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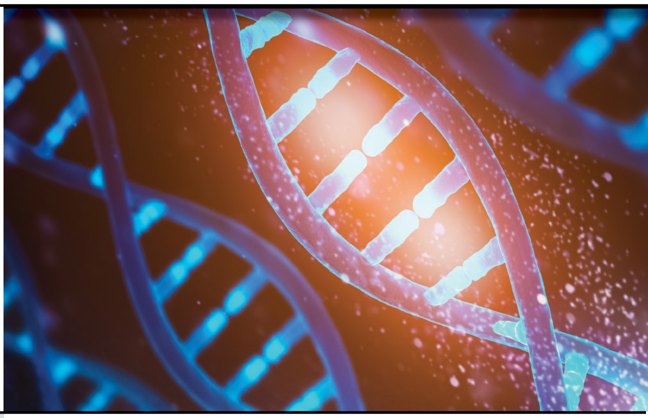
BIOTECHNOLOGY!



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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Smithsonian Science Education Center Guide Development Staff

Director - Dr. Carol O'Donnell

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

Science Curriculum Developer - Heidi Gibson

Contributing Interns
Emily Chen
Sarah Gallegos
Vittal Sivakumar

Research Mentors
Young Kim, Ph.D.

Technical Reviewers
Kevin O'Connor, Ph.D.
Jan-Georg Rosenboom Ph.D.

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

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PART 3: BIOTECHNOLOGY AND MATERIALS

Part 3

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.

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.

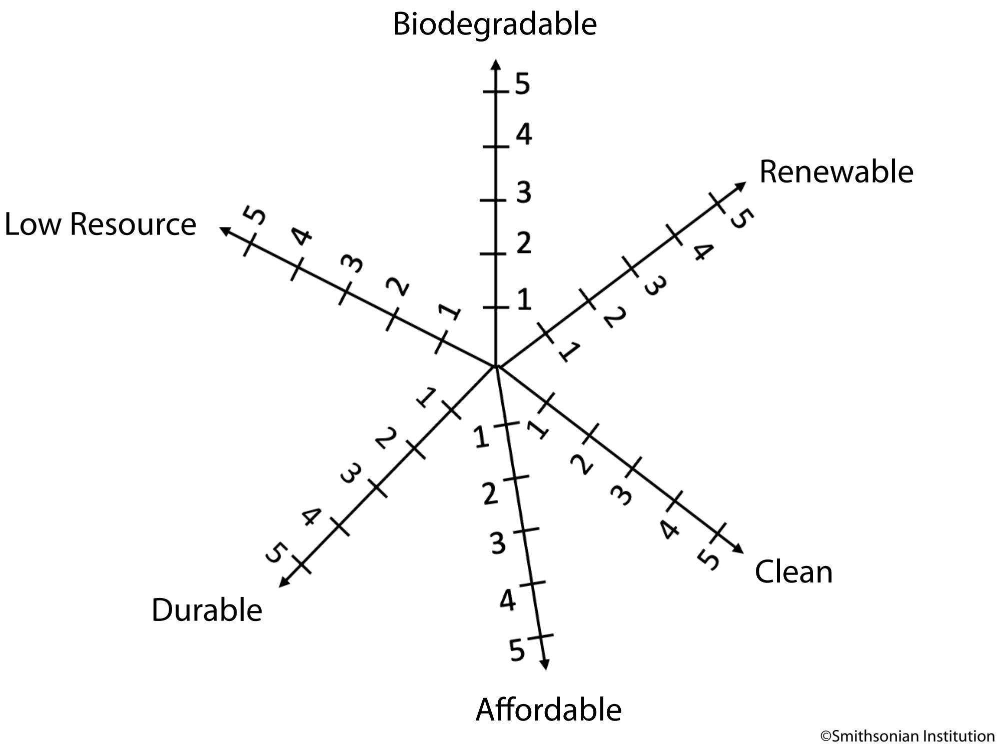


Figure 3-1: Sample Sustainability Profile chart.

