thing left behind, like a specific smell, food, scat, leaves, claw marks, pieces of hair or fur, prints, trails, holes, homes, or nests.

Prepare to observe

Take out a piece of paper to make a list of all the living things you observe or find evidence of. Draw two columns on your list. Label one "Living Thing" and the other "Evidence." Figure 5-5 shows an example.

Living Thing	Evidence

Figure 5-5: Sample Observation List of living things and evidence of them.

You can use any of your senses to make observations on your *Observation List*.

a. If you observe a living thing, write it down in the *Living Thing* column and then write how you observed it under *Evidence*.
b. If you know which living thing was in a place because of evidence you find, write it down in the *Living Thing* column and the evidence in the *Evidence* column.
c. If you can find evidence of a living thing but you don't know which living thing it is evidence of, just write down the evidence in the *Evidence* column.

Make your observations

Write or draw the things you observe on your *Observation List*.

Analyze your results

With your partner, consider:

a. Are there any living things you feel sure have been in your research area that you did not observe or find evidence of? For example, maybe you have noticed spiders in your research area before but did not find any today.
b. What would you need to do to make sure you found evidence of all the living things in your research area?

2. With your team, discuss:
   a. Can you think of any way biotechnology might help researchers know which living things have been in a place?
   b. Why do you think that might be helpful?
3. Read *Finding eDNA*.

Finding eDNA

Scientists can use eDNA analysis to collect a sample from a place and find out which living things are present. Especially when living things are hard to find or are microscopic, this can give them a lot more information. They can even discover living things they did not know were there!

eDNA can be used to gather information about many different types of environments. Samples of air, water, soil, sand, ice, and snow can all be used for eDNA analysis. For example, air may have small pollen particles that contain DNA and pond water may have small pieces of DNA from all the things living in the pond. Using eDNA gives scientists a quick, affordable way to learn about an environment.

To study eDNA, scientists often go through several steps:

a. Collect a sample from the environment.
b. Extract the DNA by separating it from everything else in the sample.
c. **Amplify**, or make many copies, of the extracted DNA.

d. Sequence the DNA.
e. Compare the sequenced DNA to databases of living things to see which ones are in the sample.

Remember in Task 1 when you learned about how scientists are collecting reference genomes. Examine the eDNA steps. Why would a database of many different reference genomes be important to help you identify which types of living things are present?

4. Match each of the investigations in Figure 5-6 with one or more sample locations where you could take eDNA samples. Share your answers with your team. Do others on your team agree on the best location for the sample?

Investigation	Sample Location
1. Use eDNA to detect **invasive** carp, a kind of fish, instead of using nets.	a. Sand
2. Use eDNA to find out which species of birds are living in an area instead of tagging them.	b. Air
3. Use eDNA to understand biodiversity in deep areas of the ocean.	c. Snow
4. Use eDNA to find out whether ancient humans lived in a specific place.	d. Water
5. Use eDNA to determine the diversity of land animals instead of using cameras.	e. Soil
6. Use eDNA to evaluate the health of endangered sea turtles instead of drawing their blood.	f. Ice
7. Use eDNA taken from core samples of a 20,000-year-old glacier to find out how the surrounding plants have changed.	g. **Sediment** (material that settles at the bottom of a body of water)
8. Use eDNA to identify lynx tracks in the snow more easily, instead of using expert identification.	

Figure 5-6: Investigations using eDNA and the types of samples they might use; can you match the investigation with the best locations?

5. With your partner, think about the living things that were missing from your list during the living things search.
    a. Where in your research area would you need to sample eDNA to find evidence of these living things?
    b. What types of things could you find out about your research area if you took eDNA samples? Read what Irene says to help give you ideas.

Irene says . . .

There is a wealth of information in eDNA. You can learn so much stuff; you can be a detective. I think it is very exciting, lots of fun!

Part 5 Task 2

Understand: *What types of problems can we use environmental genetic data to identify?*

You know that analyzing eDNA can give you more information about the living things in a specific place. But how do researchers use this information? In this task you will explore four different ways eDNA is being used in research. Then you will design a research experiment of your own for your local community.

1. Take out a piece of paper and title it "eDNA Experimental Design Organizer." Draw six rows and five columns. Label the rows and columns as shown in Figure 5-7. You will be using this paper to help you remember what you learn during this activity. If you do not have time to do all four case studies, just pick one or two to help you learn more about eDNA before you design your own eDNA experiment. More information about the real-world experiments described in the case studies can be found in the Biotechnology! StoryMap.

eDNA Experimental Design Organizer				
Study	**Type of eDNA**	**Collection Method**	**Analyzing Results**	**Making Decisions**
Invasive Species Case Study				
Public Health Case Study				
Conservation Case Study				
Ancient DNA Case Study				
Your Study				

Figure 5-7: eDNA Experimental Design Organizer.

2. Read Invasive Species Case Study and use the information you learn to fill in your eDNA Experimental Design Organizer.

Invasive Species Case Study[1]

Imagine you are plant biologist studying invasive species. You are worried that a plant called the tree of heaven is starting to invade a new area. The tree of heaven is an invasive plant from Asia that grows rapidly and crowds out native species in the United States. It even poisons the ground around it so other plant species cannot grow. The earlier you find the invasive tree of heaven, the better chance you have to remove the plants before they become widespread.

You want to monitor your research area to make sure there are no tree of heaven plants. Right now, your team members go out and do a **visual survey**, which means they move around an area looking for different types of trees. Recently, you learned eDNA can be used to analyze air samples. You wonder if this method might detect the pollen from invasive trees and if it would be a better method than a visual survey.

Your team completes a visual survey. They also collect air eDNA samples to analyze. Figure 5-8 shows their results.

Visual Survey Species	Air eDNA Analysis Species
Black willow	Black willow
Honey mesquite	Honey mesquite
	Siberian elm
	Tree of heaven

Figure 5-8: Tree species found using a visual survey and using air eDNA analysis.

Analyzing results

As a scientist, you can use your results to answer the following questions. Write or draw what you think is important in your eDNA Experimental Design Organizer, then discuss with your team:

a. How were the results different using a visual survey method and an air eDNA analysis method?
b. Did you detect the invasive species you are studying?

Part 5 Task 2

c. Which method helped you detect that species?
d. This study was done only with trees, but do you think eDNA analysis would work better than visual surveys for detecting all types of plants? Which plants might it not work as well for?
e. What would you conclude? Is the tree of heaven present in your research area?

Making decisions

Scientists and other decision-makers use information they have gathered to help make better decisions. Use what you learned to decide which actions to take next, write or draw your ideas in your organizer, and then discuss with your team. Pick one option. Do you think the community should:

a. Launch an effort to remove the invasive tree of heaven before it spreads and hurts the local ecosystem.
b. Take no action, since the visual survey did not find the tree of heaven.

Scientists also need to decide what kind of research they will do next. Pick one option and discuss your reasoning with your team. Do you think you should:

a. Monitor your research area for all types of invasive plants using visual surveys.
b. Monitor your research area for all types of invasive plants using eDNA analysis.
c. Monitor your research area for all types of invasive plants using visual surveys and eDNA analysis.

3. Think about the way air eDNA was used in the *Invasive Species Case Study*. Can you think of any other way to use eDNA to consider which species are in your community? If so, write or draw your ideas in the *Your Study* row of your *eDNA Experimental Design Organizer*.
4. Read Irene's description of another source of eDNA.

Irene says . . .

What is **wastewater**? Wastewater is a mixed water that contains human excrement—anything from the toilet—but also much more. Anything from the shower, the laundry, the dishwasher, the sink, in most cities even storm water and industrial water all end up in your wastewater.

Wastewater contains **microorganisms** such as bacteria and viruses that come from humans who have been infected by them. These microorganisms are diluted in a huge amount of water where there is also dish soap, storm water, many chemicals, and many impurities. If you are looking for human viruses in wastewater you have to look for a needle in a haystack. You have to concentrate and isolate the viruses, which means starting with a large volume of water with some human viruses in it, and ending up with a smaller volume of water with the same number of viruses in it. You can then take a subsample of your concentrated sample and do eDNA extraction, and after some molecular analysis you can get genetic codes for the viruses that were found in your sample. Those genetic codes give you indications of the viral infections that are present in the population that produced the wastewater.

Figure 5-9: A researcher working in a wastewater facility.

5. Read *Public Health Case Study* and use the information you learn to fill in your *eDNA Experimental Design Organizer*.

Public Health Case Study[2]

Imagine you are a public health researcher during the COVID-19 pandemic. You want to know when COVID-19 is spreading widely in your community to help you make decisions. The earlier you can predict that COVID-19 cases are going up, the sooner you can try to help.

You have heard about a method called wastewater surveillance. Wastewater surveillance uses eDNA analysis to find out what is in the wastewater that comes from toilets, showers, sinks, dishwashers, and washing machines. Wastewater can include DNA from the people living in a place, as well as DNA from viruses, bacteria, and other living things.

Your team decides to use wastewater surveillance for a year, starting in September 2020. You analyze the number of **genomic copies** of the SARS-CoV-2 virus, which causes COVID-19. Genomic copies are copies of a specific type of gene in a sample. How many there are shows how common something is in a population. For example, the number of genomic copies of the SARS-CoV-2 virus should show how widespread that virus is in a population.

The results gathered through wastewater surveillance are shown in Figure 5-10. The solid blue area shows the weekly average number of COVID-19 cases reported across several communities in southeastern Michigan. The orange line shows the number of genomic copies of the Sars-CoV-2 virus.

Part 5 Task 2

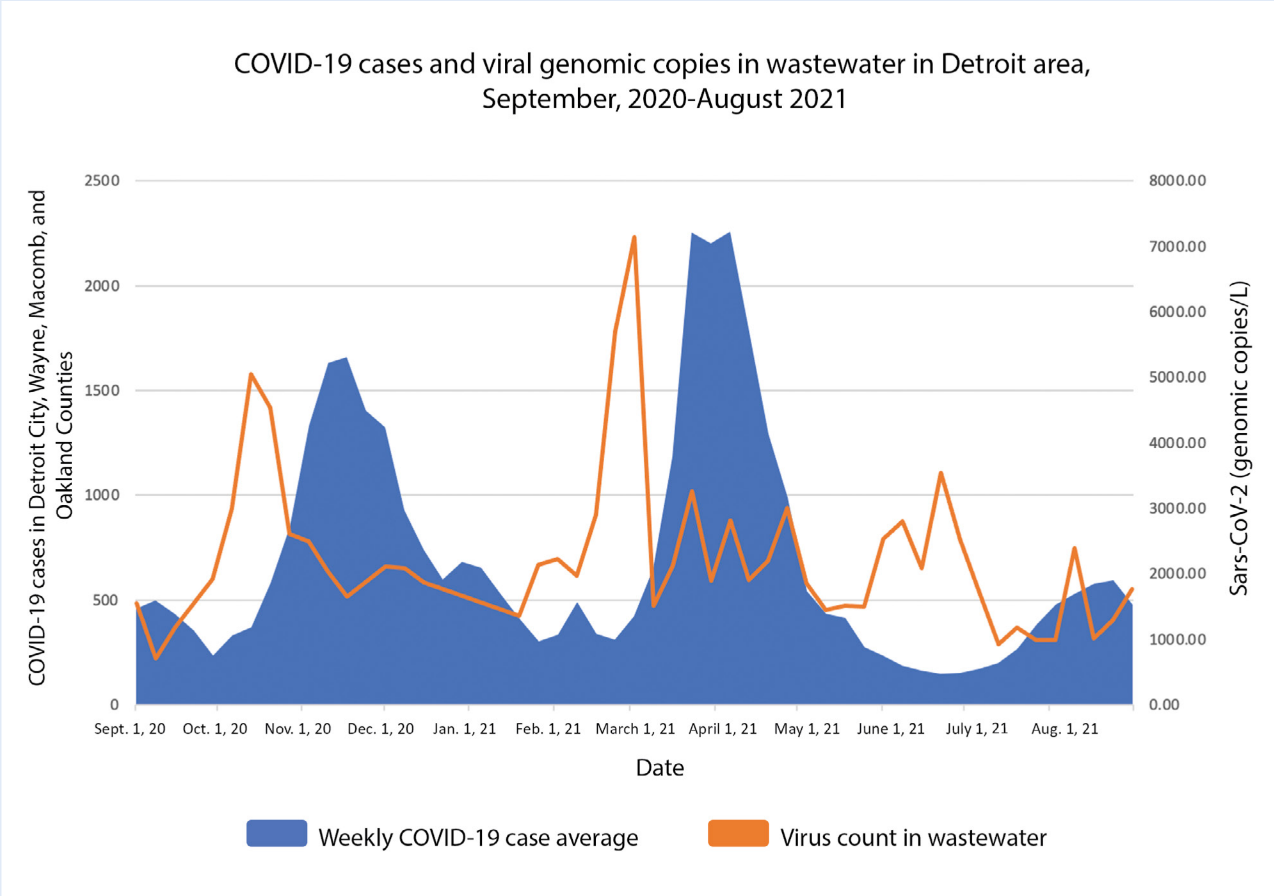

Figure 5-10: Total cases of COVID-19 in southeastern Michigan and number of genomic copies of the virus found in community wastewater, September 2020-August 2021.

Analyzing results

Use your results to answer the following questions. Write or draw what you think is important in your *eDNA Experimental Design Organizer*, then discuss with your team:

a. When were the highest peaks of the genomic copies of SARS-Cov-2?
b. When were the highest peaks of COVID-19 cases?
c. What patterns do you notice about the peaks of the genomic copies and the peaks of the cases?
d. About how long was there between a peak of the genomic copies and a peak of cases?

Part 5 Task 2

Making decisions

Scientists and other decision-makers use information they have gathered to help make better decisions. Imagine it is the end of August 2021 and you need to decide what to do next. There are many tools you can use to prepare for widespread disease, like increased community testing, masking, and planning for more medical workers. However, the community only wants to take protective actions when it is most important. Decide which action you think you should take next and record your ideas in your organizer. Then discuss with your team. Pick one option. Do you think the community should:

a. Prepare for the number of COVID-19 cases to drop.
b. Prepare for the number of COVID-19 cases to rise.

6. Read what Irene says. What are some advantages to using wastewater for analysis?

Irene says . . .

If you want to monitor an upcoming disease, how possible is it to collect clinical samples from everyone in the community and test for all potential pathogens? You are faced with two impossible tasks: collect clinical samples from everyone in the community, and test for all possible pathogenic microorganisms they may be infected with.

So I thought, "What's the easiest way to collect a community **composite sample**?" One way is to collect wastewater. You can run complex tests on a composite sample that would be expensive and difficult to run for every person.

7. Think about the way eDNA was used in the *Public Health Case Study*. Can you think of any way to use eDNA for public health in your community? If so, write or draw your ideas in the *Your Study* row of your *eDNA Experimental Design Organizer*.
8. Read *Conservation Case Study* and use the information you learn to fill in your *eDNA Experimental Design Organizer*.

Conservation Case Study[3]

Imagine you are a conservation biologist studying a local population of rare and endangered tortoises. You are wondering if the many local foxes (which are not endangered) might be eating tortoises and causing the tortoise population to decline.

Your team decides that studying fox scat (poop) would be the best way to figure out if the foxes are eating the tortoises.

You first decide to collect fox scat and visually examine the tortoise remains (bones, scales, and shells) in the samples. Out of the 212 fox scat samples you collected, you find remains from other small animals, but you find zero recognizable tortoise parts.

Zero seems like a really low number, so you decide to test your results by using eDNA analysis on the scat samples. This time, you find evidence of tortoise DNA in 27 of the 212 fox scat samples.

Analyzing results

Use your results to answer the following questions. Write or draw what you think is important in your *eDNA Experimental Design Organizer*, then discuss with your team:

a. Why do you think you found evidence of tortoise parts in the fox scat only through eDNA analysis?
b. Why might this information be important?

Making decisions

Scientists and other decision-makers use information they have gathered to help make better decisions. Use what you learned to decide which actions to take next and record your ideas in your organizer. Then discuss with your team. Pick one option. Do you think conservationists should:

a. Try to discourage the foxes from eating the tortoises. For example, you could make foxes think that tortoises taste bad by putting out foul-tasting fake tortoises.
b. Do not take action to stop foxes from eating tortoises, since it seems like it is not a big problem.

9. Think about the way eDNA was used in the conservation case study. Can you think of any way to use eDNA for conservation in your community? If so, write or draw your ideas in the *Your Study* row of your *eDNA Experimental Design Organizer*.
10. Read *Ancient DNA Case Study* and use the information you learn to fill in your *eDNA Experimental Design Organizer*.

Ancient DNA Case Study[4]

Imagine you are an archaeologist studying the ancestors of modern humans, early **hominins**. You are interested in knowing where different types of hominins lived hundreds of thousands of years ago. You are exploring where ancient hominins known as Denisovans lived, compared to where ancient hominins known as Neandertals lived.

