HOW TO USE THIS RESOURCE

The image for this resource, which shows an experimental setup for studying the evolution of antibiotic resistance, can serve as a phenomenon to explore the key concepts described below.

The pedagogical practice of using phenomena to provide a context for understanding science concepts and topics is an implementation practice supported by the Next Generation Science Standards (NGSS). Phenomena are observable occurrences that students can use to generate science questions for further investigation or to design solutions to problems that drive learning. In this way, phenomena connect learning with what is happening in the world while providing students with the opportunity to apply knowledge while they are building it.

The “Implementation Suggestions” and “Teaching Tips” sections provide options for incorporating the images into a curriculum or unit of study, and can be modified to use as a standalone activity or to supplement an existing lesson. The student handout includes reproductions of the images and the “Background Information” section.

Additional information related to pedagogy and implementation can be found on this resource’s webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Antibiotics are chemicals that kill bacteria or stop them from growing.
- Some bacteria have genes that confer resistance to antibiotics. Bacteria may acquire these genes through mutations or through bacterial conjugation.
- Bacteria undergo rapid growth in optimal conditions, such as when they have ample food or space, or when they are not treated with antibiotics.
- When treated with an antibiotic, bacteria with genes that confer resistance to that antibiotic are more likely to survive, reproduce, and pass on their genes to offspring than bacteria without those genes are. If this process repeats over many generations, most or all bacteria in the population will become resistant to the antibiotic. This is an example of evolution by natural selection.

BACKGROUND INFORMATION

If you get sick from a bacterial infection, your doctor may give you a type of medicine called an antibiotic. Antibiotics are chemicals that kill bacteria or stop them from growing. But over time, populations of bacteria can evolve **resistance** to antibiotics, which means that the antibiotics will no longer work against them.

To study how bacteria evolve resistance, scientists set up an experiment called the **MEGA-Plate** (MEGA stands for Microbial Evolution and Growth Arena). The MEGA-Plate was a bacterial growth plate similar to a Petri dish. It was a large dish (2 feet × 4 feet, or 60 cm × 120 cm) filled with agar jelly, a substance that bacteria can grow on and get food from.

The scientists divided the MEGA-Plate into sections with different amounts of antibiotics. The sections at either end had no antibiotics. The sections toward the center had higher concentrations of antibiotics (1×, 10×, 100×). The center section had the highest concentration of antibiotics (1000×), which was 1000 times higher than the 1× sections near the ends. The scientists added *E. coli*, a type of bacteria, into the sections at the ends without antibiotics. They then observed how the bacteria grew and spread over time.

This image shows the MEGA-Plate from above after 11 days. *E. coli* appear as white on the black background. Areas that are lighter in the image have a higher density of bacteria. Areas that are darker have fewer or no bacteria present.

IMPLEMENTATION SUGGESTIONS

The following suggestions outline several options for incorporating the image into a unit of study as a phenomenon:

Engagement, establishing prior knowledge, and providing context:

- Begin the lesson by asking students to brainstorm words or phrases they associate with the word "bacteria."
  - Students can write individual words or phrases on Post-It notes, then group their notes based on common themes. For online settings, you can do this with a virtual whiteboarding software, such as Google Drawings or Miro. Ask students to share commonalities, major themes, or recurring words with the class.
  - You can also use polling software, such as Poll Everywhere, to generate a word cloud.
  - Students' words may include "sickness," "illness," "disease," "antibiotics," "cleanliness," "microscopic," "germs," "microbes," etc.
- Tell students that they're going to be exploring an image of a bacterial growth plate, similar to a Petri dish. Explain that bacteria, like other organisms, need food and a habitat in order to grow and that these are provided by the growth plate.
- Show the image and ask students to make observations using the sentence stems "I notice...," "It reminds me of...," and "I wonder..."
- Use a think-pair-share protocol to have students share their observations and questions about the image. Record class observations, noting when students make similar observations and drawing attention to the range of student-generated questions.
  - Students may observe that there are "blobs" or "dots" that seem to be crossing the plate. They may notice that there seem to be lines dividing the plate into sections.
  - Students may wonder why there are more light-colored areas at the edges of the plate and fewer toward the center, what's dividing the plate into various sections, and if the bacteria in the center are different from or the same as the ones at the edges.
  - Have students read the "Background Information" for the image. As students are reading, ask them to focus on the following questions. (Before discussing students' answers, it may be helpful to show the *Superbugs* video clip from the "Exploration" section below.)
    - What is meant by bacteria having "resistance" to antibiotics?
    - What does it mean for bacteria to "evolve" resistance to antibiotics?
    - What is the MEGA-Plate? Summarize the scientists' experimental setup.
    - Which sections of the MEGA-Plate have the most bacteria? The least bacteria? What are the differences between the bacteria in the different sections?
    - What other questions do you have about this image or information?
- Transition to the "Exploration, investigation, and assessment" section by telling students they'll be exploring a subset of their observations and questions through the following activities.

Exploration, investigation, and assessment:

- Exploration:
  - Have students watch the beginning (0:00–5:47) of the short video *Superbugs That Resist Antibiotics Can Evolve in 11 Days*. A transcript of the video can be downloaded from its webpage. Discuss the following questions with students:
    - What are antibiotics, and how were they discovered?