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.

Part 3 Task 1

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.

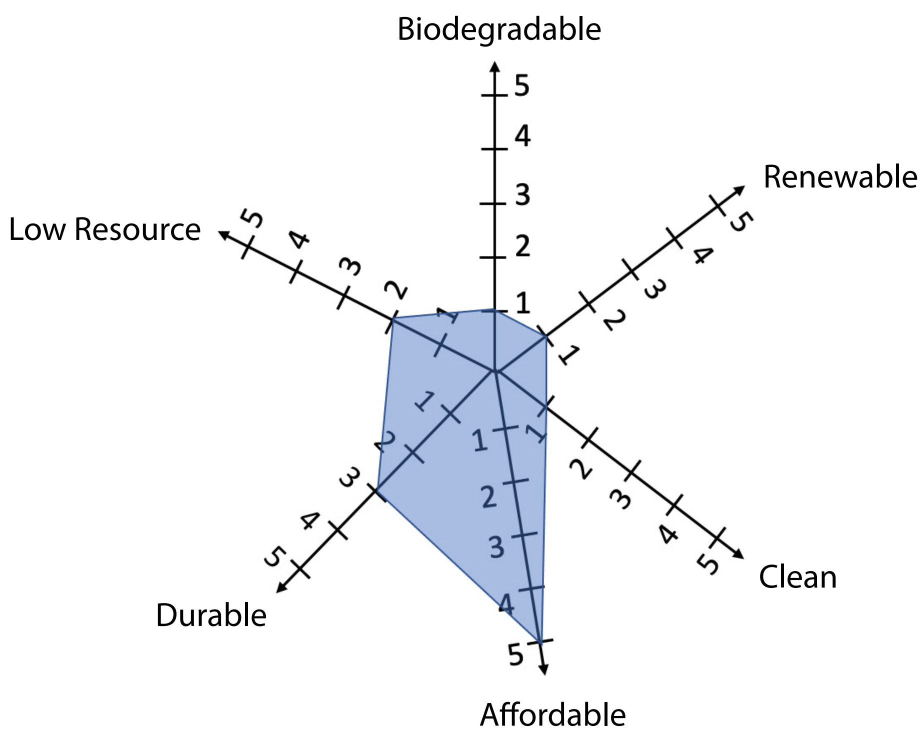


Figure 3-3: Example of a typical plastic water bottle's sustainability profile.

Part 3 Task 1

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?

