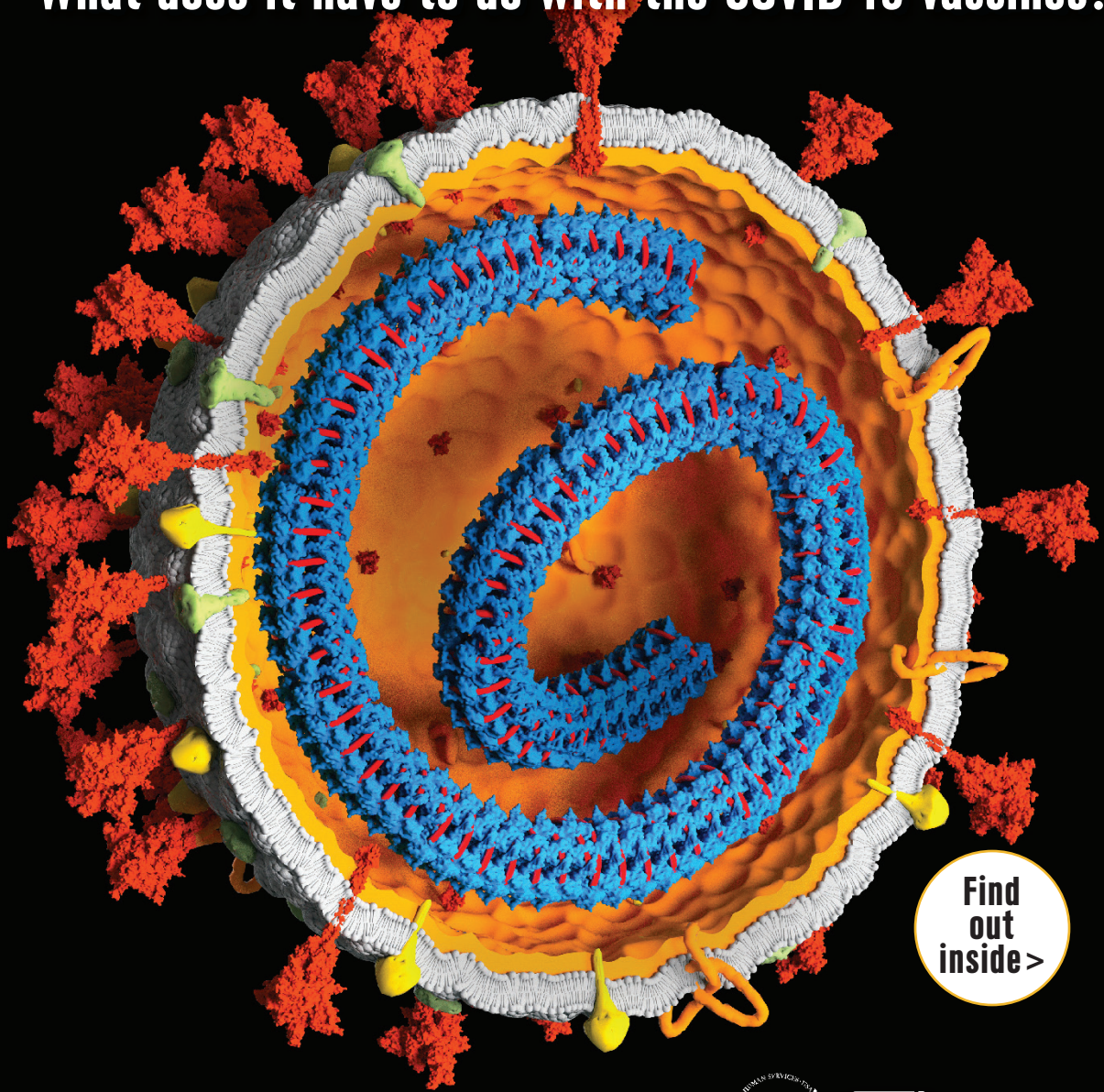
Sponsored Educational Materials

The Vaccine Science Issue

PATHWAYS

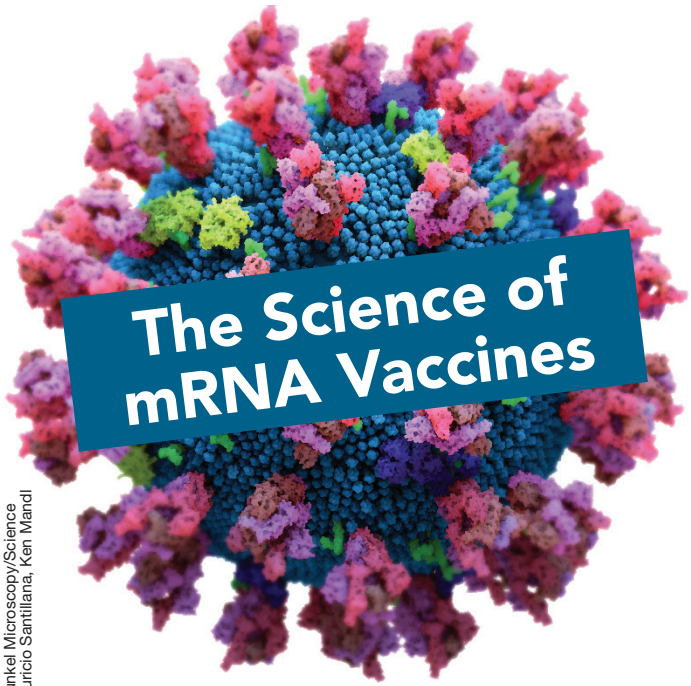
THE SPIKE PROTEIN

What does it have to do with the COVID-19 vaccines?



Find out inside >

NIH National Institute of General Medical Sciences



The Science of mRNA Vaccines

Read about vaccine research and other tools for preventing outbreaks

Vaccines are in the headlines a lot these days, but does it surprise you to know that vaccine science isn't new? Scientists around the world have been studying vaccines for more than 300 years. Fast-forward to today, we now have vaccines that can protect us from illness and death from infectious diseases like measles, polio, and—most recently—COVID-19. Scientists used a new method, built on years of research, to create one type of COVID-19 vaccine. Let's look at how it works.

mRNA Vaccines

A molecule called **messenger RNA**, or mRNA, is naturally found in every cell in your body. Cells use it to convey information about what types of proteins to manufacture so your body can function.