You collect eDNA in layers from a cave in Russia. Layers with higher numbers in the chart are buried deeper. The layers show the following results:

Layer 11.2 (shallowest layer)	Denisovan DNA (fossil)
Layer 11.4	Neandertal DNA (fossil and sediment)
Layer 12.1	Denisovan DNA (fossil)
Layer 12.3	Neandertal DNA (fossil)
Layer 14	Neandertal DNA (sediment)
Layer 15 (deepest layer)	Denisovan DNA (sediment)

Figure 5-11: Hominin eDNA found in cave layers.

Part 5 Task 2

Analyzing results

Use your results to answer the following questions. Write or draw what you think is important in your *eDNA Experimental Design Organizer*, then discuss with your team:

a. Was there evidence of hominins in the cave?
b. Why was eDNA analysis helpful in finding out who was in the cave and when?

Making decisions

Scientists and other decision-makers use information they have gathered to help make better decisions. Use what you learned to decide which actions to take next and record that in your organizer. Then discuss your ideas with your team. Pick one option. As an archaeologist should you:

a. Only test for eDNA in places where evidence of hominins has already been found.
b. Test for eDNA even in places that seem likely to have evidence of hominins, even if no fossils have been found so far.

Part 5 Task 2

11. Think about the way eDNA was used in the *Ancient DNA Case Study*. Can you think of any way to use eDNA to understand the history of people or other living things in your area? If so, write or draw your ideas in the *Your Study* row of your *eDNA Experimental Design Organizer*.
12. Examine your *eDNA Experimental Design Organizer*. You have learned about how DNA is used in ecology, public health, conservation, and archaeology. There are other uses as well. If you can think of any other information you might find out using eDNA analysis, write or draw those ideas on your organizer.
13. Pick one thing you would like to learn about your area or community using eDNA analysis. Write or draw that idea in the *Your Study* row of your *eDNA Experimental Design Organizer*.

14. Think about how you would design your investigation and describe it in your organizer. Be sure to answer:

    a. What type of eDNA sample you would use, for example, soil, air, sediment, sand, water, snow, or ice?
    b. How and where would you collect the sample?
    c. What type of results would you expect to get?
    d. What could you learn and what decisions could be made from this eDNA analysis?

Act: *Should we use biotechnology to help identify problems in the environment?*

Just because eDNA can be used to find out information does not always mean it should be used. In this task you will consider more about ethical and other perspectives. You will also consider the importance of involving the local community when you make decisions about research that could affect them. Then you will use these ideas to modify your eDNA experiment.

1. Take out your *Ethical Concerns List* from Part 1 and remind yourself what those concerns were.
2. Now think about the *Public Health Case Study* from the Understand activity. Discuss with your team: Do you notice any potential ethical concerns about gathering eDNA for public health reasons? Be sure to think about:
    a. Privacy: When collecting wastewater samples, it could be possible to obtain samples from the place where a household connects to the sewer system. If that sample is analyzed, it would reveal information about the people living in that household, including their genetic data and any diseases that are present. Is this a concern?
    b. Justice: You could examine the overall prevalence or risk of certain diseases in certain communities. While this can be useful to help design ways to help the community, what if health or life insurance companies used that information to charge people living in the community higher rates? Is this a concern?

3. With your team, discuss rules or approaches that could help address any ethical concerns. Read what Irene says to learn how her research group approaches the issue of privacy. Do you think this is a good approach?

Irene says . . .

The issue of privacy is very important. To make sure we address it, we collect samples from places that include the wastewater from thousands of people. We're zooming out and looking at the bigger scale. We don't focus on the specific households that the wastewater comes from. We focus on a population of a city or of a county at large. That way no one who looks at our results can pinpoint a specific household or a person.

4. Think back to the other case studies. Are there other ethical concerns you can think of?
5. Examine the three perspectives sheets you worked on in groups during Task 1. Do you have anything you would like to add to the social, economic, or ethical perspectives on the way genetic data can or should be used?
6. Now, with your team, create a sheet for the fourth perspective: environmental. Write or draw answers to these questions:
   a. What are the important uses of genetic data from this perspective?
   b. Are there any concerns about the use of genetic data from this perspective?
   c. Who should own or be considered when thinking about genetic data from this perspective?
7. Look at the eDNA experiment you designed from the Understand activity. Examine it carefully. Are there any potential concerns you notice from any of the four perspectives? If so, create a way to address those concerns.

8. Now pick three other people on your team and explain your experiment plans to them. Then switch roles. When researchers design a community investigation, they need to make sure they pay attention to the opinions and feelings of people living in the community. Surveys, meeting with community leaders, and holding a meeting with the public can all help with this process. By explaining your ideas to your team, you are learning about the perspectives of others in your community in a limited way.
9. When a teammate is explaining their experiment to you, think carefully. Would you have any additional concerns? If so, share those ideas with your teammate.
10. After receiving feedback from your team community, examine your experiment again. Is there anything you would like to change? What can you do to address any concerns?
11. If you feel comfortable, present your research idea to your community! You could use a poster, give a talk, or use another creative way to share your experiment with your classroom, school, or in another local space. Discuss:
    a. What question did you chose to answer using eDNA?
    b. How did you design your experiment?
    c. How have you considered the four perspectives, including the ethical perspective, and did you make any changes because of these perspectives?

Congratulations!

You have finished Part 5.

<u>Find out More!</u>

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.

Amplify: To make many copies of something

Ancestry: Information about your ancestors, such as the parts of the world they came from

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

Composite sample: A mixture of individual samples

Deidentified: Data that can be used for research without having names or other information that would identify where the data came from

Direct to consumer testing (DTC): When an individual pays a company to gather data from their DNA

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

Economic: Concerned with money, income, or the use of wealth

Environmental DNA (eDNA): A sample of all the DNA of the many living things that are present in an environment

Ethical: The fairness of something

Genetic data: The information in a genome

Genome: The complete sequence of DNA of a living thing

Genomic copies: Copies of a specific type of genome

Hominin: A species closely related to modern humans

Invasive: Not native to an area

Microorganisms: Living things that are too small to see without magnification

Next-generation sequencing: A way of sequencing DNA much faster by reading many sequences at one time and then reassembling them into the entire genomic sequence

Open access: Able to be freely accessed by other users

Patent: A license from that government that means an individual or company owns an invention for a period of time

Reference genome: The most common gene sequences across a population

Sediment: Material that settles on the bottom of a body of water

Social: The interaction of people in the community and their education, health, and well-being

Variants: Genes with one or more differences

Visual survey: To move around an area looking for a type of living thing

Wastewater: The combined water and waste produced by using toilets, showers, sinks, dishwashers, and washing machines

End Notes

1. Johnson, Mark D., Mohamed Fokar, Robert D. Cox, and Matthew A. Barnes. 2021. Airborne environmental DNA metabarcoding detects more diversity, with less sampling effort, than a traditional plant community survey. *BMC Ecology and Evolution* 21, no. 1: 1-15. Retrieved from https://bmcecolevol.biomedcentral.com/articles/10.1186/s12862-021-01947-x#Fig5.
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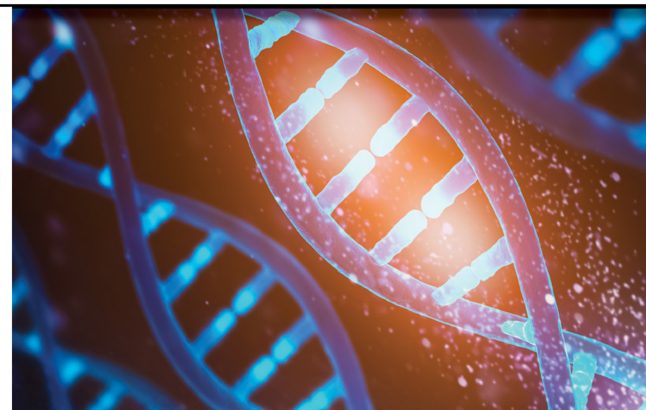

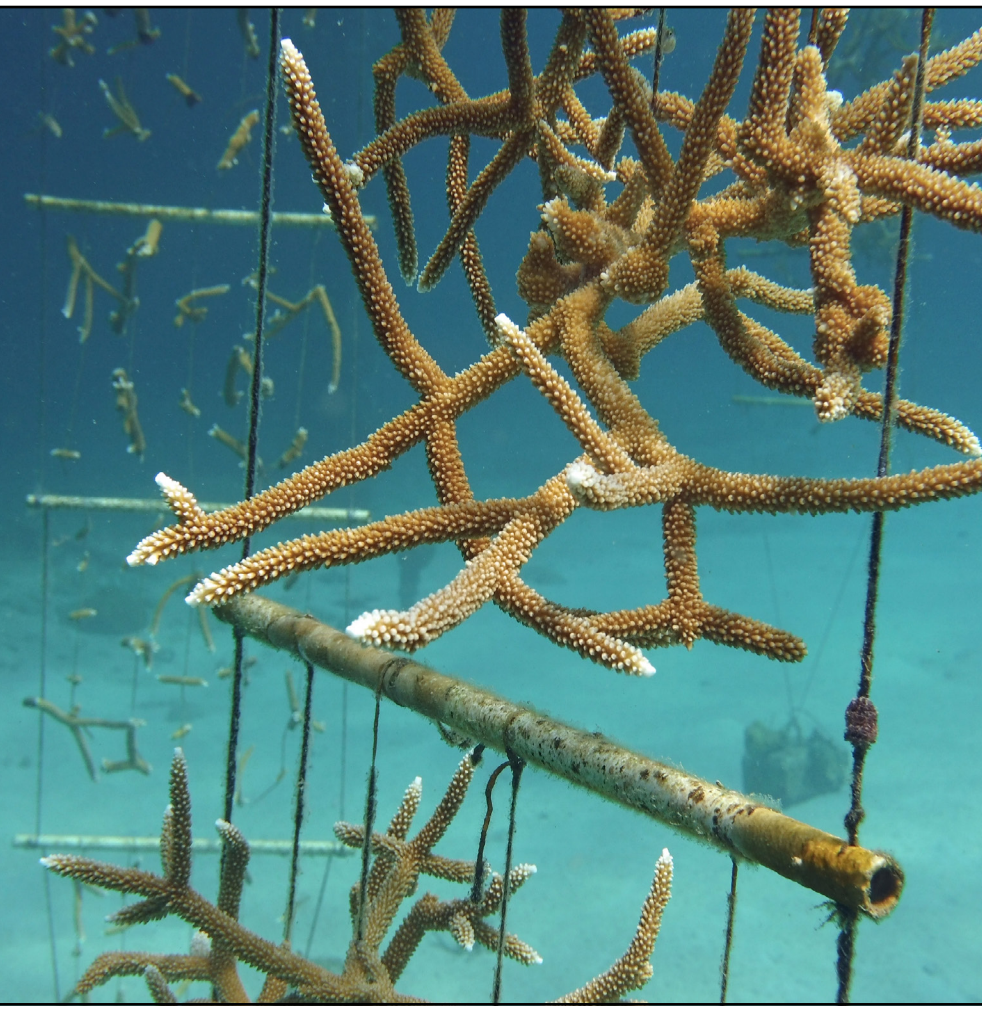

Part 6:

Biotechnology and the Environment

SUSTAINABLE DEVELOPMENT GOALS

developed by

Smithsonian
Science Education Center

in collaboration with

iap SCIENCE HEALTH POLICY
the interacademy partnership

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PART 6: BIOTECHNOLOGY AND THE ENVIRONMENT

<u>Find out More!</u>

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: How can biotechnology make our communities cleaner?					
Discover	Observe air, land, or water pollution in your community.	• Paper • Pencils or pens		45 minutes + observation time	212
Understand	Create a model of different pollution problems and how biotechnology can help make them better. Then apply what you have learned to a problem you observed.	• Paper • Pencils or pens • Scissors	Printout of Figure 6-5 (optional)	40 minutes	217
Act	Consider different perspectives on how you could address the problem you identified and create a plan.	• Paper • Pencils or pens		50 minutes	223
Task 2: How can biotechnology help restore biodiversity to ecosystems?					
Discover	Model the importance of genetic diversity to an ecosystem.	• Paper • Pencils or pens • Scissors	*Identity Map* (Part 1) Printout of Figures 6-11 and 6-12 (optional)	30 minutes	229
Understand	Investigate the potential of biotechnology to restore biodiversity to ecosystems.	• Paper • Pencils or pens • Scissors	Printout of Figures 6-13 and 6-14 (optional)	20 minutes + investigation time	237
Act	Create a set of rules about the use of biotechnology to encourage conservation. Share these rules or a conservation plan you create with others.	• Paper • Pencils or pens		20 minutes + action time	241

Task 1: How can biotechnology make our communities cleaner?

In this task you will ***discover*** what you already know about the problems with waste and pollution in your community. Then you will create a model to ***understand*** how **biotechnology** can be used to help reduce or eliminate waste and pollution. Finally, you will ***act*** to choose and suggest some of these solutions to your community.

Meet Your Research Mentor

Meet Dr. Susie Dai. Susie (pronounced SOO-zee) is one of the many researchers around the world trying to use biotechnology to help the environment. Her team tries to find ways to use living things, such as fungi and bacteria, to break down harmful chemicals in the environment.

Susie is a scientist and researcher at Texas A&M University in the United States. She has a PhD in chemistry. However, she also has knowledge and perspectives that came from other parts of her **identity**. Since Susie is now working with you, it is important to understand who she is.

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

- 41 years old
- Asian woman
- Lives in Texas
- Is a working mom
- Was born in China and still has relatives there, but family lives in the US
- Likes science, engineering, and poetry; enjoys reading and writing
- Is short with black hair, and wears glasses or contacts
- "I felt very bad about being short when I was young. I gained more confidence after walking into the professional world. What you look like does not speak for who you are, but what you do is what characterizes you."

- Is a funny person, and loves humor! "I think of being hardworking as the salt, which makes life tasty; love is sugar, which makes life sweet; humor is the light beam, which makes life pleasant."
- Is the planner for her family. "I also volunteer in community events that I believe my expertise can contribute to; otherwise, I follow community leaders. There should not be too many cooks in a kitchen."
- Advice for young people: "Never forget what interests you when you are in school. The questions you ask at this age are important questions. You should seek those answers over your lifetime. I encourage everyone to always ask questions!"

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

- Are there things you have in common with Susie?
- Are there ways in which you are different from Susie?
- Can you see anything about Susie's identity, in addition to her university degrees, that would help her understand different perspectives or ideas about the environment?

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

Discover: *How do waste and pollution affect my community?*

Most communities have some kind of waste or **pollution**. Waste and pollution can take the form of plastic trash, used cooking or mechanical oils, leftover or unused food, smoke or **smog**, harmful chemicals, or other materials. Waste and pollution can be found in the air, on land, and in water. In this activity, you and your team will observe the waste and pollution already in your community.

1. Take out a piece of paper. By yourself, think about the following questions and draw or write your answers.
   a. Where have you already noticed waste or pollution in your community?
   b. Do you think you can make those parts of your community cleaner? Why or why not?

2. Read what Susie has to say. She explains the kinds of waste and pollution she is most concerned about in communities.

Susie says . . .

Many governments, including the United States government, have standards to make sure drinking water is safe. You can go to the Environmental Protection Agency website and find a very long list of **contaminants** that are part of those standards. You might say, "Oh, this pesticide is on that list, so I should not find this in the public water I drink."

But there are other chemicals that humans are constantly producing that may not be in the standards yet. We call those **emergent** contaminants. What I'm focused on now is those emergent contaminants. One of those contaminants is PFAS, or polyfluoroalkyl substances. PFAS are also known as "forever" chemicals because of how long it takes for them to break down.

3. Now you are going to make some observations about waste and pollution in your community. Choose a partner or a small group and pick one of the observations listed in *Community Observations* to complete in your community.

Community Observations

Make sure your team divides as evenly as possible into three groups to conduct your observations. Each group will observe either air, water, or land.

You can do the observations by moving around your local area yourself, or by collecting information using maps, photographs, social media posts, conversations with community members, or another method that works well for your team. Choose a kind of investigation that allows all members of the team to participate. You can also choose the area you want to observe. It could be just a small area around your school or it could be a bigger area, like your neighborhood or your town.

Part 6 Task 1

Remember that your task is just to observe and notice. It is okay if you can't answer all the questions in your section. It is okay if you notice something that makes you wonder or want to find out more. It is okay if you notice only one problem in your community. You are just collecting as much information as you can about your community!

Observation #1: Air

You will try to notice any waste or pollution in the air in your community. Use the following suggestions to help you make your observations.

- Are there any places where cars, trucks, or other vehicles wait while their engines are on (such as a bus lot or a school pickup/drop off area)?
- Are there streets with heavy traffic during certain times of day?
- Is it smoggy or smoky on certain days?
- Can you tell where the smog and smoke are coming from?
- Is it ever hard to breathe or exercise in your community?
- Are there factories, construction sites, or other spaces in your community that cause smoke, dust, or other kinds of air pollution?
- Do you notice any signs of smoke, smog, or pollution on statues, monuments, or buildings in the community?
- Is anyone from your community already trying to improve air pollution? What are they doing to help?