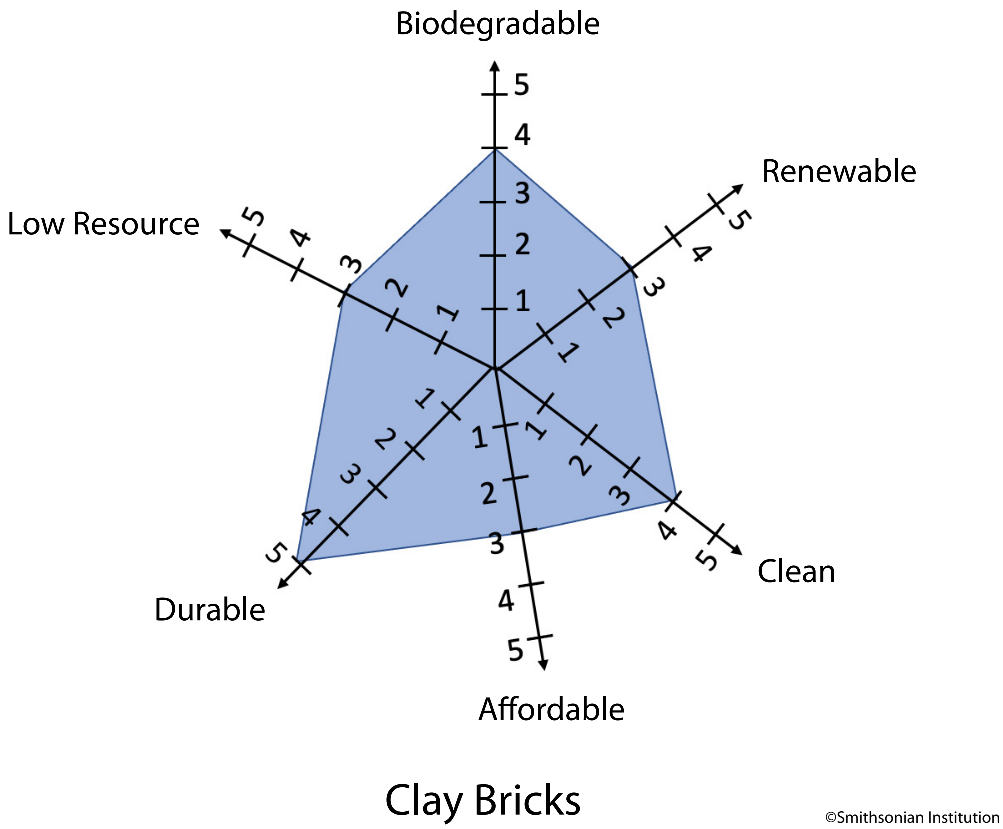


Figure 3-5: Sustainability profile of clay bricks.

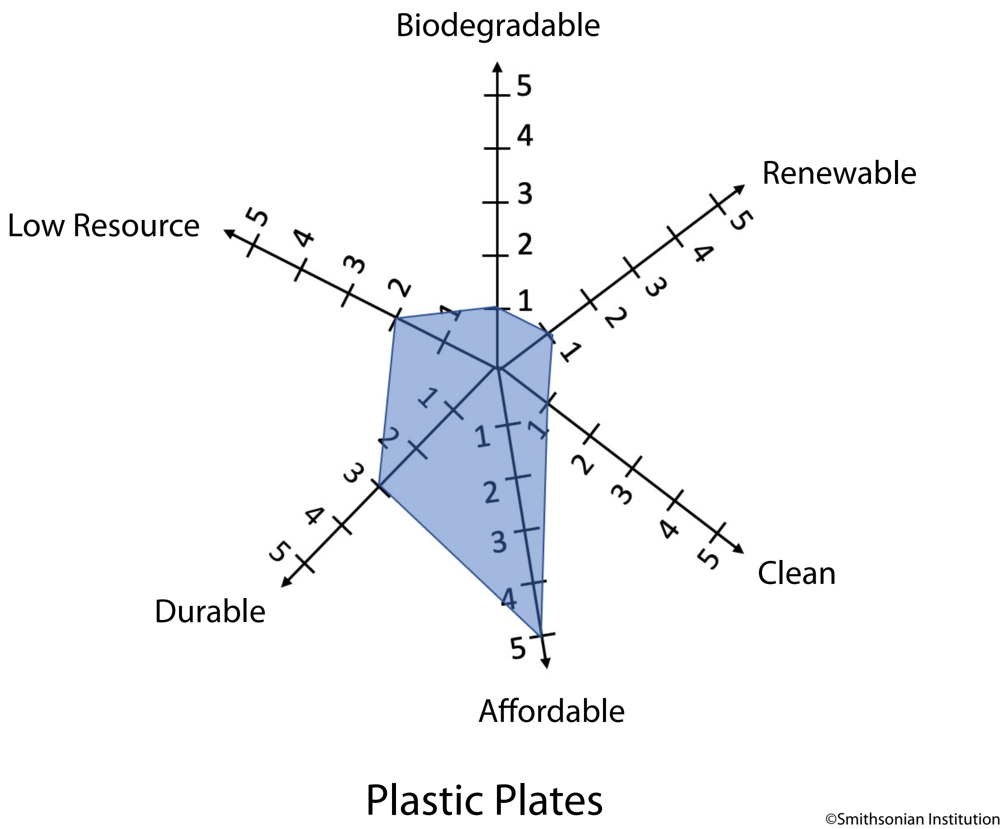


Figure 3-6: Sustainability profile of plastic plates.