COVID-19 mRNA vaccines (including the Pfizer and Moderna vaccines) use mRNA to give your body important information to defend itself against COVID-19. Check out the infographic to learn how.

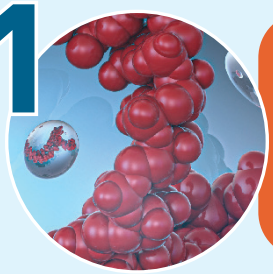
The Spike on Screen

When Dr. Kizzmekia Corbett's coronavirus vaccines team at the National Institutes of Health was tasked with addressing the COVID-19 outbreak, she felt prepared. "We knew exactly what to do, based on our past work," says Dr. Corbett, an expert immunologist,

Journey of an mRNA Vaccine

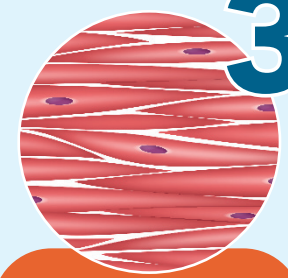
The SARS-CoV-2 virus (the virus that causes COVID-19) has a spike protein that it uses like a tool to break into and infect cells. But scientists have found a way to safely use this spike to develop the mRNA vaccine.

1



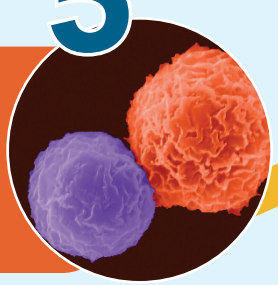
Scientists make copies of **mRNA** with instructions that tell the human body how to make **only** the outer ***spike protein*** of SARS-CoV-2.