Figure 6-1: A city with a lot of air pollution.

Observation #2: Land

You will try to notice any waste or pollution on land in your community. Use the following suggestions to help you make your observations.

- Are there any places where the soil has been dug up, turned over, or disturbed, such as construction sites, gardens, or farms?
- Are there places like restaurants, car repair shops, gas stations, or factories where you notice liquids or solids from those businesses seeping into the ground?
- Where does food waste go in your community?
- Are there places with abandoned buildings, or where people dump appliances, cars, or electronics?
- Are there places where trash doesn't get picked up? Are there places with a lot of litter?
- Have any trees been cut down recently in your community?
- Are there any areas in your community that smell bad or different?
- Is anyone from your community already trying to improve waste and pollution on land? What are they doing to help?

Figure 6-2: Construction equipment digs up an area of land.

Part 6 Task 1

Observation #3: Water

You will try to notice any waste or pollution in water in your community. Use the following suggestions to help you make your observations.

- When it rains, were does water go in your community?
- Are there spaces that are **impermeable**, meaning water can't seep through to the ground (such as pavement)?
- Does your community have streams, rivers, ponds, lakes, wetlands, or **reservoirs**?
- Are there any places with standing water after a rainstorm, or places that take a long time to drain?
- Think about the street where you live or the street where your school is.
    - Do you know which way the water flows when it rains?
    - Does your community have storm drains?
    - Do you know where water in the storm drains ends up?
- Are there any buildings, businesses, factories, landfills, or construction sites that have materials, chemicals, trash, or food waste that could go into the water in your community during a heavy rainstorm?
- Is anyone from your community already trying to improve waste and pollution in water? What are they doing to help?

Figure 6-3: Water flows into a storm drain.

Part 6 Task 1

4. Think to yourself first, and then discuss with a partner:
    a. How does what you noticed during your observations make you feel?
    b. Are there any problems you want to solve more than others?
5. Read what Susie says quote about her research and why she does this work.
    a. How did noticing a problem help motivate Susie?

Susie says . . .

Many people in the United States have access to safe drinking water. But we cannot forget that some people do not. Those people may rely on **raw water**, which is water that has not been treated to remove contaminants. For example, 10% of the US population relies on private wells for their drinking water.

That got me into my current research, which has two parts. One part is trying to understand to what extent people are exposed to **toxic** chemicals in the environment. The other part is trying to understand how to **mitigate** and treat those risks.

It's important to understand how we can confine contaminants. I'm not saying we'll stop producing chemicals. But we as human beings need to be responsible and accountable to manage those things that we produce. We have to look at what we put in the environment, and look into solutions to **remediate** those contaminants.

***Understand**: How can biotechnology help solve problems of waste and pollution in a community?*

In the Discover activity, you and your class made observations about the waste and pollution in the air, land, and water in your community. In this activity, you will model a community that has problems with pollution and waste in its air, land, and water. You will learn how biotechnology can help with these problems through something called **bioremediation**. Bioremediation is using living things to correct, stop, or reverse damage to the environment.

Part 6 Task 1

1. Choose a partner or a small group.
2. Take out a piece of paper or open a digital document.
3. Read *Community Problems with Waste and Pollution* and choose one problem that interests or feels most important to you and your group.

Community Problems with Waste and Pollution

This section describes several waste and pollution problems that a community might have.

Abandoned building: An abandoned building has lead paint on its indoor and outdoor walls. The lead paint has peeled off the building and lead has now gotten into the soil near the building. When it rains, some of that lead-filled soil washes away.

Shopping area: A shopping area has paved roads, paved sidewalks, and paved parking lots. These surfaces are impermeable, meaning rainwater cannot be absorbed. During storms the rainwater goes into storm drains instead. The rainwater contains waste and pollution like motor oil, pet waste, tiny rubber pieces from car tires, and cigarette butts.

Figure 6-4: Water from this paved road drains into a grassy area.

Part 6 Task 1

Construction site: A construction site is digging a large hole for a new building. Digging up the soil releases some of the **carbon dioxide** that was trapped in the soil. And some of the construction vehicles release carbon dioxide from their engines. Carbon dioxide is one of the causes of global climate change.

Athletic field: The community uses a chemical called an **herbicide** to prevent weeds from growing on the grass athletic fields. The herbicide washes away during heavy rainstorms and enters the local rivers, streams, and storm drains.

Backyards and parks: People in the community use a chemical **pesticide** to reduce or eliminate biting mosquitoes in their backyards and parks. But those pesticides may kill many other kinds of insects, including honeybees and ladybugs. They can also accidentally poison birds, cats, dogs, fish, and other animals.

Bus parking lot: A fenced parking lot is used to store all the school buses for the community. The buses run their engines when leaving, waiting, and returning, and release pollution into the air. Motor oil leaks from the buses. When the buses are washed, soap and other kinds of cleaning products end up on the pavement and seep into storm drains.

Asphalt road and roofs: The roads in the community are made with a material called asphalt. Some home and building roofs also use asphalt shingles on the roof. On hot, sunny days, the asphalt heats up and can release pollution into the air.

Pond: A pond in the community is near the shopping area and the abandoned building. Some of the water from these areas runs into the pond when it rains.

4. Write down or draw the problem you picked on your piece of paper. You can use the title of the problem, the description, a symbol, an illustration, or another marking to represent the problem you chose. For example, if you chose Shopping Area, you might draw a shopping bag and a parked car.

5. Read each of the _Bioremediation Solution Cards_ in Figure 6-5. You will use one or more of these solutions to try to solve the problem you chose in your model.
6. If you can, print Figure 6-5 and cut out each solution card. You only need one set of _Bioremediation Solution Cards_ for each group. You can also just read the solutions here and use the icons to record your ideas.

Bioremediation Solution Cards

Rain Garden

A rain garden is a group of plants that can quickly absorb and filter **runoff** from roofs, driveways, and sidewalks. The plants trap water and help it be absorbed into the soil more quickly. Rain gardens reduce the amount of standing water where mosquitoes can breed. The plants, fungi, and bacteria in the garden may also filter out some of the **pollutants** from the water. This helps to keep pollution out of the storm drains and waterways.

Evergreen Tree

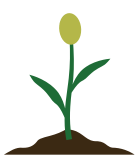
This type of tree can trap air pollution in its needle-like leaves, branches, and trunk. Evergreen trees have leaves all year round. Like all other plants, an evergreen tree absorbs carbon dioxide from the air. Because it is so tall and is alive during every season, it can absorb a large amount of carbon dioxide over time.

Sunflower

This plant uses its roots to absorb heavy metals, like lead, from the soil. Like the evergreen tree, it also absorbs carbon dioxide. But the sunflower dies off when the temperature gets too cold.

Water Hyacinth

This kind of plant lives in water. It can remove heavy metals like lead from water. It can also remove pollutants from water. It grows incredibly quickly.



Cover Plants

These are plants that are planted in areas with bare soil, like empty farm fields or construction sites. One example is the mustard plant. These kinds of plants keep soil, pollution, and heavy metals from being washed away by rain. They can absorb harmful materials and remove them from the soil, as well. They can also take carbon dioxide out of the air and help trap it in soil.

Figure 6-5: Bioremediation solutions for problems with waste and pollution. (continued)

Aquatic Bacteria

Certain kinds of bacteria can remove pollution and waste from water, such as motor oil or poop from humans or other animals. These bacteria break pollution and waste down into materials that are not harmful.

Soil Bacteria

Certain kinds of bacteria can help remove heavy metals like lead from soil. They use the heavy metals for energy and break them down into materials that are not harmful. Sometimes this process can take a long time.

Genetically Modified Bacteria

Scientists can change the **genome** of certain bacteria to help them break down heavy metals and pollution faster than bacteria found in nature.

Genetically Modified Plants

Scientists can add **genes** to a plant that help it make its own protection against pests. For example, there is a certain kind of bacteria that make a substance that kills flies. If genes from those bacteria are added to a plant, the plant can make the substance and protect itself from flies.

Biochemical Pesticide

A **biochemical pesticide** is **nontoxic** and is produced naturally by a living thing. One example is a scent that attracts certain kinds of pest insects to a trap or prevents them from mating.

Microbial Pesticide

Microbial pesticides use bacteria, fungi, viruses, or other small living things to kill pests or plants. For example, a certain fungus can grow on a caterpillar that is a pest. The fungus absorbs water and nutrients from the caterpillar until the caterpillar dies. Then the fungus can spread through the air to other caterpillars.

Figure 6-5: (continued)

7. Ask each member of your group to choose the bioremediation solution (or solutions) they think will solve the problem you chose. They can show their choice by placing the card on top of the problem, or by drawing the icons on your paper.
8. Now, as a group, add, rearrange, or remove the solution cards according to what you think will best help solve the problem in your model. Try to agree as a group how you want to solve the problem. Use these questions to guide you:
   a. Do any of these solutions seem easier to use than others?
   b. Do you think people in the community might be worried, curious, or want more information about some of the solutions?
   c. Will the solutions work for a short time or a long time?
9. By yourself, think about these questions:
   a. Was it easy to agree? Why or why not?
   b. Were there any solutions that made you worried, uncomfortable, or that you wanted to know more about before using?
   c. Were there any solutions that you were excited about?
10. If you would like, choose another model community problem and repeat steps 7 and 8.
11. Think about one problem that you noticed in your community during the Discover activity.
12. Are there any bioremediation solutions from the Understand activity that would help you solve that problem? Why or why not?
13. Researchers are working on many different types of bioremediation solutions. Read what Susie says about her research into how fungi can help remediate contaminants in the environment.
    a. Susie is trying to find a bioremediation "superhero." If you were also searching for a bioremediation superhero, what would you want it to do?

Susie says . . .

If you go out to the forest and look at a piece of dead wood, it has mushrooms growing on it, right? The mushrooms are breaking down the material in the dead wood. One of those materials is lignin. Lignin is the part of a plant's cell wall that is very hard to break down. That's why expensive furniture is made out of wood with lots of lignin. The furniture lasts a long time because of the lignin in the wood. Fungi, like the mushrooms on dead wood, can break down lignin.

In my research, we are trying to use the same systems in a fungus that can break down lignin to break down contaminants like forever chemicals. We are using tools that nature already has in place, but that people haven't really appreciated yet.

There are fungi that we have worked with in the past for bioremediation, but I am trying to find a new fungus that can do a better job than the ones we already know. What I hope to do is find a superhero that can break down many contaminants at once!

Act: *How can I solve waste and pollution problems in my community?*

In the Discover activity you noticed the problems with waste and pollution in your community. You learned about how biotechnology can help solve problems in the Understand activity. Now it is time for you to use what you have learned about your community and about biotechnology to plan and share how to solve problems in your community.

1. Think back to the *Bioremediation Solution Cards*. You are going to rank each solution according to how comfortable and confident you would be using it and whether you think you would have the power to use this solution in your community. Figure 6-6 shows an example.

Most (11)
11. Rain garden
10. Cover plants
9. Sunflower
8. Water hyacinth
7. Aquatic bacteria
6. Soil bacteria
5. Evergreen tree
4. Biochemical pesticide
3. Microbial biopesticide
2. Genetically modified bacteria
1. Genetically modified plants
Least (1)

Figure 6-6: An example of solutions ranked by how comfortable and confidant you would feel using them and whether you think you have the power to use them in your community.

2. Consider the solutions you ranked at the bottom of the scale. Think to yourself:
   a. Would learning more about those solutions make you feel more comfortable and confident? How or where could you find more information?
   b. Who would you need to communicate with in your community to get more power to suggest or use those solutions?
3. Thinking about the **social**, **economic**, **environmental**, and **ethical** perspectives of biotechnology solutions is an important part of taking action. With your partner or a small group, read *Perspectives on Waste and Pollution Solutions*.

Perspectives on Waste and Pollution and Solutions

Social

Genetically engineered bacteria can help break down the harmful pollution and metals in soil and water more quickly than bacteria found in nature. But the risks of releasing genetically modified bacteria into the natural environment are still being studied. Some people in a community may not feel comfortable introducing genetically engineered organisms into the environment. They might voice concerns such as, "Can the **DNA** from these bacteria transfer to other living things?" Is it right to use genetically engineered organisms if some people are worried? How should communities make this decision, and who should be involved?

Economic

Plants like sunflowers and evergreen trees can help remove pollution from the air and soil. But it costs money to buy, plant, and take care of these plants. It also takes time to get permission to plant them, decide where to plant them, and take care of them once they are planted. Who in a community should be responsible for using their time and money to take care of plants to help with waste and pollution?

Environmental

Water hyacinths can help to remove pollution and heavy metals from water. They are inexpensive, grow fast, and work quickly to clean water. But when they are not native to an area, they can spread quickly, block other plants from growing, harm fish populations, and clog rivers, streams, and ponds. Would you use water hyacinth if it was not native to your community? Why or why not?

Figure 6-7: Invasive water hyacinths cover the entire surface of this river.

Ethical

A community may have many different problems with waste and pollution. These problems may affect some groups of people more than others. How should a community decide which problems are the most important to solve?

4. Choose one perspective from *Perspectives on Waste and Pollution Solutions* to discuss with your partner or a small group. Try to agree on an answer to the question at the end of each one. When you are done, find another group that chose the same perspective. Compare your answers.
5. Read what Susie has to say about the perspectives she has to consider when researching bioremediation. Do you think any of those perspectives will be important to your community?

Susie says . . .

One of the very important goals of bioremediation is that it works quickly and is affordable.

If my boss says, "Deal with this chemical within two weeks," I have to get it done in two weeks! If Congress says, "By 2025 we have to achieve this remediation goal," and I say it will take me 100 years to do it, those politicians will kick me out of the room. If I want to produce a biofuel, but it's $20 a gallon, who is going to buy that at the pump station?

Using a fungus to clean up a contaminant is not fast enough for modern society. That's why my research is trying to move things faster!

We want to help a natural organism, like a fungus, remediate in a reasonable amount of time. What we hope to do is to combine bioremediation with other potential systems and tools that already exist in engineering, chemical engineering, or environmental engineering, and can be readily integrated into the systems we already have.

Part 6 Task 1

6. By yourself, think back to the problems you noticed in your community from the Discover activity.
    a. Is there one problem in your community that you feel confident you could help to solve? Choose just one.
    b. Are there any bioremediation solutions from the Understand activity that could help you solve that problem?
7. After you have selected a problem you feel you could solve, answer these questions and record your answers on a piece of paper or digital document.
    a. How could you get started right now on solving this problem in your community?
    b. Who in your community could help you with this solution?
    c. What makes you worried about trying this solution?
    d. What makes you excited about trying this solution?
8. Find a person in your household, school, or community to share your ideas with. Explain your solution and ask for feedback.
9. Read what Susie says about how to engage with the community. How do you think you might try to use education and outreach to get your community to understand bioremediation?

Susie says . . .

Sometimes you have a wonderful solution, but the people in the community do not agree with you. But you can never push any agenda. We are a human society. We have to consider the current standards and make small steps to get the community to accept our solution. Education and outreach can help. We can educate our community and our next generation.

Task 2: How can biotechnology help restore biodiversity to ecosystems?

Many living things around the world are struggling because of the impacts of humans on the planet. Human activities often have a negative impact on **biodiversity**. Biodiversity is the variety of the many different living things on Earth. In this task you will ***discover*** more about the biodiversity problems caused by people. Then you will investigate to ***understand*** more about how biotechnology can provide useful tools to help conserve biodiversity. Finally, you will ***act*** to increase knowledge and understanding of biodiversity and biotechnology issues in your community.

Meet Your Research Mentor

Meet Dr. Mary Hagedorn. Mary (pronounced MARE-ee) is one of the many researchers around the world trying to use biotechnology to help the environment.

Mary is a research scientist at the Center for Species Survival at the Smithsonian Institution in the United States. She has a PhD in marine science. However, she also has knowledge and perspectives that came from other parts of her identity. Since Mary is now working with you, it is important to understand who she is.

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

- Female
- Lives in Hawaii, USA
- Likes to cook, travel, swim, snorkel, garden, and read
- Only girl in a family of seven brothers
- Explorer: "Have been an explorer since I was a small child, as I constantly explored the space in and around my neighborhood"
- Traveler: "Traveled internationally on my own in high school and lived with a family in Sicily"
- During graduate school, traveled and lived throughout Central and South America working on science research

- "After I got my doctorate, I traveled and lived in a small village in West Africa, which transformed me as I learned more about this wonderful community that cared for each other as part of the social good."
- Caring: "I would like to think that the social good of caring for others could also be extended to caring for and protecting our ecosystems and our planet, so that every child can grow up to see and experience beautiful and wild places on Earth."

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

- Are there things you have in common with Mary?
- Are there ways in which you are different from Mary?
- Can you see anything about Mary's identity, in addition to her university degrees, that would help her understand different perspectives or ideas about the environment?