Part 3 Task 1

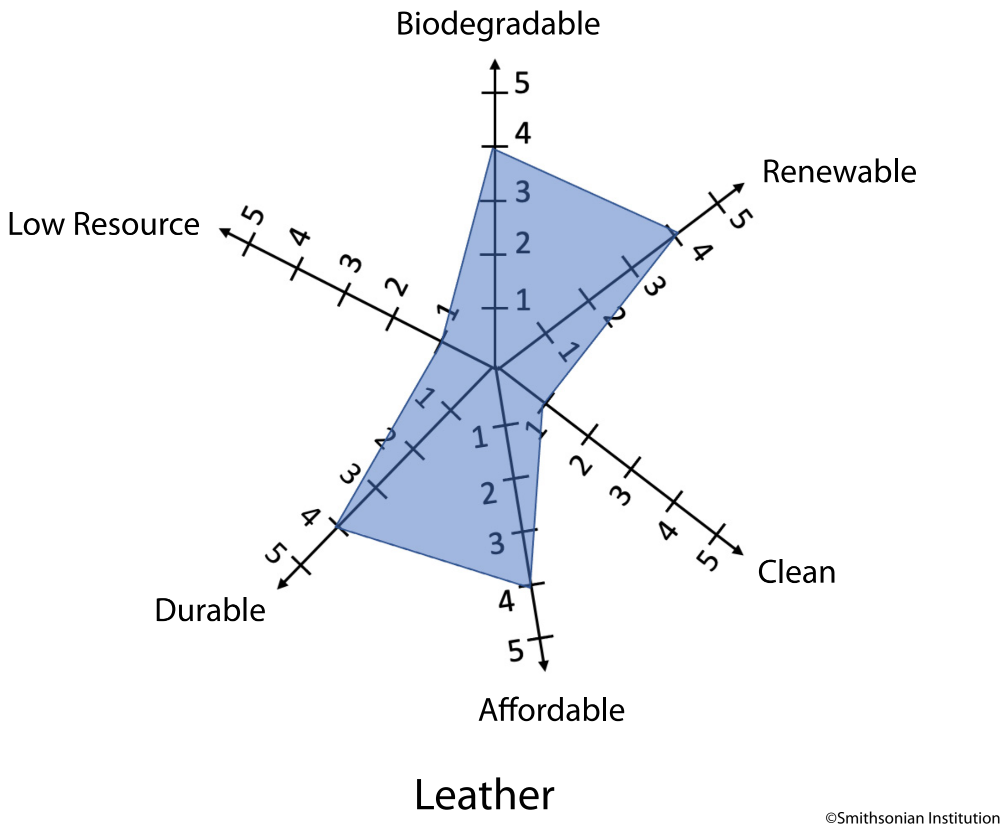


Figure 3-7: Sustainability profile of leather.