3



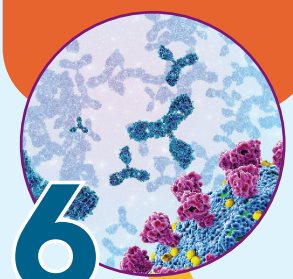
The vaccine's mRNA instructions pass into **muscle cells** (near where a vaccine injection is given), and those muscle cells make copies of the spike protein.

5



The body eliminates the vaccine material. Special white blood cells called **memory cells** "remember" the spike protein and which antibodies to make if they happen upon the spike again.

6



If SARS-CoV-2 (and its telltale spike proteins) enter a vaccinated person's body, the immune system reacts with **antibodies** that defend against infection more swiftly than it otherwise could if it had never seen the spike protein.

Illustrations: DESIGN CELLS/Science Source; LAGUNA DESIGN/Science Source; iStock/Getty Images; Juan Gaertner/Science Source; Dennis Kunkel Microscopy/Science Source; MEHAU KULYK/Science Source. Photos: Dr. Kizzmekia Corbett and Dr. Jason McLellan, courtesy of Dr. Corbett and Dr. McLellan; Dr. Mauricio Santillana; Ken Mandl

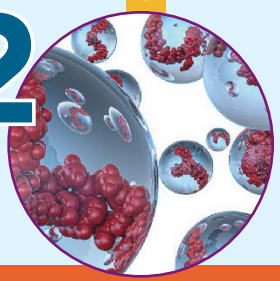
Cover: Top image is an illustration of vaccine particles containing mRNA instructions for producing the spike protein portion of SARS-CoV-2. Main image is an illustration of the SARS-CoV-2 virus, with the spikes on the outside and the full RNA **genome** on the inside.

Wait! Is the spike protein dangerous?

NO

On its own, the spike protein is harmless and can be used as a tool to train your immune system to defend against the virus.

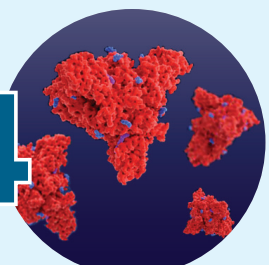
2



mRNA is packaged inside tiny globules called **lipid nanoparticles**. Lipids (fatty acids) are used as the vehicle because they:

- Protect the mRNA from breaking down
- Help it pass through cell membranes and into the body's cells

4



Though the spikes are harmless, the body's immune system recognizes them as **antigens** (foreign substances) and produces targeted antibodies to defend against them.

now an assistant professor at Harvard.

To develop a vaccine, Dr. Corbett and her team needed to identify the **antigen** (in this case, the spikes on the outside of the virus)—the part of the virus that triggers immune systems to develop antibodies to keep us safe. Dr. Corbett explains, "The cool thing [about mRNA technology] is you don't even need the lab to design the vaccine. All you need are the letters, or **sequence**, that **encodes** the virus's genetic material, on your computer screen."

Once they identified the part of the genetic sequence that represents the spike protein, it was time to figure out the best way to send that information, via a vaccine, to people's immune systems.

The Spike Through the Lens

"The SARS-CoV-2 virus is 1,000 times tinier than the width of a human hair," says Dr. Jason McLellan, professor of molecular biosciences at University of Texas at Austin. "A **cryo-electron microscope** let us look at the virus at that scale and create a detailed map of the [spike] protein."

The problem? "The spike protein is tricky," says Dr. McLellan. "Sometimes it looks like a baseball bat and other times, a spade. We needed to help the body recognize the most dangerous version—the spade shape." Dr. McLellan and his team tweaked the spike protein's genetic code, replacing two of its **amino acids** with sturdier ones to lock it in the spade shape.