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

Discover: *What are the biodiversity issues caused by people?*

Life on Earth depends on biodiversity. Many different living things are part of the ecosystems on which life depends, including human life. In this activity you will find out more about your relationship with biodiversity. You will also explore the threats to biodiversity at different levels.

1. Take out your *Identity Map* from Part 1 and examine it closely. Remember that each person is unique.
   a. What are some things about your identity that makes you different from others around you? Pick one thing to share.
2. As a team, use a board, a shared piece of paper, or a shared digital document to create a *Team Identity Map*.
   a. Draw a circle in the center, just like you did for your identity map.
   b. Label this circle "Our Team."

c. Have each team member add to the _Team Identity Map_ by drawing or writing the part of their identity they picked to share.

3. As a team, examine the _Team Identity Map_. Discuss:
   a. What is the advantage of having people with many different identities be part of the team?
   b. Are there ideas or types of knowledge you have as a group that you would not have as individuals?
   c. Is this true for people in general? Is it useful to have lots of different skills and interests?
4. Read what Mary says about why she thinks diversity is so important. Why do you think diversity is important? Share your thoughts with a partner.

Mary says . . .

In countries that have diversity of thought, diversity of beliefs, diversity of backgrounds, diversity of abilities, we do better in facing problems. This is because when you only think in one way, you will tend to answer a problem in only one way. So having diversity of thought, people, and beliefs helps us become stronger and have a variety of different approaches. It's the same thing in plants, in animals, in other living things: When you have more diversity, it just gives you more options to respond to different challenges.

5. Read _What Are Types of Biodiversity?_

What Are Types of Biodiversity?

The variety you find among people is partially due to small differences in their genomes. This can be thought of as **variations** in the sequence of genes, which can lead to all sorts of differences in individual humans.

The same is true for other **species**. A species is a type of living thing, like a human or a dog or a coconut tree. Variations in the genome of a species are called genetic diversity. High **genetic diversity**, which is a large variety of different **traits** in the

Part 6 Task 2

population, gives the population a greater chance to survive threats and stresses in the environment. Even if a specific individual within a population doesn't survive a threat, a species with high genetic diversity is more likely not to go extinct. Figure 6-8 shows some of the genetic diversity of dogs.

Figure 6-8: Different breeds show the genetic diversity in dogs.

However, diversity isn't only within a genome. Having lots of different species present in a place is also important. This is called **species diversity**. Species fill many different roles in an **ecosystem**. An ecosystem is a community of living and non-living things. Some species produce food, like plants. Others eat plants, like humans and deer. Others **decompose** or break down once-living things, like fungi and bacteria. Many species are involved in each of these roles within an ecosystem. Generally, when a greater number of species live in a place, the ecosystem is better able to overcome challenges, like a changing climate or the loss of one species in the ecosystem. Figure 6-9 shows an example of a coral reef ecosystem with many different species. How many can you spot?

Figure 6-9: Example of species biodiversity within a coral reef ecosystem.

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A variety of ecosystems is also an important part of biodiversity. There are many types of ecosystems, from a swamp to a mountain meadow to a coral reef. A wide variety of ecosystems is called **ecosystem diversity**. Ecosystem diversity encourages a broader range of species and is important for the planet. For example, think of how many different types of species could live in the ecosystems found in Figure 6-10.

Figure 6-10: A place with a variety of ecosystems: lake, rocky beaches, pine forest, and snowy mountains.

6. Discuss with your team:
    a. How do you think genetic diversity, species diversity, and ecosystem diversity relate to one another? For example, does genetic diversity lead to species diversity?
    b. Why do you think it is important to have biodiversity on Earth? Make sure you think about how all species, including humans, are connected to one another.
7. You will be using elkhorn coral populations as an example to investigate how genetic diversity affects the ability of a population to survive. Read Mary's thoughts. What are some of the problems facing the species of elkhorn coral in the Caribbean?

Mary says . . .

The ocean in the Caribbean is in a very bad shape. It's small and it only has about 60 species of coral. It has a history of pollution, diseases, and other local stressors. Imagine you have all these beautiful islands, and they all have these amazing corals around them. Over time some of these corals were blown up to make bays and things like that. It only got worse as more people went into the Caribbean, in terms of tourism and boats and traffic. You also have global stressors, such as climate change, on top of that. Some scientists predict that by the mid-2030s, only 1% of global corals will still exist.

8. Read *Genetic Diversity Card Game Instructions* and play the game.

Genetic Diversity Card Game Instructions

The problem

Elkhorn coral is a species of coral that lives in the Caribbean, Florida, and the Bahamas. Although elkhorn coral are just a single species, they are a very important part of their ecosystem. Elkhorn coral form dense groups called **thickets** in shallow water. These thickets provide places for fish and other wildlife to live. However, human impacts threaten the elkhorn coral population.

Your goal

Your goal is to have as many elkhorn coral individuals survive as possible.

Types of cards

There are two types of cards:

a. Elkhorn Coral Cards (12): Each of these cards represents an individual coral that is part of the elkhorn coral population. Each individual is genetically

Part 6 Task 2

unique and has different traits and abilities. Four traits are represented in the cards:

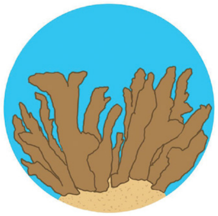
- Myxococcales level: Myxococcales is a bacteria that helps elkhorn coral resist white band disease. Some coral encourage the growth of more myxocaccales around them.
- Heat resistance: The ability to live in warming water
- Deep sea level: The ability to live in deeper water
- Oxygen strength level: The ability to survive when there is less oxygen in the water

b. Scenario Cards (4): Each card shows a situation that could happen to the coral population.

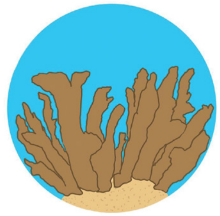
Playing the game

1. Print and cut out the Elkhorn Coral Cards in Figure 6-11 and the Scenario Cards in Figure 6-12. If you cannot print the cards, you can write the information from the cards on a piece of paper and cut it apart.
2. Divide the Elkhorn Coral Cards evenly among your group. There are 12 cards, so if possible make your group a size where the cards can be evenly distributed.
3. Place the Scenario Cards face down between the players.
4. Have one player pick a Scenario Card and read it to the group. Each scenario will focus on a specific trait.
5. Each trait on the Elkhorn Coral Cards has a different number value. If the number is below the allowed number on the Scenario Card, discard the Elkhorn Coral Card.
6. After each round, count how many corals are left.
7. Then draw another Scenario Card and continue.
8. Keep playing until all four Scenario Cards have been used.
9. How many corals are left at the end?
10. Play again to see if the number of corals left at the end changes if you pick the Scenario Cards in a different order.

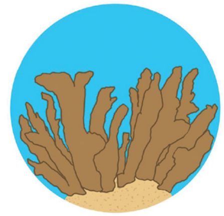
Elkhorn Coral Cards



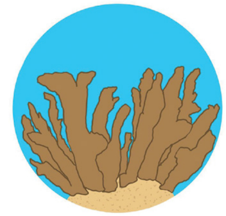
Myxococcales level: 4
Heat resistance: 5
Deep sea level: 7
Oxygen strength level: 8



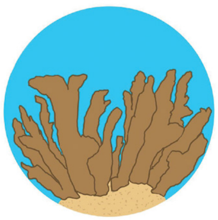
Myxococcales level: 2
Heat resistance: 6
Deep sea level: 5
Oxygen strength level: 7



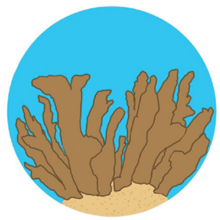
Myxococcales level: 1
Heat resistance: 6
Deep sea level: 3
Oxygen strength level: 2



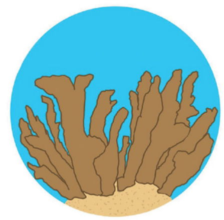
Myxococcales level: 8
Heat resistance: 7
Deep sea level: 7
Oxygen strength level: 7



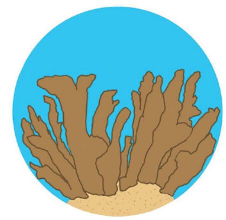
Myxococcales level: 0
Heat resistance: 1
Deep sea level: 1
Oxygen strength level: 3



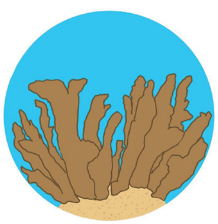
Myxococcales level: 2
Heat resistance: 1
Deep sea level: 3
Oxygen strength level: 3



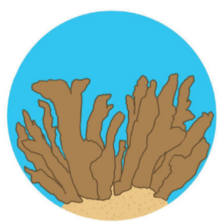
Myxococcales level: 4
Heat resistance: 2
Deep sea level: 5
Oxygen strength level: 1



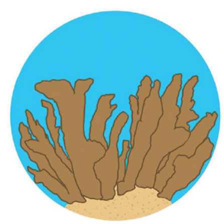
Myxococcales level: 3
Heat resistance: 6
Deep sea level: 4
Oxygen strength level: 4



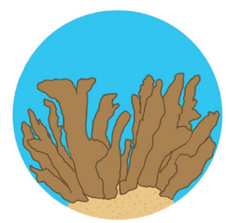
Myxococcales level: 6
Heat resistance: 5
Deep sea level: 3
Oxygen strength level: 6



Myxococcales level: 9
Heat resistance: 8
Deep sea level: 6
Oxygen strength level: 7



Myxococcales level: 1
Heat resistance: 4
Deep sea level: 2
Oxygen strength level: 6



Myxococcales level: 4
Heat resistance: 6
Deep sea level: 1
Oxygen strength level: 7

Figure 6-11: Elkhorn Coral Cards.

Scenario Cards

Scenario: Habitat Loss and Pollution

Runoff from agricultural lands and other sources has polluted shallow waters. The pollution makes it difficult for corals to grow in shallow waters and increases the growth of harmful algae. Only elkhorn corals that can live in deeper water can survive.

Action: Discard all Elkhorn coral cards with deep sea levels 4, 3, 2, or 1.

Scenario: Climate Change

Oceans are warming due to climate change. This heat can stress coral and cause coral bleaching. Some elkhorn coral live alongside helpful heat-resistant algae that help the corals survive even with coral bleaching.

Action: Discard all elkhorn coral cards with heat resistance levels 5, 4, 3, 2, or 1.

Scenario: Invasive Species

The lionfish is an invasive species to the Caribbean. It eats fish that would usually eat algae off coral. This upsets the reef ecosystem and means less oxygen is available for coral. Some coral can survive on less oxygen.

Action: Discard all elkhorn coral cards with oxygen strength levels 6, 5, 4, 3, 2, or 1.

Scenario: Disease

White band disease is spread by aquatic snails and stimulated by human pollution. It destroys the coral tissue in elkhorn coral, slowly killing entire reefs. Only elkhorn corals that support large amounts of a bacteria called Myxococcales will be able to survive.

Action: Discard all Elkhorn coral cards with Myxococcales levels 6, 5, 4, 3, 2, or 1.

Figure 6-12: Scenario Cards.

11. After you finish playing the game, discuss with your group:
    a. How did human activities cause the problems with the elkhorn coral?
    b. What could people have done differently to change the scenarios?
    c. What do you think would be most important to change about the scenarios if you were trying to help keep the elkhorn coral alive?
    d. Why was the genetic diversity of the coral important when trying to survive the scenarios?
    e. What if all the corals had no genetic diversity and so all had the same ability to survive different threats? What would the risk be for the species?
    f. Is the genetic diversity of the surviving corals greater or less than before they faced the different scenarios? How might this affect the elkhorn corals' ability to survive threats in the future?
12. Think back to your *Team Identity Map*. Discuss with your team:
    a. How do different people with different characteristics help a group respond to challenges?
    b. How are the differences in your team similar to the genetic diversity of corals?
    c. Do you think it is important to have a team with different traits?
    d. Is it also important to have different traits and ideas among populations of people in your local community or globally?
13. By yourself or with a partner, think about the living things in your local area. Can you think of a species that lives near you that you think would be important to protect? What do you think the threats to that species might be?

Understand: *Can the tools of biotechnology help with conservation?*

You know that people can have a negative impact on biodiversity. But there are also ways people can help, for example, by reducing pollution or controlling invasive species. Biotechnology can also help preserve and restore genetic diversity.

1. Gather together with your team in a circle. The practice of **conservation** is about protecting, preserving, and restoring biodiversity. Go around the circle three times and share any ideas you already have about ways people can take conservation actions. If you are not sure, that's okay, you will learn more soon. Just do your best.

a. First, share ways that people can protect biodiversity by stopping any further damage to the environment.
b. Second, share ways that people can preserve biodiversity by keeping the genetic and species diversity that currently exists.
c. Third, share ways that people can restore biodiversity by adding genetic, species, or ecosystem diversity back to the environment.

2. Read what Mary says. Why do you think **biobanks** might be a part of protecting, preserving, and restoring biodiversity? A biobank is a library of samples of different organisms. Often these samples are **cryopreserved**, or frozen in a way that they can be thawed and still be alive. When a seed, egg, or tissue is biobanked, it preserves the genetic diversity of that living things so it can be studied or added back into an ecosystem in the future.

Mary says . . .

Biodiversity stabilizes ecosystems and maintains them. Even when there are threats, adaptation is easier with higher levels of biodiversity. We can preserve genetic and species biodiversity through biobanks. Once you put something in liquid nitrogen and it's frozen but alive, it can stay there for tens or maybe even hundreds of years. So biobanks do buy us some time by maintaining biodiversity and genetic diversity.

It's so important to create biobanks because sometimes social processes can be slow, and changes in education and policies can take a long time. Biobanks can give us that time to try and come to grips with what's going on, and still not lose vast amounts of genetic diversity and biodiversity on the plant.

3. Take out the cards from the Genetic Diversity Card Game from the Discover activity. You will now have a chance to play this game again, but with some tools from biotechnology to help you.
4. Print and cut out the cards from Figures 6-13 and 6-14. If you cannot print the cards, you can write the information from the cards on a piece of paper and cut it apart.

Part 6 Task 2

Biotechnology: Biobanking

Biobanking is a preservation technique that can store biological material, including DNA, for long periods of time. Scientists and researchers are able to study these preserved materials in controlled settings. They could also be used to reintroduce the biobanked genetic diversity back into an ecosystem.

Action: Must be played before using the cloning and selective breeding cards.

Biotechnology: Cloning

Cloning uses preserved cells and DNA to create copies of a previously existing living thing. Scientists and researchers might use cloning to help introduce genetic diversity into species that are endangered.

Action: Choose three elkhorn coral cards to revive from your discarded pile.

Biotechnology: Selective Breeding

Selective breeding is when humans choose two animals within a species to mate, to try to produce **offspring** with desirable traits. Scientists can use biobanked materials to selectively breed elkhorn coral for more genetic diversity.

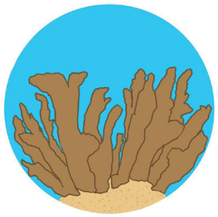
Action: Choose two coral cards that are still in the game to represent parents, and take a new blank Elkhorn Coral Card. Create a new Elkhorn Coral Card from your blank that uses the traits of the parents (Figure 6-15 shows an example). Add the new card to the game.

Biotechnology: Gene Drive

Gene drive is a technique using **CRISPR** that modifies specific genes and makes sure the modified genes are inherited by the next generation. Gene drives can change the genetic makeup of a species over time.

Action: Gene drive prevents the corallivorous snail from passing on white band disease. All elkhorn corals remaining in the game cannot contract this disease.

Figure 6-13: Biotechnology Cards.

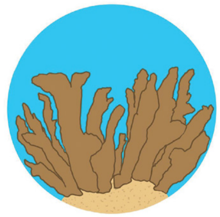


Myxococcales level:

Heat resistance:

Deep sea level:

Oxygen strength level:

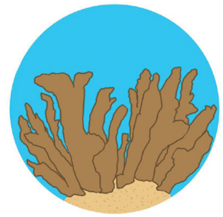


Myxococcales level:

Heat resistance:

Deep sea level:

Oxygen strength level:

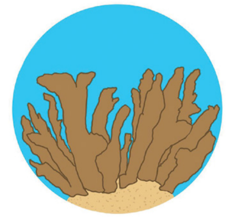


Myxococcales level:

Heat resistance:

Deep sea level:

Oxygen strength level:



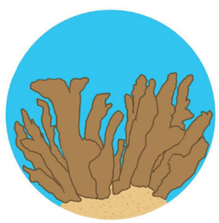
Myxococcales level:

Heat resistance:

Deep sea level:

Oxygen strength level:

Figure 6-14: Blank Elkhorn Coral Cards—use these to create new cards.