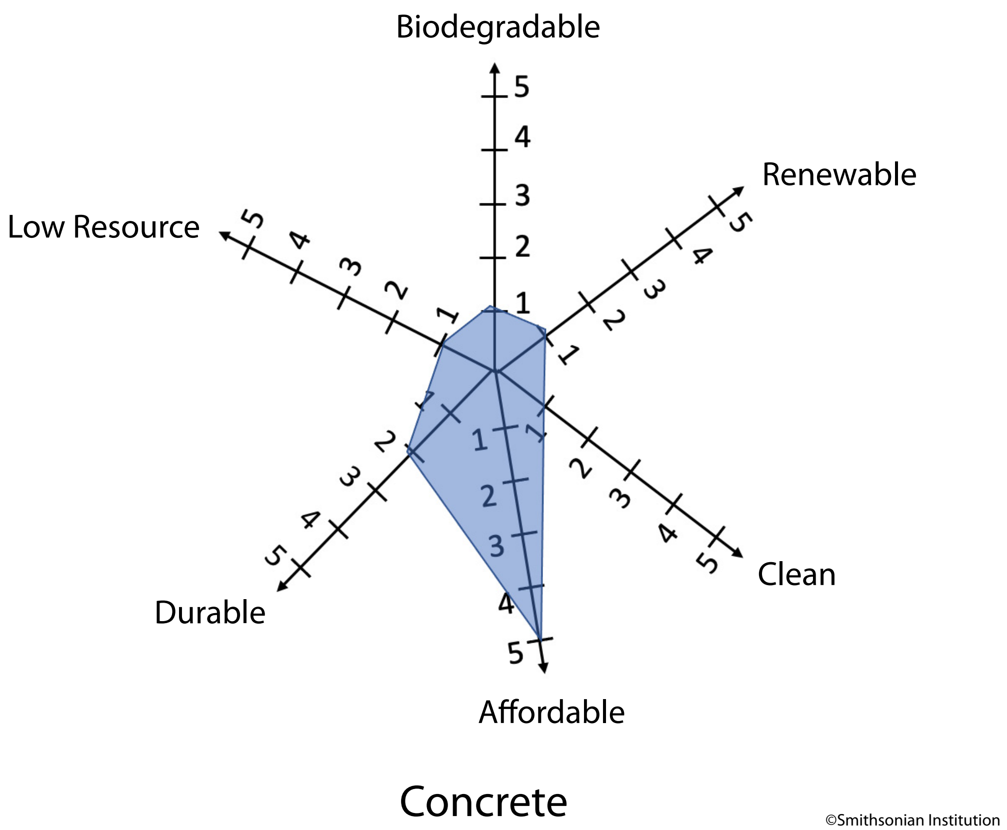


Figure 3-8: Sustainability profile of concrete.

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.

Part 3 Task 2

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.

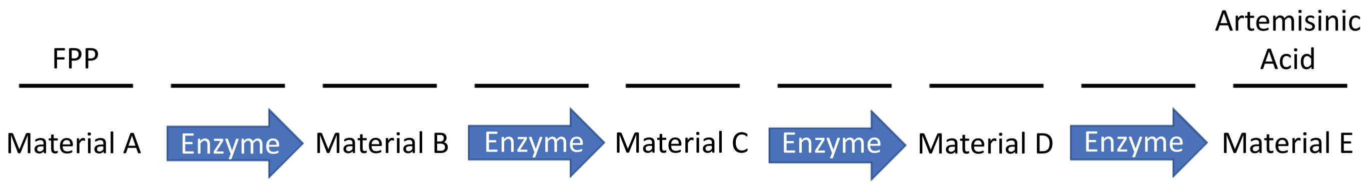


Figure 3-11: The biotransformative pathway from FPP to artemisinic acid.

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.

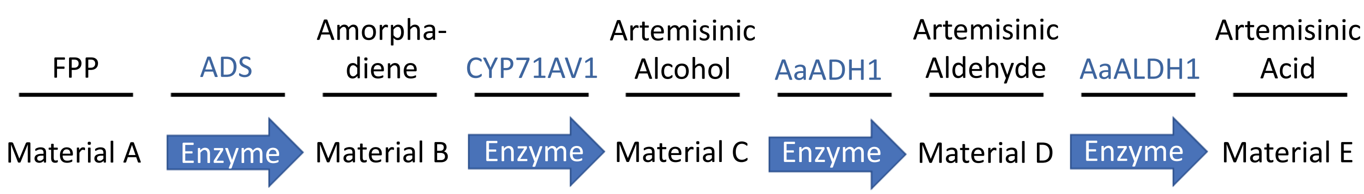


Figure 3-13: Correct biotransformative pathway from FPP to artemisinic acid.

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.