Dr. Corbett's findings on the genetic sequence of the SARS-CoV-2 virus and Dr. McLellan's procedure for stabilizing the spike protein are two examples of how scientists built on decades of existing research to develop the mRNA vaccines against COVID-19. Once the vaccines were created, they had to be thoroughly tested. Scientists use **clinical trials** to collect data on how well vaccines work. Most advanced clinical trials involve fewer than 3,000 volunteers and require a year to get the necessary data. In contrast, advanced clinical trials for COVID-19 vaccines enrolled more than 30,000 volunteers each—ten times more people! This allowed researchers to analyze sufficient data on the safety and efficacy of the vaccines in under four months.

"The SARS-CoV-2 virus is 1,000 times tinier than the width of a human hair."

Seeing Into the Future

Data can help address pandemics in many ways. Dr. Mauricio Santillana, director of the Machine Intelligence Research Lab at Boston Children's Hospital, predicts the future—not with a crystal ball, but with **machine learning** and mathematical modeling. His team uses data to make evidence-based predictions. Dr. Santillana explains, "If many people are searching for 'cough syrup' or 'symptoms of COVID-19' today, it may signal a problem." Coupled with mobility data (think: lots of people headed to a concert), Dr. Santillana can predict an outbreak weeks before it occurs.

"We share our findings with governors and health officials to help them make informed decisions, to help save lives."

From top: Dr. Kizzmekia Corbett, Dr. Jason McLellan, and Dr. Mauricio Santillana

Find definitions of bolded words on the bonus vocabulary sheet.

A MESSAGE FROM

VICE PRESIDENT KAMALA HARRIS

Science Is for Everybody!

When I was a child, my sister, Maya, and I used to go to our mother's lab. She was a breast cancer researcher—and she would give us jobs to do, like cleaning test tubes. When you are the daughter of a scientist, science has a way of shaping the way you think. For our mother, the scientific method was a way of life. And she would tell us about all the scientists she had worked with over her career—their many backgrounds, interests, and skills.

My mother believed in the power of scientific collaboration. Over the last two years, our nation has seen that power in action. To create the COVID-19 vaccines, all types of scientists came together to save countless lives. No matter who you are or what you are interested in, there are many ways to build a career in science.

- Do you like **solving mysteries**? You could be a **researcher**, uncovering how biological, chemical, social, and physical processes work.
- Do you like **drawing or coding**? You could be a **molecular animator**, creating 3D models of microscopic specimens and processes to visualize the results of experiments.
- Do you like **working with numbers**? You could be a **data scientist**, searching for important trends and insights in large amounts of data.
- Do you like **writing or speaking**? You could specialize in **public health communication**, helping to educate Americans.

The scientists who worked on the COVID-19 vaccines were once students just like you. One day, our nation might need your help to stop the spread of disease, invent life-changing new technology, or teach the next generation of scientists. So pursue your passions. And remember: Science is for everybody.

Scientists in the Spotlight

There are so many ways to be a scientist! Meet two top scientists with two different paths.

Erin A. Mordecai, Ph.D.

Associate Professor in Biology and Senior Fellow at the Woods Institute for the Environment, Stanford University

WANTS TO FIND OUT: how human impacts on the environment affect infectious diseases

What might surprise students about being a researcher?
It's not all about test tubes in the lab! One researcher might analyze mobile phone data to understand human mobility and contact patterns, where another might study satellite imagery of changing forest cover in the Amazon.

Wait, the Amazon rainforest? What does that have to do with infectious disease?
There are links between our impacts on the environment and our health. For example, climate change is making mosquitoes more capable of transmitting diseases in places where they couldn't before. Simultaneously, progress on malaria eradication is stalled by deforestation and destructive mining practices (which produce large areas of stagnant water, creating breeding grounds for disease-carrying mosquitoes).

Marcos J. Ramos-Benítez, Ph.D.

NIGMS Postdoctoral Research Associate Training Fellow, National Institutes of Health; Founder and President at Ciencia en Tus Manos, Inc.

WANTS TO FIND OUT: how the human body interacts with viruses during an infection

How do you hope your research will help people?
During an infection, human cells undergo changes. Though small, they really add up—resulting in severe illness. I study the small changes with the aim to discover targets for new treatments. I am proud to be part of a team that has tested a new drug for the treatment of severe COVID-19 infection.