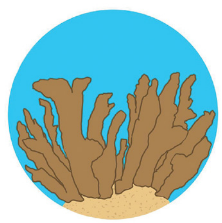
(EXAMPLE PARENT 1)

Myxococcales level: 4

Heat resistance: 5

Deep sea level: 7

Oxygen strength level: 8



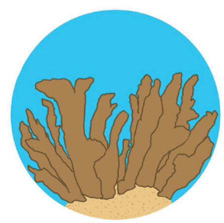
(EXAMPLE PARENT 2)

Myxococcales level: 2

Heat resistance: 6

Deep sea level: 5

Oxygen strength level: 7



(EXAMPLE NEW CORAL)

Myxococcales level: 4

Heat resistance: 6

Deep sea level: 7

Oxygen strength level: 8

Figure 6-15: Example of how a new coral card can inherit selected traits from two parent cards.

5. Place the Biotechnology Cards face up on the table. Distribute the other cards the same way you did when you played the game before.
6. Start playing the game again, but this time when time you pick a Scenario Card, you also have the option to pick and use a Biotechnology Card.
7. Compare your results this time with your results from the first time you played the card game. Did the biotechnology help you protect, preserve, or restore genetic diversity?

8. By yourself or with a partner, think about the species you wanted to keep healthy from the Discover activity. How can you find out more about the conservation of this species? Do some research to find out more about the situation of this species. Is it in danger? What threats does it face? For example, you could:
   a. Use the Internet, a library, or other written materials to learn more about your species.
   b. Reach out to an organization, such as a nature or science center, to find out if they have more information.
   c. Find a local scientist who researches your species and contact them to learn more.
9. Now consider, what actions do you think you could take to help your species? Be sure to consider:
   a. Ways you could take action to reduce the threats to your species
   b. Ways biotechnology tools could help protect, preserve, or restore your species
10. Take out a piece of paper or open a digital document and title it "Conservation Plan." This *Conservation Plan* will be your plan to help your species. Write or draw:
   a. Which species are you focusing on?
   b. What are the threats to this species?
   c. What would you like to do?
   d. What methods, such as reducing pollution, biobanking, or cloning, would you use?

Act: *How should we use biotechnology to have an impact on ecosystems?*

Biotechnology provides powerful tools to help conserve species and ecosystems. However, these types of interventions must be carefully considered. In this activity you will think about your approach to using several types of biotechnologies.

1. Read *The Black-Footed Ferret Case Study*.

The Black-Footed Ferret Case Study

Black-footed ferrets once lived all over the prairies of North America. However, by the mid-1900s the species was declining rapidly because of human activities. Scientists thought the ferrets were extinct, but managed to find one remaining population in the 1980s. To preserve the species, all of the remaining animals were brought into captivity. Seven were able to breed and their DNA is the foundation for today's black-footed ferrets. Today around 10,000 black-footed ferrets are descended from the original seven and many have been reintroduced into the wild.

Figure 6-16: A black-footed ferret.

However, the level of genetic diversity is very low, since all the black-footed ferrets come from the original seven. **Inbreeding**, or producing offspring from close relatives, means all the black-footed ferrets are genetically as closely related as half-siblings. When an individual has DNA from two closely related parents, the likelihood of problems caused by genetic mutations increases. However, scientists are trying to increase the genetic diversity of the population through biotechnology.

In the 1980s scientists added frozen tissue from Willa, an unrelated black-footed ferret, to a biobank. In 2020 Willa's biobanked tissue was used to create a clone, Elizabeth Ann. Willa and Elizabeth Ann are genetically identical. If Elizabeth Ann is bred with existing black-footed ferrets, her DNA can add genetic diversity to the population. As you learned with elkhorn corals, genetic diversity is very important for species survival.

2. Divide your team into six groups. Have each group discuss one of the following questions. Then share your answers with the rest of your team.
   a. Since people caused the problems with the black-footed ferret population, do you think they are responsible for helping to create a healthy population?
   b. Right now Elizabeth Ann lives in captivity. Would releasing her descendants into the wild in the future be okay with you?
   c. Elizabeth Ann is a clone of Willa. But what if her genes had been genetically engineered to add the maximum amount of genetic diversity to the black-footed ferret population? Would that be okay with you?
   d. Some scientists worry that if people know there is a way to add back genetic diversity through biobanking, then they will not act quickly to stop problems like habitat destruction or climate change. Do you agree?
   e. What if the black-footed ferrets were already extinct? Would it be okay to use biotechnology tools to restore the population?
   f. In some countries, cloning as a technology is used frequently in livestock production (such as cows or pigs). Should the rules for cloning a wild species be different than the rules for cloning a **domesticated** species?
3. As a team, imagine you are in charge of creating a set of rules that would decide if and when a species can be restored, using biotechnologies such as cloning. Write down the rules you decide on. Use what you have learned in this task to help you make decisions. For example:
   a. When should species be restored? Does the species have to be going extinct or just struggling?
   b. Which species should be restored? Does it make a difference how important human activities were in creating problems or how important the species is to an ecosystem?
   c. If it means a species will be restored, is it okay to release cloned individuals into the wild?
   d. Is it okay to genetically engineer a species to survive better, such as adding an ability to tolerate disease or heat?
   e. Who should be consulted when these decisions are being made?
   f. Who should be able to make the final decision?

   g. What other rules do you think should exist?
   h. Are there things that should be done now, like biobanking, to create options for biodiversity restoration in the future?
4. By yourself, apply those rules to your *Conservation Plan*. Does anything need to change? Make those changes to your plan now.
5. Read Mary's ideas about the importance of conversations and other social processes to help the environment. Consider the conversations your team has had, the rules you created, and your *Conservation Plan*. What do you think is most important to share with others?

Mary says . . .

We can't just restore coral reefs because we have done biobanking or selective breeding. The situation is more complex. You've got public perceptions and management decisions, in addition to already existing global and local threats. Those are the just a few of the factors. The public doesn't understand that we can do this one little piece (biobanking), but the big thing is how we think about helping the environment and restoring it. Things are more complicated when you consider the entire interacting social aspects rather than just the scientific aspect.

6. Choose one group and share your rules or conservation plan with them. For example:
   a. Family and friends: You could have a conversation about the use of biotechnology for conservation with family or friends. You could share the rules you created and ask others if they would create the same rules.
   b. Research scientists: You could find researchers working on the conservation of species you identified in the Understand activity. You could have a meeting or write them a letter and share both your conservation plan and the rules you developed.
   c. Government officials: Often governments are in charge of making rules. Find out which part of your government might be in charge of making rules

about the use of biotechnologies in conservation. Write them a letter or send them a social media post explaining the rules you suggest and why they are important.

d. Pick another group you think should be involved in making these decisions.

Congratulations!

You have finished Part 6.

<u>Find out More!</u>

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

Part 6 Task 2

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.

Biobank: A library of biological samples of different living things

Biochemical pesticide: A nontoxic substance produced by a living thing that helps fight pests such as insects

Biodiversity: The many different living things on Earth

Bioremediation: Using living things to correct, stop, or reverse damage to the environment

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

Carbon dioxide: A greenhouse gas that is part of Earth's atmosphere; increasing carbon dioxide levels in the atmosphere is one of the causes of climate change

Cloning: Using preserved cells and DNA to create exact copies of a previously existing living thing

Conservation: Protecting, preserving, and restoring biodiversity

Contaminant: A substance that makes water unsafe to drink or another material unsafe or unusable

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

Cryopreservation: A storage method used in biobanks where samples of live organisms are frozen and later thawed for research or use

Decompose: Breaking down living things so their matter can reenter the ecosystem

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

Domesticated: A species that has been changed from its wild state to make it more useful for a specific purpose

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

Ecosystem: A community of interacting living and non-living things within a physical environment

Ecosystem diversity: The variations in the different types of ecosystems

Emergent: New or just introduced

Environmental: About the natural world

Ethical: The fairness of something

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

Gene drive: A technique that edits specific genes in one generation of species to make sure the edited genes are inherited by all their offspring, rather than being inherited by random chance

Genetic diversity: Variations in the genome of a species or population

Genetically modified: A living thing that has DNA that has been changed by humans

Genome: The complete sequence of DNA of a living thing

Herbicide: Chemicals used to control or kill undesirable plants such as weeds; typically used in farming

Identity: The characteristics that make you you

Impermeable: Not allowing anything, such as liquids or gases, to pass through

Inbreeding: When close relatives mate and produce offspring

Microbial pesticide: Using bacteria, fungi, viruses, or other small living things to kill pests or plants

Mitigate: To make less severe or less harmful

Nontoxic: Something that will not harm living things

Offspring: The children of parents

Pesticide: A substance used to eliminate pests, such as insects, that might harm cultivated plants

Pollutants: Harmful materials that cause pollution

Pollution: Natural and unnatural harmful materials that are introduced into an environment

Raw water: Water in the environment that has not been treated to remove contaminants, such as rainwater or water from a stream

Remediate: Correct, stop, or reverse damage to the environment

Reservoir: A large human-made place to store water

Runoff: Water that runs off roofs, driveways, sidewalks, and agricultural lands, often picking up chemicals and soil in the process

Selective breeding: A process in which humans choose two animals within a species to mate to try to produce offspring with desirable traits

Smog: A mixture of harmful pollutants in the air at ground level

Social: Relating to the interaction of people in a community

Species diversity: The variations in the different types of living things within an area

Species: A type of living thing, like a human or a dog or a coconut tree

Thickets: Dense groups of elkhorn coral

Toxic: Harmful or poisonous

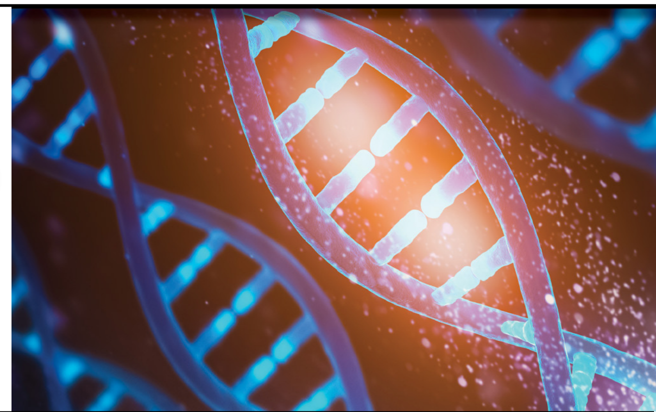
Traits: Characteristics

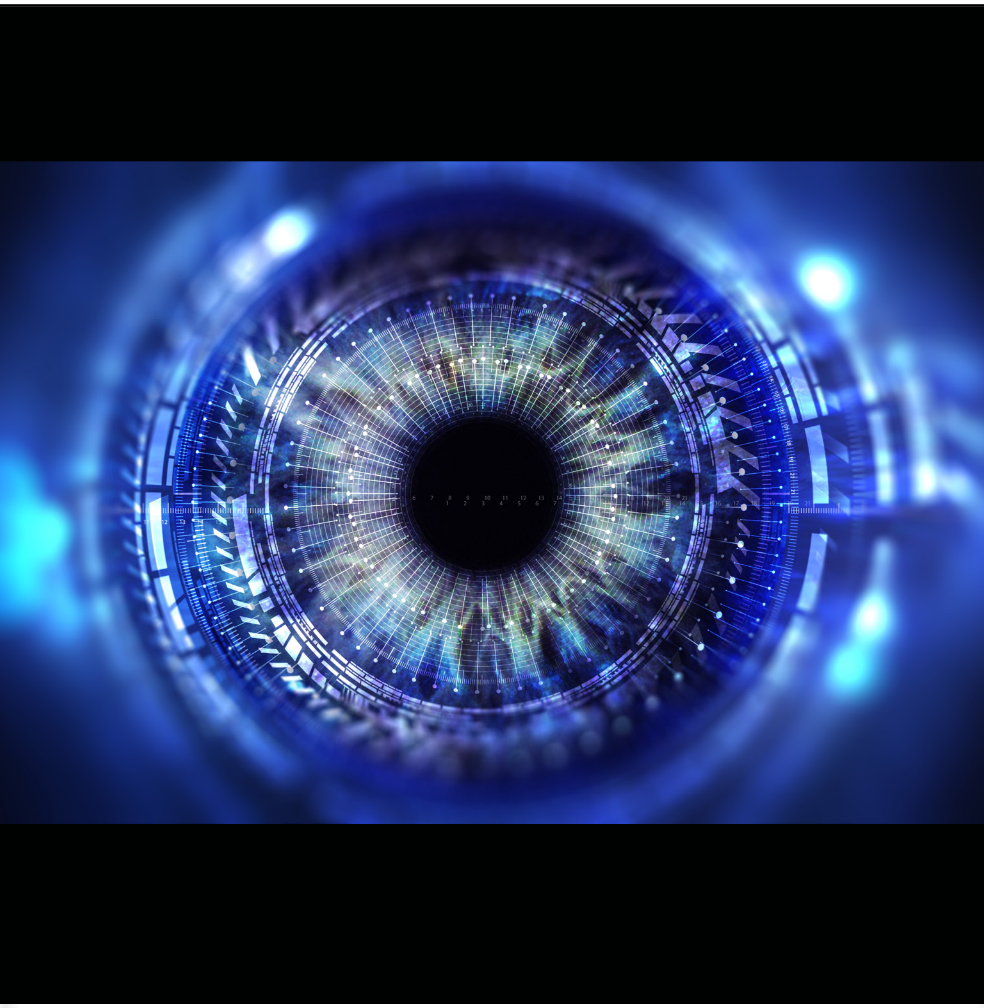
Variations: Differences in living things

Smithsonian

SCIENCE
for Global Goals

BIOTECHNOLOGY!





Part 7:

Biotechnology and Security

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 7. 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.

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Figure 7-12 - Heidi Gibson, Smithsonian Science Education Center

PART 7: BIOTECHNOLOGY AND SECURITY

Find out More!

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

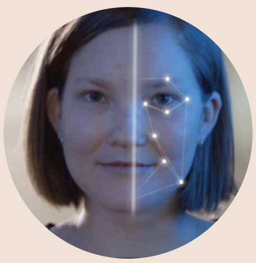
Planner

Activity	Description	Materials and Technology	Additional Materials	Approximate Timing	Page Number
Task 1: How can biotechnology help with security?					
Discover	Explore how biometrics work and how you use them.	• Paper • Pencils • Clear adhesive tape		25 minutes	256
Understand	Model facial recognition technology and consider any issues with how it is used.	• Paper • Pens or pencils • Straight edge	Printouts of Figures 7-8 and 7-10 (optional)	25 minutes	262
Act	Draft a set of rules for when and how you think biometrics should be used.	• Paper • Pens or pencils	*Ethical Concerns List* (Part 1)	20 minutes	268
Task 2: What are the threats to security presented by biotechnology?					
Discover	Explore possible outcomes of bio-threat scenarios.	• Paper • Pens or pencils		20 minutes	273
Understand	Investigate bio-threat vulnerabilities within your community and think about possible ways to prevent problems.	• Paper • Pens or pencils • Computer (optional)		30 minutes + investigation time	276
Act	Share information about bio-threats with your community.	• Paper • Pens or pencils • Computer (optional)		15 minutes + action time	280

Task 1: How can biotechnology help with security?

Humans have many individual physical differences. We use these physical differences to help identify one another. **Biometrics** is when this identification is automated by measuring the physical differences of individuals. Biometrics can be very useful, but there are concerns that they can also be used in a harmful way. In this task you will first ***discover*** more about how you and your community are already using biometrics. Then you will ***understand*** more about how biometrics work and design your own biometric system. Finally, you will consider the consequences of widespread biometrics use and decide how you will use that information to ***act***.

Meet Your Research Mentor



Meet Dr. Monique Mann. Monique (pronounced mo-NEEK) is one of the many researchers around the world trying to harness **biotechnology** to ethically improve security. As action researchers you are also trying to ethically improve security through new technology. Monique will be your research mentor to help you understand more about the role biotechnology can play in security.

Monique is a senior lecturer on criminology. She has a PhD in the human rights impacts of organized crime policing. However, she also has knowledge and perspectives that came from other parts of her identity. Since Monique is now working with you, it is important to understand who she is.

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

- 34 years old
- Caucasian
- Female
- Lives on the beach in Victoria, Australia
- Interested in new technology, surveillance, and human rights
- Likes yoga, surfing, going on adventures in nature, and camping
- Longsighted, so wears glasses to read, has green eyes

Part 7 Task 1

- Curious
- Dog lover: "I have two dogs that I love very much—Maxi is a Dalmatian and Felix is a German Shorthaired Pointer."

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

- Are there things you have in common with Monique?
- Are there ways in which you are different from Monique?
- Can you see anything about Monique's identity, in addition to her university degrees, that would help her understand different perspectives or ideas about security?

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

Discover: *How do you use biometrics?*

There are billions of people on Earth, and each person is unique. This **variation** is useful in many ways. For example, variations among **genes** make it more likely for the human population to have people who can resist a disease or live in a harsh environment. Variations among cultures can provide new approaches to problems. Variations among ideas can offer new solutions or breakthroughs. Variations in human appearance can help identify you as a specific individual. Using your biology in this way can be a useful tool for security. For example, biometrics can be used to make sure the right people have access to things like a phone, or information such as a bank account statement.