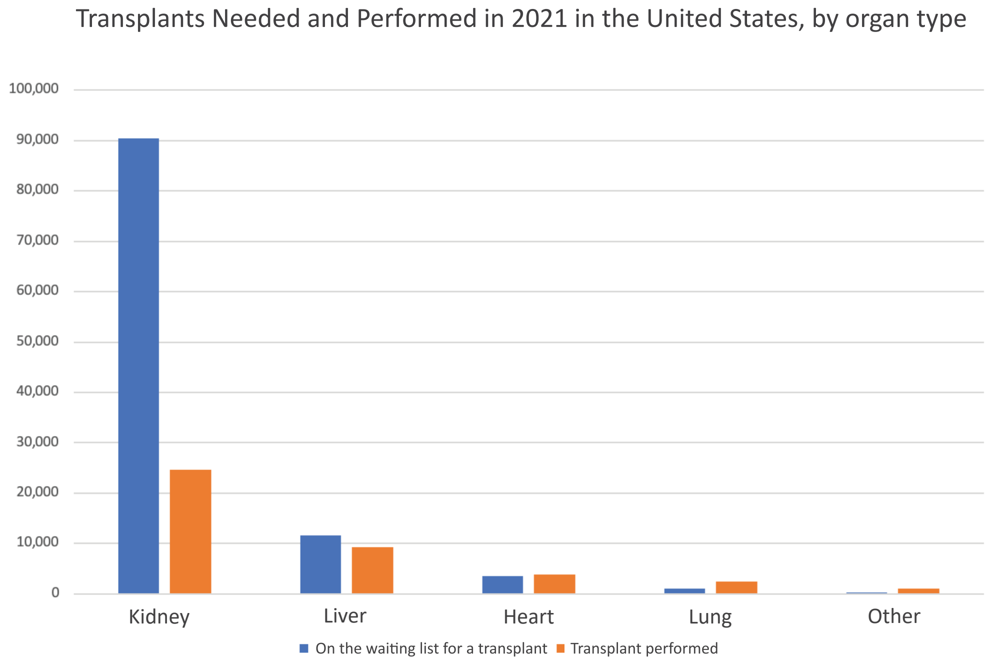


Figure 3-14: Transplants needed and performed in 2021 in the United States, by organ type.[1]

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?

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.

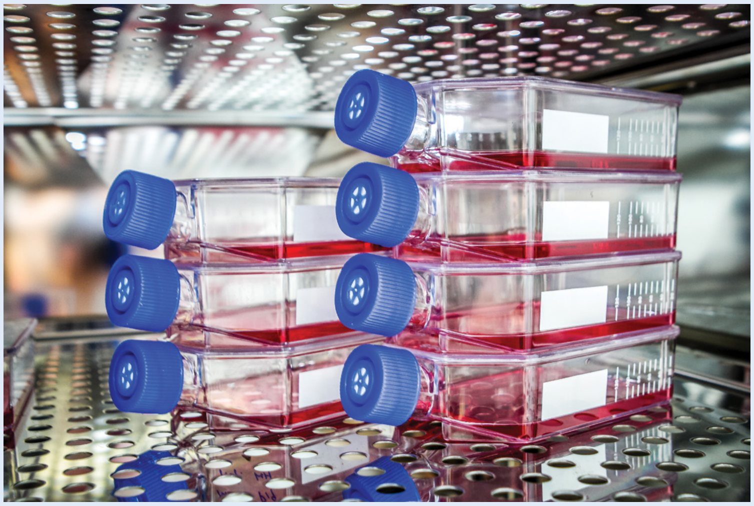


Figure 3-15: Tissue culture flasks in a laboratory.

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?

Part 3 Task 2

⚠ 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.

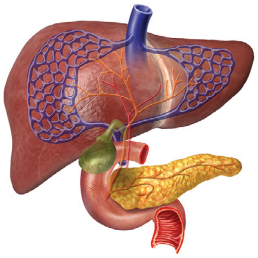
Organ Card: Kidney

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

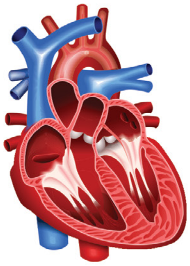


Cell types: 4 cell types

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.