What role does science communication play in your work?
As a Hispanic first-generation scientist, I founded Ciencia en Tus Manos, Inc. (translated: Science in Your Hands), a nonprofit dedicated to scientific communication for the Hispanic community, using language that's entertaining and easy to understand. Throughout the COVID-19 pandemic, I've seen directly how science communication saves lives.

Photos: Dr. Erin Mordecai, courtesy of Stanford University; Dr. Marcos Ramos-Benítez, courtesy of Dr. Ramos-Benítez

Sponsored Educational Materials

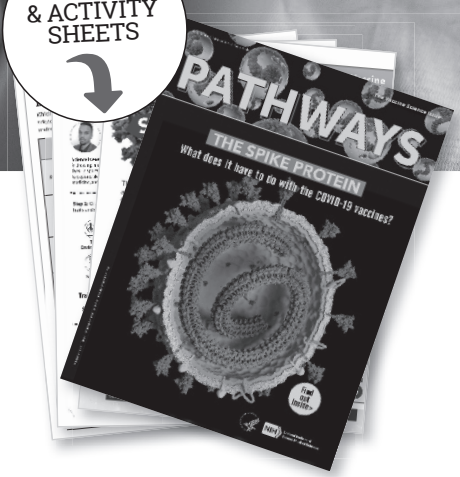
GRADES 6–12

PATHWAYS

The Science of mRNA Vaccines and How They Protect Against COVID-19

Plus: Using Data to Predict Outbreaks

MAGAZINES & ACTIVITY SHEETS



TEACHING GUIDE

Science and ELA Activities Investigating Vaccine Science and Research Careers

Visit **scholastic.com/pathways** for additional lessons, videos, and more.

BROUGHT TO YOU BY:

NIH National Institute of General Medical Sciences

Image: JGI/Tom Grill/Getty Images

Biomedical Research and Vaccines: The Fight Against Infectious Disease

Have students take on the role of biomedical researchers as they study a simulated pathogen and design an immunity-building vaccine.

Objective

Students will synthesize information using a range of sources and write for a domain-specific purpose.

Standards

NGSS

- **MS-LS1-3** Body subsystems
- **HS-LS1-2** Interacting body systems

CCSS Literacy in Science

- **RST.1** Cite evidence when analyzing science texts
- **RST.9** Compare and synthesize information from a range of sources
- **W.4** Produce writing appropriate to task

Time

75 minutes + additional time to complete activity sheets as needed

Materials

- *Pathways* magazine
- Paper, scissors, rulers
- Find Your Inner Scientist activity sheet
- Model mRNA Vaccine Science activity sheet
- Optional: Vocabulary sheet at **scholastic.com/pathways**

1 **Ask** student volunteers to take turns **reading** the magazine aloud. Acknowledge that many of us have been impacted by COVID-19. Discuss how science can be an empowering way to address a challenging situation.

2 **In pairs,** have students do the Find Your Inner Scientist activity sheet.

3 **Model** how to create a "paper pathogen" (see diagram below). **Direct** students to work in pairs and create a few paper pathogens of their own. Encourage pairs to experiment and come up with varied "spike" shapes.

4 **Explain** that a ***pathogen*** is an organism (e.g., bacterium, fungus, virus) that causes disease. Say: This pathogen is a virus. On its surface (point to spikes) there are ***antigens***—substances your immune system recognizes as foreign to your body and so it produces ***antibodies*** in response.

5 **Ask** pairs to choose their most interesting paper pathogen and cut one of its ***antigenic*** spikes free. Have students observe and record a description of the antigen's shape, its measurements, and the location of its notable features.

6 Then, tell students to **create** a one-page guide with ***instructions*** for how to create a copy of their antigen (students may template their antigen by tracing it).