Early humans lived in small groups and may have been able to recognize almost everyone they needed to interact with because they personally knew them. However, in modern times most people interact with many people they do not personally know, often every day. How does someone know that you are you, and why is that important? In this activity you will start thinking about those questions for yourself and for your community.

1. Examine the zebras in Figure 7-1. At first you may think they seem identical, but examine them closely. Do you notice any differences in the markings between the two zebras? Work with a partner and point out any differences you notice.

Figure 7-1: How are these two zebras different?

2. Think quietly to yourself. Each zebra's stripe pattern is unique. This means the pattern can be used to identify a specific zebra. Are there things about your physical appearance that are unique, like a zebra's stripes? Create a list of physical **traits** you think could be used as biometrics to uniquely identify you.
3. One thing you may have listed is your fingerprints. Now you will take a few minutes to explore the differences between your fingerprints and your classmates'.
4. Read *Fingerprinting Activity Instructions.*

Fingerprinting Activity Instructions

For this activity you will need a piece of white paper, a pencil, and a few pieces of clear adhesive tape.

a. Near the top of the paper, use your pencil to shade in a small area.
b. Rub your fingertip over the shaded area until the graphite from the pencil is all over the end of your finger.

c. Press your finger onto the sticky side of a piece of tape.
d. Turn the tape over and stick it onto the bottom of the piece of paper.
e. Repeat with different fingers, if you would like.
f. Examine your fingerprint carefully. There are three main types of patterns you will see—arches, loops, and whorls—but there is variation within these types. Which type or types do you notice in your fingerprints?

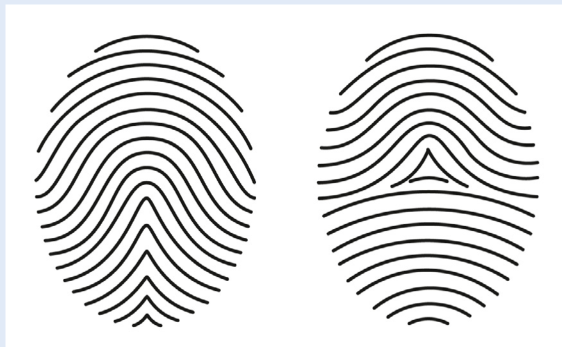


Figure 7-2: Examples of arch patterns in fingerprints.

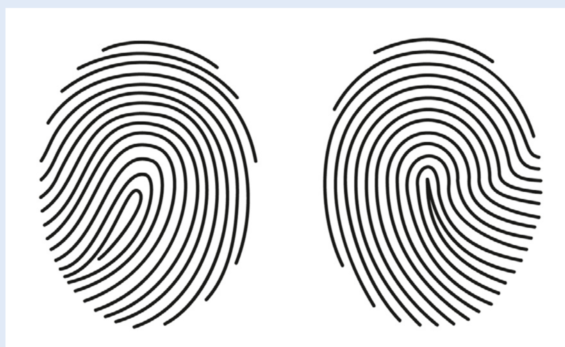


Figure 7-3: Examples of left loop and right loop patterns in fingerprints.

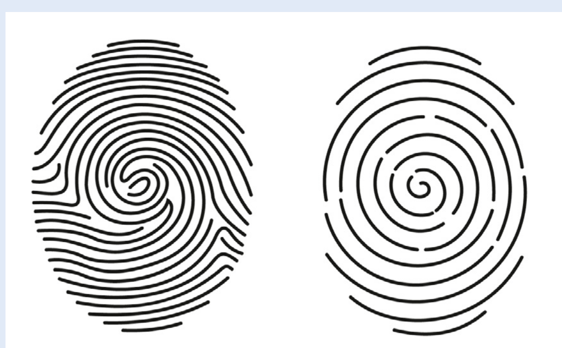


Figure 7-4: Examples of whorl patterns in fingerprints.

g. Compare your fingerprints to those of your teammates, especially if they have the same type of pattern as you. Are any of them exactly the same?

5. Discuss with your teammates places or times you have noticed fingerprints being used to identify people. Have you ever had your fingerprints used to identify you?

> **⚠ Emotional Safety Tip**
>
> Sometimes fingerprints can be used by police or other law enforcement officers. You may have had your fingerprints taken or know someone who had their fingerprints taken for this purpose. You may have strong feelings about that experience. That is okay. You will be thinking later in this task about when you think biometrics such as fingerprints should be used. But if you are upset now, it is okay to pause and take a break. If you do not feel comfortable sharing about your experience with fingerprints, you do not need to share.

6. Go back to the list you made of traits about people that could be used to identify individuals. Share your ideas with your teammates and build a group list. Think together about whether there is anything else to add. Be sure to consider:
   a. Can you think of any biometrics that might rely on more than appearance? For example, do you think humans may have unique sounds or smells?
   b. Are there ways to tell people apart if you have a sample of cells from their body, like a drop of blood or a bit of saliva or a hair?
7. Read *Biometrics and Identity*.

Biometrics and Identity

Some people think that physical items like keys or cards, or information like a password or identification number, are not secure. Physical items or information can be lost, stolen, or given to another person.

What if instead you used the variations among humans as a security tool? There are many unique biometrics of humans that can help identify specific people.

Computers can be programmed to identify you using your unique biometric information. The computer does this by comparing a sample of your biometric information (like your fingerprint) against a **database** of many people's biometric information, until the computer finds a match. Some biometric databases, or sets of information, include more than one billion samples.

Physical appearance

Biometrics are most commonly related to physical appearance, such as:

- Fingerprints
- Facial recognition
- Iris (eye) scan
- Palm prints
- The pattern of your veins (vascular biometrics)

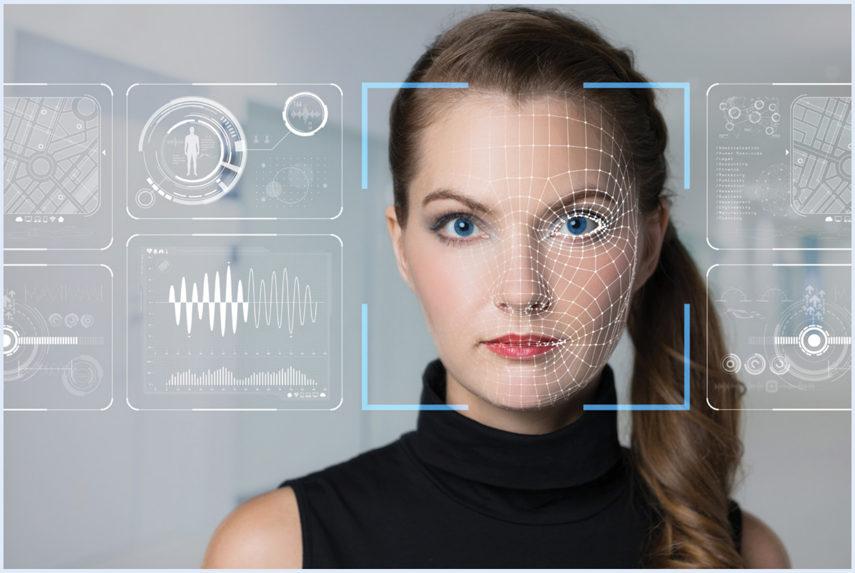


Figure 7-5: Examples of biometric types, including face, voice, and iris.

Other biometrics

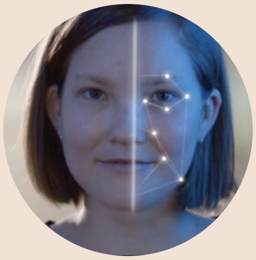
Tools to identify other biometrics are sometimes used as well, such as:

- Voice recognition
- Gait analysis (the way you walk)
- **DNA** analysis

8. Think about the different types of biometrics and your experience with them. If you are comfortable, tell your teammates about a time you had a biometric used to identify you.

9. With your team, discuss any examples you can think of related to how biometrics might be used to:
    a. Allow you to access or not access specific places
    b. Allow you to access specific things that you own or use
    c. Allow you to access or not access specific data or information
    d. Find out who was or is in a specific place
10. Have each team member pick one type of biometric from the *Biometrics and Identity* box and share with the team the advantages and disadvantages related to:
    a. How accurate you think it is, like could it be used to identify you without mistaking you for someone else
    b. Whether it could be used without your knowledge
    c. Whether there are physical differences that might make this biometric impossible to use for someone, such as if a person is missing a finger and the biometric is a fingerprint
11. Read Monique's thoughts on collecting data through biometrics. Why might people be concerned about having data about themselves collected through biometrics?

Monique says . . .



I think people really need to be aware of what's happening in terms of why their information is being collected and how it's being used, stored, shared, and analyzed. Often when you come to terms of use or service, you just click "accept" and you don't know what that really means. There are definitely positive applications of biometric technology. But we need to think about collecting data for a specific purpose and only that purpose, and then deleting it when that purpose has been met.

Part 7 Task 1

Understand: *How is your face used to identify you?*

There are many types of biometrics, but for most of them you have to individually scan something—like an eye, a fingerprint, or a DNA sample. Facial recognition technology is a little different. It can scan many people very quickly. It can be used in a public area and sometimes without people's knowledge. In this activity you will learn more about how it works and think about ways in which it can be used.

1. Read *Facial Recognition*.

Facial Recognition

Think of your face as a map. In facial recognition technology the features that stand out easily, like your nose, eyes, and mouth, are called **landmarks**. Facial recognition works by creating points at different parts of the landmarks and then measuring the space between them. For example, maybe the space between two edges of an eye or the space between an upper lip and the bottom of a nose could be measured. Figure 7-6 shows some examples. The white dots are landmarks, and the lines measure the space between them.

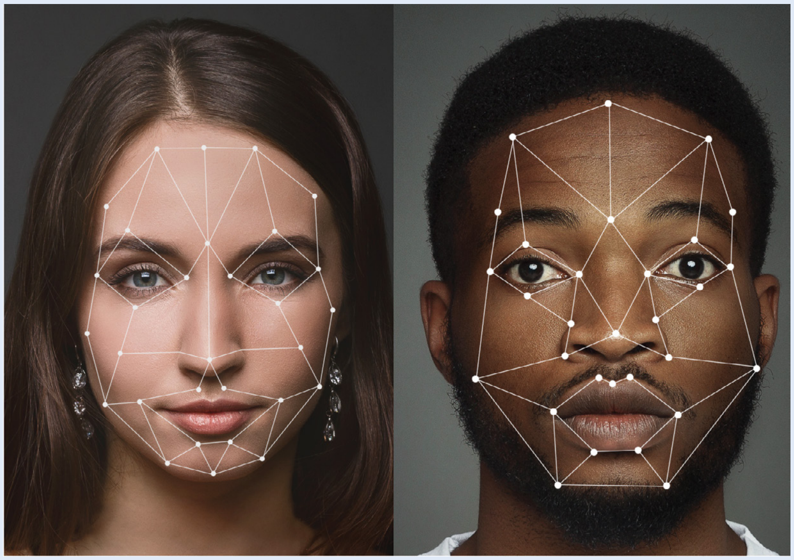


Figure 7-6: Examples of facial recognition landmarks.

Once the distance between landmarks is measured, this is compared to existing data to locate a match.

Part 7 Task 1

Sometimes it is compared to one existing biometric scan to verify that the scanned person is the right person. This is called one-to-one facial recognition. This is the way facial recognition on phones works, for example. Your phone contains a stored copy of your facial recognition scan that it matches to your face to unlock your phone.

Figure 7-7: Using a phone for facial recognition.

Sometimes an image is compared to a large database of images to identify someone. This is called one-to-many facial recognition. An example of this would be using facial recognition in law enforcement to identify someone suspected of committing a crime.

2. Think like a biometric designer and share your answers to these questions with your team.
   a. What would be some of the difficulties in measuring landmarks on a face?
   b. Which landmarks do you think you would use on a human face?
3. Now you will have a chance to create a facial recognition biometric using non-human faces. Pick one of the wild cat pictures shown in Figure 7-8.
4. If you are using a printed version of these pictures, either lay a piece of paper that you can see through over the picture you picked or hold the picture up to the window and put a piece of paper over it. If you are using this guide digitally, put a piece of paper over the screen. Use a pencil to lightly mark dots on the edges of major facial landmarks. Use 10 dots or less. Do not show anyone else which cat you are using to create your biometric scan.

Figure 7-8: Wild cat pictures.

5. Put your paper back on a flat surface and use a straight edge to connect the dots to create a biometric scan. Figure 7-9 shows an example.

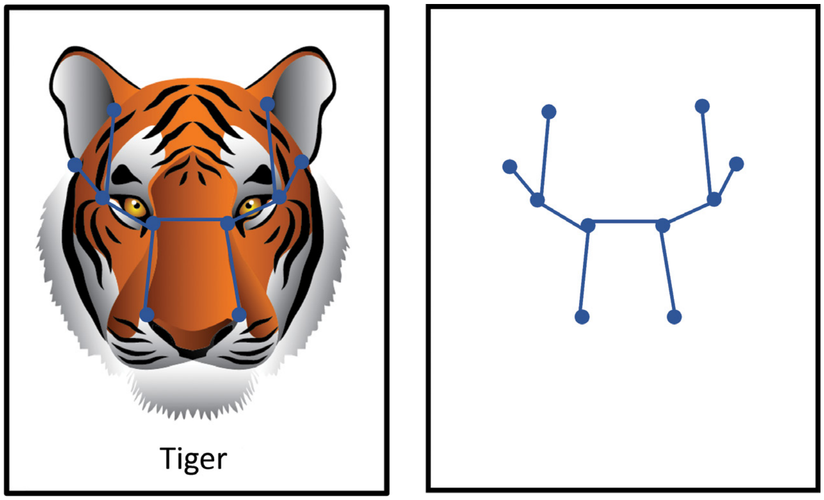


Figure 7-9: A facial recognition biometric of the tiger picture.

6. Switch biometric scans with a partner. Can you both identify which cat you used to create your biometric scan?
7. Discuss with your team:
   a. What was difficult about this activity?
   b. Do you think some of the cats are harder to create facial scans of than others? If so, why?
8. Now create a biometric scan of the tiger face in Figure 7-10. You may need to use more dots to create landmarks. Try to use as few as possible.

Figure 7-10: Tiger face.

9. Compare your biometric to the animals shown in Figure 7-11. Can you find a match? Do not use the picture to compare—only your biometric scan. Compare your answer to those of your teammates.

Figure 7-11: Wild cat biometric database.

10. Read *Bias and Facial Recognition*.

Bias and Facial Recognition

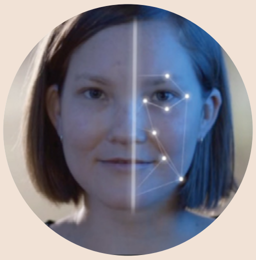
Facial recognition currently does not work equally well for all groups. For example, for people with darker skin or wearing makeup, many facial recognition scanners may have trouble figuring out where to place the facial landmarks. Computers scan many reference photos to learn to recognize the differences between faces. But if these reference photos are too similar, like the people in them come from largely one ethnic group or gender, then sometimes the computer will become better at identifying the differences among people from that group than among people from other groups. These problems with the technology creates **bias**, a situation in which specific groups are treated unequally.

There is also another problem of bias in facial recognition. If there are many people who look like you in a database, you are more likely to be falsely identified as a match, known as a **false positive**.

You may have just created a false positive in the last activity. Did you find a match for your tiger biometric? None of the tigers in Figure 7-11 match your biometric scan. Yet, because there were so many tigers present in the database, you or someone in your team may have identified a match.

11. Consider the following scenario: A law enforcement database has a lot of people from one specific racial or ethnic group. Discuss with your team:
    a. Would you be more likely to have a false positive if you were part of that racial or ethnic group?
    b. What impact do you think those false positive identifications might have?
    c. Read Monique's ideas. What problem does she identify?

Monique says . . .



One-to-many facial recognition uses databases to identify unknown persons. Often one-to-many is also used in a changing, live environment, like tracking someone as they move in a public space through CCTV (closed-circuit television) or security cameras. In those situations, facial recognition has been demonstrated to be biased against people of color and particularly women of color. Part of this is due to the **algorithms** and the data sets used to train the computer to make a match. The other issue is the data used to create the database. For example, if you use photos taken when people are arrested, if you have groups, like people of color, that are disproportionately overrepresented in things such as the criminal justice system, then that bias also becomes part of the database and the facial recognition system.

12. Discuss with a partner:

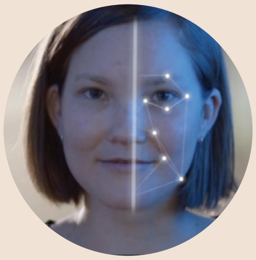
    a. What are your thoughts about the advantages and disadvantages of using facial recognition technology?

    b. What are some opportunities to use facial recognition in a positive way?

    c. How could facial recognition be used to track where people go and what they do? Do you think that is a problem?

    d. Read Monique's ideas. Do you share her concerns?

Monique says . . .



We are all under surveillance and it is not just from the government and law enforcement; the ones who are really the best at facial recognition is companies, like social media companies. If you have a social media account where you upload pictures, often these pictures can be used to create a biometric template and added to a facial recognition database. Sometimes these databases can be accessed by law enforcement agencies.

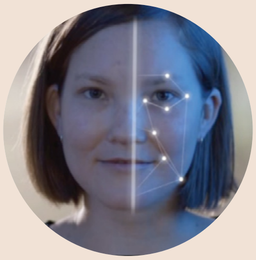
Companies also use this information to develop profiles about people to target advertising at them to convince them to buy things. Biometrics have the potential to link your physical presence in real life and potentially all this other information out there about you that's held in databases or on the Internet.

Act: *How should we be using biometrics?*

Biometrics can be a useful tool to identify people. In this activity you will consider ethical concerns with using biometrics and create a set of rules for when and how biometrics should be used.

1. Look at the *Ethical Concerns List* you created in Part 1 and then read what Monique says. Are there any ethical concerns that might relate to using biometrics? Use these ideas in the next activity.

Monique says . . .



We must be really mindful of the context and purpose of using a technology and what that means for individuals in society. With biometrics there are clear risks in terms of violation of fundamental human rights: not only the right to privacy, but many others, like freedom of political expression, anti-discrimination, and **freedom of association** [the freedom to join together with others to express or defend similar interests]. Privacy is a foundational right that is needed for all these other rights.

2. Read *Biometrics Situations*. Assign each team member a situation or create your own situations. Think about the situation and share with your team:
   a. Which ethical issues might be a part of this situation?
   b. Do you think a biometric tool should be used? Why or why not?

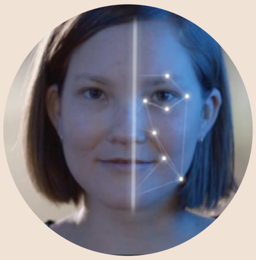
c. If you choose to use a biometric tool, which one would you use? For example, would you use facial recognition, iris, palm prints, fingerprints, voice, gait analysis, or DNA?

Biometrics Situations

a. There is a large sporting event that many people attend and you are searching for any wanted criminals.
b. You own a company that has sensitive information stored inside the building where employees work.
c. You design a country's border controls and you want to make sure you know who is entering and leaving your country.
d. You work for local law enforcement and you are searching for a missing child.
e. You have a banking system that people need to securely access online.
f. You own a large shop and would like to make payment options more convenient.
g. You work at a social media site and want to make it easy to identify people in photos that are posted.
h. You want to stop vandalism in a downtown park.
i. You want to find an easy and secure way for people to access their smartphones.
j. You are trying to advertise your products and want to be able to personalize the billboards people see.
k. You want to have your phone or personal home device recognize your voice when you ask it a question out loud.
l. You are a school leader and want to make sure only students and staff are present in the school building.
m. You work for a transit authority and want to find a way to cut down on lines to go through entry control.
n. You are trying to identify bodies of people killed in a natural disaster.
o. You are a government worker and many people are protesting something the government has done. You would like to find out more about who is part of the protest.

3. Think quietly to yourself. Do some people on your team have different perspectives on when biometrics should be used? Why is what others think important when considering biometrics?
4. Different places are making very different rules when it comes to facial recognition. Read Monique's ideas to find out more.

Monique says . . .



Different places have different rules for data protection and privacy. For example, there are proposals in the European Union to ban facial recognition or limit the use of facial recognition in public spaces unless it is in certain extreme conditions, like a missing child or an imminent terrorist attack. Other places it is more unregulated and, for example, companies can film you if they just put a little sign up somewhere saying they are doing it. People may not even be aware, and they may or may not know exactly what's happening.

5. Read these three facial recognition rules. Pick the rule that would make you most comfortable. Discuss with your team why you picked the one you picked.
   a. A country has decided not to use facial recognition at all in public areas to stop any abuses and protect people's privacy.
   b. A country uses some facial recognition in public areas and allows a facial recognition database to be built from the driver's license pictures of some people from the country.
   c. A country uses facial recognition widely. Public spaces and transportation are all monitored using facial recognition to stop any crime and ensure that people are who they say they are.
6. Think to yourself: If you had to make the rules about when and how biometrics could be used, what rules would you make? Write down or find another way to record your answer. Be sure to consider:
   a. Should biometrics be used when people are not aware they are being used?
   b. How do you protect people from false positive identifications?

c. Are there certain places it is okay for biometrics to be used? Do think certain other places are not okay?

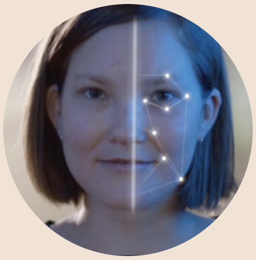
d. Is it okay for biometrics to track you as you move around during the day?

e. Who should be able to access collections of biometrics data and how long should the data be kept?

f. How should biometrics databases be built? For example, should you have to agree to participate? Or should the database include only people who have been arrested? Or should you be allowed to pull pictures that were posted on social media to create the database?

7. Why do you think it is important to talk to others about these ideas? Read Monique's thoughts and consider what conversation you would like to have about the use of biometrics.

Monique says . . .



I think we need a broader consultation and community discussion about the role of technology in our lives and the type of society we want to live in. There are both positive and negative applications of biometric technology. We should think about the kind of values we're embedding in technology and the way we're using it. What does it mean if we live in a surveillance state where technology can be used to surveil and control the entire population? What are we trying to achieve in terms of the type of society we want to live in and the appropriate protections for human rights?

8. Discuss your thoughts on biometrics rules with a friend or family member later today or tomorrow. Do they have some ideas or concerns that are different from yours? Listen carefully to understand why they might have a different perspective from you, and carefully explain your perspective.

Task 2: What are the threats to security presented by biotechnology?

Biotechnology uses living things, parts of living things, or things produced by living things to solve people's problems and meet their needs. Sometimes this means engineering new or modified organisms through selective breeding or genetic modification. Sometimes this means moving biological systems or organisms to new places or using them in new ways to create things or perform services that are useful to people. As you have learned, both of these biotechnological approaches create tremendous opportunities for better human health, food, materials, and more **sustainable** resource use. These approaches also create potential threats to a secure future for people and the planet.

In this task you will be learning about those threats and how you can help prevent them. First you will ***discover*** ways in which biotechnology might cause harm. Then you will investigate vulnerabilities in your community to ***understand*** more about ways to guard against these threats. Finally, you will ***act*** to share this information with others in your community.

Meet Your Research Mentor

Meet Dr. Zabta Shinwari. Zabta (pronounced ZAB-tah) is one of the many researchers around the world trying to protect the planet from threats from biotechnology. As action researchers you are doing the same. Zabta will be your research mentor to help you understand more about the possible threats from biotechnology.

Zabta is professor emeritus at Quad-i-Azam University in Pakistan and a former secretary-general of the Pakistan Academy of Sciences. He is a specialist in biotechnology and biosecurity and received the 2015 UNESCO Avicenna Prize for Ethics in Science. However, he also has knowledge and perspectives that came from other parts of his identity. Since Zabta is now working with you, it is important to understand who he is.

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

- Born in the Shinwari tribe on the border of Afghanistan and Pakistan
- Tall, with black hair and fair skin
- Likes to travel, chat with friends, walk in the wilderness
- Funny, kind, and sensitive
- Committed to extending higher education to neglected communities in Pakistan
- Born into a big family—seven brothers and a sister!
- Married another Pakhtoon (his ethnicity) and they have five daughters and two sons
- Four of his daughters got PhDs, which makes him very proud!
- Interested in working with Indigenous communities in Pakistan, trying to safeguard their knowledge and find ways to reduce poverty
- Likes to write—has published nine books and 445 articles

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

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

Throughout this task you will notice Zabta 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: *How could biotechnology be harmful?*

Every day you probably think about the future and risk. For example, if you are thinking about your day and know that you are going to be out at lunchtime, you may think there is a risk you will be hungry and so you take a snack. Or if you are walking near a busy road you may think there is a risk you will be injured by a car, so you stay away from the edge. Thinking about what is likely to happen in the future is called

foresight. In this activity you will use foresight as a tool to think about possible futures of different biotechnology tools.

1. Take a paper and divide it into two columns. Title the first column "Helpful." Title the second column "Harmful."
2. Read *Scenario One* quietly to yourself. Each scenario in this section is based on a real-world event. For more information, see the *Biotechnology!* StoryMap.

Scenario One

A group of scientists is researching ways that viruses might mutate to become more dangerous. They use biotechnology tools to produce targeted mutations to create viruses that are more harmful to humans so they can understand how to fight these viruses. These genetically engineered viruses and the information about them are kept in secure labs. If the viruses were out of the lab and spreading in the population, there would be risks to human health.

3. Discuss with your team the possible future **outcomes** you can think of for this scenario. An outcome is the end result or consequence of something. Think about the possible ways the situation described in the scenario could create outcomes that benefit or hurt people and the planet. Write or draw your ideas in the appropriate column.
    a. *Helpful:* What are the possible future outcomes that could help people or the planet? List them on this column.
    b. *Harmful:* What are the possible future outcomes that could harm people or the planet? List outcomes might harm a few people or other living things in this column, or could hurt many people or whole ecosystems.

Emotional Safety Tip

Thinking about terrible things that might happen in the future can be scary and stressful. No bad outcomes or catastrophic outcomes are already decided. By understanding issues that concern you now, you can become part of the effort to prevent these outcomes. Scientists and others around the world are also working hard to prevent these types of outcomes.

4. Read Zabta's thoughts. Do his ideas make you think of any additional possible helpful or harmful outcomes? If so, add those to your list now.

Zabta says . . .

Using biotechnology and gene editing is getting easier. It is getting easier to modify viruses. This means more researchers have access to this technology and there is more possibility of viruses getting out of a research setting. It is important to make people aware of ways that biotechnology can be misused, to understand how it can become dangerous. Viruses don't respect borders. Once a virus is circulating in a population, it can go anywhere, as we learned with COVID-19.

5. Read *Scenarios Two*, *Three, Four*, and *Five* by yourself. For each scenario, record things that could be helpful and harmful in the appropriate column on your paper. Make sure you consider how diseases, pests, and misinformation can spread and how that can affect human and animal health, the environment, and economies.

Scenario Two

Many farms around the world raise pigs for meat. Sometimes equipment, people, or feed goes from one farm to another. Recently some pigs have been getting very sick with a disease that kills most of them within 20 days. The disease does not harm humans, even if they eat meat from infected pigs. There is a risk that this disease could spread between pigs in different farms, affecting farmers, consumers, and the whole economy.

Part 7 Task 2

Scenario Three

In one country the main staple food is maize (or corn). Although they grow a lot of maize, this country also imports it from other places. One of those places is on another continent. Maize growers on that continent are struggling because there is an insect that attacks and eats their crops. There is a risk that this insect could spread to the country through the imported maize.

Scenario Four

Scientists are able to use biotechnology to rapidly create useful and safe vaccines, drugs, and therapies to help prevent and cure illnesses. However, there is misunderstanding and misinformation about these technologies, leading to a lot of fear and suspicion about using the vaccines, drugs, or therapies. There is a risk that this misinformation could spread among people and lead them to make decisions that are not good for their health.

Scenario Five

The ability to rapidly sequence DNA and develop therapies that target specific sequences of DNA is revolutionizing medicine. Yet there is a risk that scientists could use DNA sequences to create a **bio-weapon** that would target a specific person or a group of closely related people, such as a family or ethnic group.

6. Compare your *Helpful* and *Harmful* lists with your team members.
   a. Are there some outcomes other team members thought of that you would like to add to your lists? You can do that now.
   b. How could some of the things that might happen help or harm you personally?
7. Consider the harmful outcomes you listed. Examine your *Futures Mood Board* from Part 1. Add any new concerns you now have. In the next activity you will be thinking about how to stop those outcomes from happening.

Understand: *How can we keep ourselves safe?*

Some biotechnology tools and research can be called **dual use technologies**. Dual use technologies can be used for a good or helpful purpose, like to prevent and fight illness, to make people healthier, or to protect food systems. These biotechnologies can also have the potential to create harm, like to create viruses that could causes diseases in humans or other living things.

The harmful outcomes you identified in the Discover activity can also be called **bio-threats**. Bio-threats can be caused by mistakes people make, or **bio-error**. They can also be caused deliberately to create harm; this is called **bio-terror**.

1. Reread the *Scenarios* from the Discover activity. You are going to create a *Process Map* of steps that might lead to the harmful outcomes you identified.
2. Divide your team into four groups and assign each group a scenario from one to four. For each scenario, map out the process of different steps that might lead to harmful outcomes. Figure 7-12 shows an example using *Scenario Five*. Use a different scenario to create your own *Process Map*.

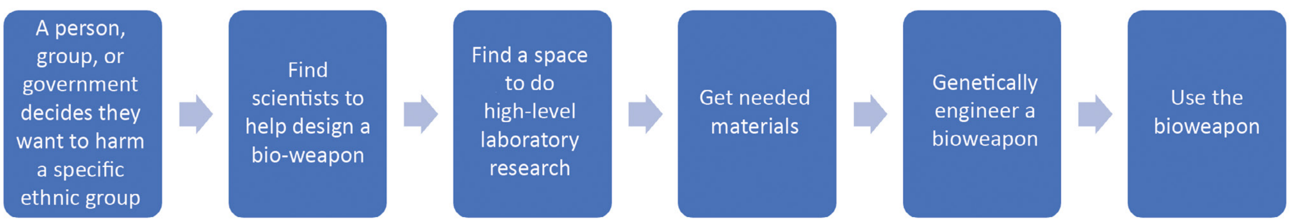


Figure 7-12: Mapping the process that leads to harmful outcomes from Scenario Five.

3. For each step in this process, consider ways this might happen. Write or draw them on the *Process Map*.
   a. Think about bio-error possibilities—ways mistakes might be made that lead to harmful outcomes. List or draw those ideas above your *Process Map*. You may want to use another color pen or marker.
   b. Think about bio-terror possibilities—ways someone might deliberately cause a harmful outcome. List or draw those ideas below your *Process Map*. You may want to use another color pen or marker.

4. Now examine your *Process Map*. For each step think about how you could prevent the next step from happening if:
   a. The problem was bio-error: Write or draw those ideas next to the bio-error possibilities on the *Process Map*.
   b. The problem was bio-terror: Write or draw those ideas next to the bio-terror possibilities on the *Process Map*.
5. Have each group share their *Process Map* with the rest of the team.
6. Discuss with your team:
   a. Are there ways you personally might be able to help stop bio-error or bio-terror?
   b. Are there other people, organizations, or governments you think could help stop bio-error or bio-terror?

Zabta says . . .

Education is important. Science is a public good. We need to think together about how to be good citizens and good human beings. We need to think carefully about the information we spread; information itself can become a weapon if it stops people from acting safely.

I work with international organizations to help coordinate scientists working to stop bio-threats. I work with groups of scientists around the world. But I also work with students in my country because everyone needs to understand that they have a part to play in keeping our world safe.

7. Sit in a circle with your team. One by one go around the circle and list places or things in your local community that might be vulnerable to bio-threats such as disease or invasive pests. Be sure to consider:
   a. Human health
   b. Shared food or water sources
   c. Your local economy
   d. Your local natural environment
   e. Places in your community, like laboratories, where biotechnology research is happening

8. Pick one vulnerability to investigate further. Then read the *Bio-Threat Vulnerability Investigation Instructions*.

Bio-Threat Vulnerability Investigation Instructions

Consider how you can find out more about the vulnerability your team picked. Make sure you find out:

1. What are the bio-threats to this vulnerability?
2. How serious are they?
3. How can they be prevented?
4. How might you help?

Possible methods to find this information

a. Online: Check for government, scientific, or news websites that contain details about the vulnerability you are thinking about. For example, if you are investigating what might threaten a crop lots of farmers in your area grow, you could search for potential diseases or invasive pests that would hurt that crop.
b. In print: Many bio-threats have been around for years. You may be able to use a library or other place to learn more.
c. Contact a local organization: Is there an organization in your community that helps support the thing or place you are investigating? They might have a lot of useful information. You can search for any documents they share with the public. Or you can contact them and ask to interview them.
d. Interview a scientist: A scientist who studies the bio-threat might be a good source of information. You can contact them and ask to interview them.
e. Another method: Be creative. Maybe you know another way to get the information you need.

Tips for conducting an interview

a. Make sure to ask permission to record a person's answers.
b. Ask permission to share the interview with the rest of your team, class, or other people in the community. People might be more willing to share if their interview is anonymous.

c. If it feels as if someone didn't answer your question, don't be afraid to ask the question again in a different way.
d. Let the person you are interviewing answer the questions in the way they want. Be patient. Listen carefully. Understand that they might give answers you didn't ask for or expect.