7 Have students **trade** their guide with another student pair.

8 **Ask** pairs to use the instructions they've received to create four identical copies of the antigen and design four antibodies that can fight it. For example, they may trace the antigen, then cut around that "negative space" to create shapes that fit the spikes like puzzle pieces. Affix them to a bulletin board.

9 **Distribute** the Model mRNA Vaccine Science activity sheet. Discuss which parts of their classroom activity represent real-world mRNA vaccine science. Have students fill in steps 1–4.

10 **Point** to the bulletin board. Ask students to explain how the body would react to a collection of new antigens. *Prompt for: build antibodies.*

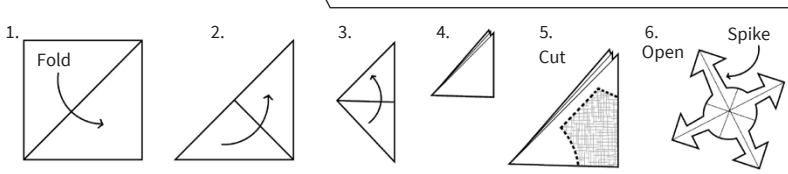
11 **Move** one of the antigens to your whiteboard, draw a rectangle around it, and title it like a "Wanted / Have you seen this antigen?" poster. Explain that once your body creates enough antigen-fighting antibodies, it will "remember" and be on the lookout for the antigen. Hold up an intact paper pathogen, pointing to a spike. If the body encounters the antigen again, it will know what to do—reacting quickly with the right antibodies to fight an infection.

12 In groups, **finish** the Model mRNA Vaccine Science activity sheet.

13 **Wrap up** with a discussion about new and surprising learnings about vaccine science, careers in biomedical research, and questions students would like to research next.

Activity Sheet Answers: Classroom: 1. paper pathogens created, 2. observations recorded, 3. guides with instructions created, 4. instructions received and antigen copies made, 5. antibodies made, 6."antigen wanted" poster created, 7. original pathogen/antigens revisited **Magazine:** 1. COVID-19 outbreak, 2. Dr. Corbett computer sequencing, Dr. McLellan mapping the antigen, 3. instructions for producing spike protein in stabilized shape are packaged into lipid nanoparticles in the vaccine, 4. muscle cells make copies of spike protein, 5. immune system makes targeted antibodies, 6. memory cells remember instructions, 7. vaccinated immune system reacts more swiftly than it otherwise could, 8. COVID-19 vaccine trials enrolled 30,000 people

Steps for Creating a Paper Pathogen



Name _____

Find Your Inner Scientist

There are many pathways to becoming a scientist—and many ways to combine science with what you already love to do!

Marcos J. Ramos-Benítez, Ph.D., Microbiology and Immunology

Science is everywhere. There is science in drawing, music, and all aspects of our lives. In sports, there are tons of things to explore, like biomechanics, sports medicine, and data analytics.

Erin A. Mordecai, Ph.D., Ecology of Infectious Disease

Add math. Many students find that math is much more interesting outside of the textbook, in the real world, when it's used to solve problems—like how to stop the next pandemic!

Jason McLellan, Ph.D., Molecular Biosciences

Go ahead and game. Playing video games when I was younger taught me problem-solving and other ways of thinking—and to make connections between old and new challenges. I still play them!

Step 1: Circle or highlight your top interest(s) as well as your traits and skills, or add your own on a separate sheet. Reflect on how you can combine these to embark on a career in science.

Environment | **Social Media** | **Math** | **Writing** | **Sports** | **Video Games**

Science | **Computers/ Tech** | **Art** | **Food/Cooking** | **Travel/ Exploration** | **Helping**

Traits: Patient | Flexible | Creative | Caring | Curious | Analytical | Detail-oriented

Skill Areas: Communication | Numeracy | Logic | Critical Thinking | Organization

Step 2: Choose an area of research from the list below. Then, on a separate page, write a persuasive paragraph that explains how you could use your unique interests and skills to contribute to biomedical research and advancements in the area of research you chose.