Safety tips for interviewing people

Ask your teacher for guidelines. They will know what is safest in your community.

⚠ **Physical Safety Tip**

Never conduct an interview alone and always be aware of your surroundings. You might want to suggest recording the interview in a quiet public place.

⚠ **Emotional Safety Tip**

It can be hard to communicate with other people in the community. You may feel shy or nervous. Someone may tell you they don't want to talk. That's okay! It doesn't have anything to do with you. It just means they don't want to share. You can show them respect by thanking them and moving on to another person.

9. Pick one or more methods to conduct your investigation.
   a. Decide who on your team will do what. Remember, including everyone is important. Try to pick methods that allow everyone on your team to participate in some way.
   b. Make notes or find other ways to record what you learn about the bio-threat during your investigation.

Act: *How can we work toward a safe future?*

Having foresight and understanding the threats to your community is important. This allows you and others to take action to combat these threats. In this activity you will think about how to share what you have learned with others.

Zabta says . . .

Youth can be change managers. People need to gain awareness and realize that they can anticipate things and take responsibility for the future. We need to think as a whole species, what will help us survive and do well? I wish the world leadership would change the phrase "national interest" into "human interest," because we are all connected.

1. Take out your notes from your bio-threat investigation in the Understand activity.
2. Discuss with your team, who in your community do you think should know more about this vulnerability? Pick one audience to focus on. For example, do you want to share what you have learned with other young people, with adults, with people who work in a specific type of job, people who live in a specific place, or another group?
3. Consider the audience you chose. What is your goal in communicating with them? For example, do you want them to just be more aware of the threat, do you want them to be more careful, do you want them to create a law or regulation, do you want them to understand how their actions affect other people, or do you want them to do something else?
4. Decide on your message. What are the most important ideas to share? Think about the information you gathered and the harmful outcomes you listed in the Discover activity. Choose information that will lead your audience toward your goal.
5. Design the message. What would be the best way to share this information? Be creative! For example, maybe you could create a poster or infographic, you could record a short video to share on social media, you could use a podcast to tell a story about the vulnerability, you could create a meme, or choose another way to reach your audience.

6. Take the message you designed and share it with your audience.
7. Reflect with your team about the process of creating and sharing your message. Discuss:
   a. What went well?
   b. What could have gone better?
   c. What would you do differently next time?

Congratulations!

You have finished Part 7.

<u>Find out More!</u>

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.

Algorithm: A process or set of rules followed to solve a problem or do a calculation, often by a computer

Bias: A situation where different groups are treated unequally

Bio-error: A bad outcome of biotechnology caused by a mistake someone made

Biometrics: Identifying someone by measuring the physical differences among individuals

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

Bio-terror: A bad outcome of biotechnology caused intentionally to harm others

Bio-threat: A harmful outcome from biological agents or biotechnologies

Bio-weapon: Viruses, bacteria, fungi, or other living things or toxic substances from living things released to deliberately cause harm

Database: A large set of information stored digitally

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

Dual use technologies: Products and tools that can be used for a helpful or a harmful purpose

False positive: When a match is incorrectly identified as present

Foresight: Thinking about what is likely to happen in the future

Freedom of association: The freedom to join together with others to express or defend similar interests

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

Landmarks: In facial recognition technology, these are the features that stand out easily on your face, like your nose, eyes, and mouth

Outcome: The end result or consequence of something

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

Traits: Characteristics

Variations: Differences in living things

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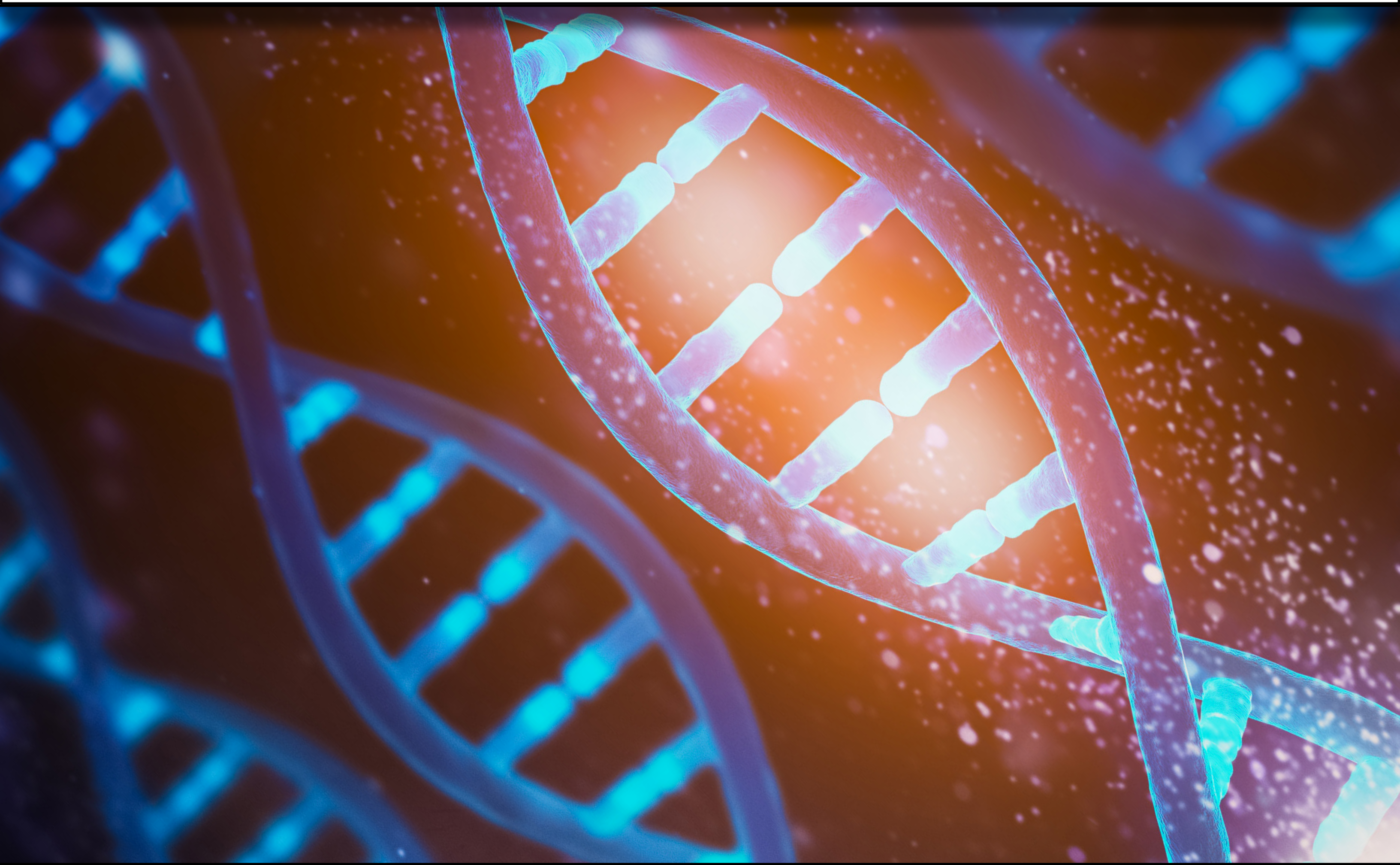
BIOTECHNOLOGY!

Part 8: Taking Action



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 8. 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

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Part 8

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PART 8: TAKING ACTION

Part 8

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: How will I help create a sustainable world using biotechnology?					
Discover	Use your *Futures Mood Board* to decide what future you want to take action to support.	• Paper • Pens or pencils	*Futures Mood Board* (Part 1)	20 minutes	289
Understand	Come to consensus and plan your action.	• Paper • Pens or pencils	*Identity Map* (Part 1)	45 minutes	291
Act	Implement your action plan and reflect on your action.		*Futures Mood Board* (Part 1)	15 minutes + action time	293

Task 1: How will I help create a sustainable world using biotechnology?

As **action researchers** you now have a lot of information. You discovered what is important to you and your team. You understand more about the science of **biotechnology**. You understand the values of people in your **community**. Now you will put those ideas together. In this part you will decide how your team will act to create the future you want. Then you will put those plans into action.

In this task you will ***discover*** more about your and your community's hopes for the future. Then you will ***understand*** more about your role in working toward those goals. Finally, you will ***act*** on your ideas and work toward a **sustainable** and positive future.

Discover: *How do I want biotechnology to be used in the future?*

Before you decide what you want to do, you need to think about what you want to accomplish. Many different futures are possible. Which one do you want to work toward?

1. Take out your *Futures Mood Board* from Task 1.
2. With your team, think about everything you have learned in this guide. Is there anything you would like to add to your *Futures Mood Board*? If so, add it now.
3. By yourself, examine the *Futures Mood Board*. Pick one part of the future that relates to biotechnology that you would like to work toward. It could be a concern you have about the future that you want to avoid, or it could be a hope about the future that you want to encourage.
4. Share your ideas with your team.
5. As a team, come to **consensus** on one part of the future you want to take action on. A consensus is a balanced decision that works for everyone in the group. There are many ways to come to consensus. Here are some ideas. You can choose whatever works best for your team.
   a. List the good things and bad things about taking action for each future. Discuss as a team.
   b. Try to find the same values. Are there some ideas about the future that are similar? Try to combine them.

c. Build a sense of the group opinion. Are there some ideas about the future that many people would be interested in working toward?

d. Find a slow consensus. Find a partner and as a pair find consensus on which future idea is most important. Then in a group of two pairs (four team members) you can build consensus among the four of you. Then in a group of four pairs (eight team members) you can discuss further to build consensus. Keep adding groups together until you have found a team consensus.

e. Consider your **impact**. Think about who would benefit from your team working toward a specific idea about the future. Which group are you most interested in helping?

6. Once you have chosen a future you want to work toward, you need to think of an action to take that might help create that future. Get out a piece of paper and write or draw any actions you can think of. If you are having trouble thinking of actions you can take, here are some ideas you may want to consider.

   a. Personal: Could you personally become involved in discovering and using biotechnologies? You have learned about many types of STEM careers from your research mentors. Choose the one that interests you the most and figure out how you could follow that career path.

   b. Educate others: Other people you know may not know much about biotechnology. Could you choose a group to educate to help them learn more?

   c. Communicate with your community: Help your community understand a part of biotechnology or a concern you have by designing posters, composing songs, recording podcasts, making public service announcements, setting up a social media campaign, or using other ways to communicate.

   d. Government change: Try to change the rules your local or national government has about biotechnology. For example, you could write letters to officials or speak at local government meetings to share the actions you think are necessary to create the future you want.

   e. Global change: Collaborate with others around the world who are worried about the same problem. For example, join a group that is using biotechnology for sustainability or a group that represents any concerns you have.

   f. Come up with your own ideas!

Understand: *What will my role be?*

Now it is time to plan your action. As you have learned, variations among people's perspectives and abilities can make the whole team stronger. Think about what role you will take to help with the team action.

1. Take out your *Identity Map* from Part 1 and examine it closely. Make a note of things about your identity that might help you decide how you would like to act. For example:
   a. Are you part of any groups that you could communicate with?
   b. Do you have any special talents, such as art or music, that might be useful to capture people's attention?
   c. Are you interested in science and engineering or other ways to try to find innovative solutions?
   d. Do you have good planning or organizational skills?
   e. Are there other things about your identity that might help you work toward the future you want?
2. Gather with your team. Write "Team Strengths" on a sheet of paper or on the board.
3. Under *Team Strengths*, write down all the ideas each person had about things from their identity that might help you all act.

⚠ Emotional Safety Tip

Everyone has strengths and weaknesses. As a team member, sharing your unique strengths is important, even if it feels uncomfortable. It is important to respect your own strengths and to respect what others identify as their strengths.

4. As a team, discuss the actions you thought of in the Discover activity. Remove any actions that would not be helpful or that you cannot do.

Part 8 Task 1

5. Share your ideas and listen to others. Come to a consensus about which action you will take, using your *Team Strengths* list to help you decide the best action for your team. You can use some of the consensus-building ideas from the Discover activity, if you want.
6. Think quietly to yourself about the steps that could be part of planning the action your team picked.
7. Write, draw, or use another way to record your ideas on small pieces of paper. Each piece of paper should have one step.
8. Have each team member share their steps by placing their pieces of paper on a table or by using a digital tool for collaboration.
9. Read through the steps from your teammates.
    a. Did you notice any steps that were similar to yours?
    b. Do you think your team is missing any steps?
10. Start to organize your team's steps. You can move the pieces of paper around as you do this. Thinking about your team's steps will help you decide how you will take action.
    a. Group any similar steps together.
    b. Remove any steps you don't think are needed to help your team take action.
    c. Think about how each team member will help. Put their names with the steps they would like to help with.
    d. Think about what steps might be missing. Add those steps.
11. Put the steps in order. For example, what do you think the team needs to do first? Place that piece of paper before all the others.
12. Title a sheet of paper "Action Plan" and record the following:
    a. The steps your team would like to take
    b. The order of those steps
    c. Who will help with each step (it might be more than one person)
    d. When and where you will take these steps
    e. Partners or other people you will involve
    f. How you will communicate your action plan to the community

13. Think about what you will do if your plan doesn't work or you run into another problem. For example, what will you do if an adult in your community says you need permission to do something in your plan. Record these ideas as part of your action plan.
14. Remember to create an **inclusive** action plan. Being inclusive means everyone on your team can participate in some way. You may need to make changes to the plan so that everyone feels safe, comfortable, and able to help. Those changes are okay! They are part of being a good teammate.

Act: *How will I put my ideas into action?*

The time has come to act! You can use everything you have learned to take action to help create the future you want.

1. With your teammates, implement your *Action Plan*. This may take some time. There is no need to worry; take the time you need. When you are finished, come back and complete this activity.
2. Think quietly about the action you took. Consider:
   a. What went well?
   b. What do you think could have gone better?
   c. How would you change your action if you had to do it again?
3. Discuss with your team:
   a. What makes you proud of yourselves as a team?
   b. What do you think you have learned for next time?
4. Examine your *Futures Mood Board* from Part 1. How are you feeling about the future now?
5. Think quietly to yourself about what you plan to do to create the changes you want to see in the future.

Congratulations!

You finished the *Biotechnology!* Community Research Guide!

All of us should be trying to do what we can to change ourselves and our world for the better. Maybe you took a big action. Maybe you took a small action. Maybe it had a big impact. Maybe it had a small impact. The most important thing is that you did something. When you take action to make your community better, you create the world you want to live in. You and your team are changing the world, one step at a time!

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.

Action researcher: A person who works with their community to discover, understand, and act on local and global problems they learn about

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

Community: A group of people who share something in common, such as a space or an identity

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

Impact: The effect one thing has on another

Inclusive: Making sure no one is left out

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

Meet Heidi Gibson, Your Biotechnology Guide Developer

Meet Heidi Gibson. Heidi (*Hi-dee*) was the main person writing this guide. She talked with lots of researchers to get information. However, like anyone, she has her own perspective. You have learned it is important to consider the perspectives of your teammates and research mentors. Perspectives affect what we think and how we think. It is also important to think about the perspective of the writer. This can help you understand why the guide was written the way it was. Considering the source of information is always a good idea.

Heidi has degrees in biology and international education. However, she also has knowledge and perspectives that come from other parts of her identity. Since you have been reading a lot of what Heidi has written, it is important to know who she is. To help you, Heidi filled out an identity map, just like you did in Part 1. Heidi's identity map includes the following things.

- Purpose is to help young people realize their power to transform the world
- Past jobs include laboratory research, civic education, international development, and diplomacy
- Grew up and lives now in Arlington, Virginia, USA
- Husband is Scottish and they lived there as a family, so that feels like her second home
- Also lived in Germany, China, Malawi, and Fiji
- Two children, ages 15 and 12
- Six siblings
- Loves being outdoors, especially the beach
- Walks around her garden looking at what is growing every day
- Enjoys travel, reading, singing, and being with family and friends
- Likes learning new things—cultures, ideas, languages, skills

Before you finish the guide, think quietly to yourself about Heidi's identity map.

- What questions do you have about the way the guide was written?
- What perspectives does Heidi have that might have made her write the guide the way it is?
- Are there things you would include that were not included?

Do you want to tell Heidi what you would change about the guide? Email her at scienceeducation@si.edu. She'd love to hear from you!

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Parents, Caregivers, and Educators
Action Plans can be shared with us by using hashtag #SSfGG!

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Smithsonian Science for Global Goals (SSfGG) is a freely available curriculum developed by the Smithsonian Science Education Center in collaboration with the InterAcademy Partnership. It uses the United Nations Sustainable Development Goals (SDGs) as a framework to focus on sustainable actions that are student-defined and implemented.

Attempting to empower the next generation of decision-makers capable of making the right choices about the complex socio-scientific issues facing human society, SSfGG blends together previous practices in Inquiry-Based Science Education, Social Studies Education, Global Citizenship Education, Social Emotional Learning, and Education for Sustainable Development.

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References