Disease
Aging
The Brain
Biomechanics
(how the body moves)

Growth & Development
The Heart
Genetics
Pharmacology
(medications)

Immunology & Viruses
Data, Modeling & Artificial Intelligence (AI)
Mental Health
Chronic Pain

Name _____

Model mRNA Vaccine Science

Which steps from your "paper pathogen" classroom simulation align with real-world mRNA vaccine science? Record related facts and information from your *Pathways* magazine to support your understanding.

In the Classroom		In the World	Supporting Facts and Information From the Magazine
Step 1		A new pathogen emerges that endangers human health.	
Step 2		Scientists work to identify the pathogen and use tech like genome sequencing and cryo-electron microscopy to identify the structure of an antigen (foreign substance) at the atomic level.	
Step 3		Scientists develop an mRNA vaccine that packages how-to instructions for building the antigen.	
Step 4		The vaccine is given to people in clinical trials. Cells in the body use the instructions to create copies of the antigen.	
Step 5		The immune system responds to the presence of antigens by creating antibodies.	
Step 6		The immune system stores a "memory" of the antigen so that it "remembers" what to do if it encounters it again.	
Step 7		If the body encounters the virus, the immune system recognizes the antigen and is prepared to react swiftly to fight infection—quickly generating the antibodies it already knows how to make.	
Step 8		Scientists analyze data from clinical trials to confirm the vaccine is safe and effective; then it's given to the general public.	

VOCABULARY LIST

GENETICS

amino acid *(noun):* a chemical building block of proteins.

- Amino acids are present in all living organisms.

DNA *(noun):* the molecule found in cells that carries instructions for cell structure and processes in the body.

- DNA contains genes that are passed on from parents to offspring and give living things their inherited characteristics. The letters DNA stand for **d**eoxyribo**n**ucleic **a**cid.

encode *(verb):* to be responsible for producing a substance or behavior (when referring to a gene).

gene *(noun):* a small section of DNA that contains instructions, usually for making a specific protein.

genome *(noun):* the complete set of genes in an organism.

messenger RNA *(noun):* a molecule that delivers genetic instructions from DNA so the cell can produce a specific protein.

- Also known as mRNA, it is naturally found in every cell in the body. The letters RNA stand for **r**ibo**n**ucleic **a**cid.

sequence *(noun):* a particular order (such as, among the base components that make up DNA or RNA; different sequences form different genes).

IMMUNOLOGY

antibody *(noun):* a protein the immune system produces in response to a foreign substance.

antigen *(noun):* the part of an infectious organism that the immune system recognizes as foreign, such as an outer piece of a virus.

lipid nanoparticle: a tiny particle (smaller than one-billionth of a meter!) made up of lipids—or fats. In medicine, they're used to deliver drugs or nucleic acids like mRNA to certain parts of the body. Their outer lipid layer works like a protective shell to guard their contents until delivery.

memory cell *(noun):* a type of white blood cell that "remembers" antigens as well as which antibodies the immune system should produce to defend against those specific antigens.

muscle cell *(noun):* A type of cell that groups together to form muscles. Muscles attached to bones can help the body move.

vaccine *(noun):* a substance that helps protect against certain diseases by helping the immune system recognize and destroy specific microbes.

SCIENTIFIC RESEARCH

clinical trial *(noun):* a research study involving human participants to gather data on the safety and effectiveness of a health treatment.

cryo-electron microscope *(noun):* a type of microscope that blasts a beam of electrons into a frozen specimen, such as a virus. A specialized camera detects how the electrons interact with the atoms in the specimen, which tells scientists where the atoms are located.

- This technology allows scientists to determine the 3D structure of specimens that are too tiny to be seen with light.

machine learning *(noun):* an approach to artificial intelligence in which a computer algorithm (a set of rules and procedures) is developed to analyze and make predictions from data that is fed into the system.

- Machine learning-based technologies are routinely used every day, such as personalized news feeds and traffic prediction maps.

TAKE IT FURTHER

Choose five vocabulary words that you think will be hardest to remember, and then write a paragraph with them (nonfiction or fiction).