    - The narrator, Ed Yong, describes antibiotics as "shock and awe weapons." What does he mean by this?
    - Yong describes the MEGA-Plate experiment as "evolution at warp speed." What does he mean by this? Why do bacteria evolve so much faster than other types of organisms?
    - Revisit the other questions from the "Engagement" section above. Did your answers change after watching the video?
  - Students often have misconceptions about bacteria being one type of organism rather than a diverse domain of organisms. They may also conflate bacteria, viruses, and other pathogens as all being "germs" and struggle to understand the relative sizes of bacteria, viruses, and eukaryotes.
    - To address these misconceptions, it may be helpful to have students watch the short video *Animated Life: Seeing the Invisible* and complete the related activity "What van Leeuwenhoek Saw," which center around van Leeuwenhoek's use of microscopy to visualize microorganisms. These resources have students explore the diversity of organisms seen by van Leeuwenhoek, including bacteria (many of which are nonpathogenic) and eukaryotes, and construct scale models of microbes.
    - It may also be helpful to show the "Relative Sizes" diagram from *Virus Explorer*, which shows viruses with a scale in nanometers, and compare this to microorganisms shown with a scale in micrometers.
- Investigation:
  - Tell students that they will now use a written tool to explain how bacteria evolve resistance to antibiotics. This tool is the "Explanation Table" handout from the "Developing an Explanation for Mouse Fur Color" activity, which defines each component of a complete explanation about evolution by natural selection.
    - Begin by asking students to read through the table. It may be helpful to have them rephrase each of the provided descriptions in their own words.
    - Provide students with examples of the first two conditions (variation and inheritance) and an example of a selective force, either from previous class activities or from students' everyday experiences.
  - Have students work in small groups to watch and discuss the following resources. They should consider how the content in each resource contributes to a complete explanation of how bacteria evolve resistance to antibiotics through natural selection.
    - The *Bacterial Growth* video clip shows real footage of bacteria rapidly dividing. It explains that when bacteria are grown in the lab, with unlimited food, they reach large numbers quickly, but that they grow much more slowly in human intestines because they are competing for resources with other bacteria.
    - The *Bacterial Conjugation* animation shows how bacteria can pass antibiotic resistance genes to one another.
    - The *Penicillin Killing Bacteria* video clip shows real footage of the effects of adding penicillin, an antibiotic, to a culture of bacteria.
    - Students in advanced biology could also examine the Data Point "Origins of Antibiotic Resistance," which features a figure from a study on whether antibiotic resistance genes evolved before or after the introduction of modern-day antibiotics. Students often have the misconception that bacteria develop resistance to antibiotics in response to exposure to antibiotics. This Data Point presents evidence that even bacteria with no exposure to antibiotics may already have genes for antibiotic resistance.
  - Have students note in their explanation tables how evidence from each resource contributes to an explanation of how bacteria evolve resistance to antibiotics through natural selection.
    - For the videos, it may be helpful to provide transcripts to students and have them identify passages from the transcripts that can serve as components of their explanations.
    - Students' responses should generally note the following:

- **Variation:** Variation exists within populations of bacteria, with some bacteria being resistant to antibiotics and some being susceptible (not resistant) (*Bacterial Conjugation* and "Origins of Antibiotic Resistance").

  Inheritance: Antibiotic resistance is an inherited trait, as bacteria that are resistant to antibiotics must have genes for resistance. Bacteria may acquire these genes through mutations ("Origins of Antibiotic Resistance") or bacterial conjugation (*Bacterial Conjugation*).
- **Differential survival and reproduction:** In many environments, such as in the human intestines, bacteria must compete for food, space, and other resources (*Bacterial Growth*). When treated with an antibiotic, bacteria with genes for resistance to that antibiotic grow faster and are more likely to survive, reproduce, and pass on these genes to their offspring (*Penicillin Killing Bacteria*).
- **Adaptation:** If the process above repeats over many generations, most or all bacteria in the population will become resistant to the antibiotic.

- It may be helpful to give students an exemplar response or a rubric listing components of an answer, then have them either self-assess or discuss their responses with one or two classmates. The rubric could be adapted from the NGSS Evidence Statements for HS-LS4-2.
- Depending on students' comfort with constructing explanations about evolution, it may be helpful to do one or more of the following:
  - If students are struggling to convert their initial notes into more complete responses, provide sentence frames or starters as scaffolding, or have students articulate their answers verbally (either to one another or to themselves).
  - Determine a class color-coding system for different components of the table (e.g., purple for "variation," blue for "inheritance," etc.). Give students highlighters or markers in multiple colors, then have them color their notes accordingly.
  - Allow students to revise their responses after receiving feedback or consulting a rubric.

- Watch the *Superbugs* video from 5:47 through the end. Have students compare their explanations of how bacteria evolve resistance to antibiotics to the one that Ed Yong gives from 5:47–6:04, which is as follows: "When bacteria are exposed to antibiotics, those with mutations that allow them to survive the attacks are the only ones left standing. And when those mutant microbes reproduce, they create a population of super-resistant bugs."
- Assessment:
  - Assess students' understanding of bacterial resistance to antibiotics by having them explain the reasoning behind Yong's following claim: "The problem with antibiotics is not in their use, but in their misuse."
    - Students' answers should include components from their initial responses above, as well as additional evidence from the remainder of the *Superbugs* video.
- Extension:
  - Students may wonder about what happens when multidrug-resistant bacteria, such as MRSA, become common. Use the following resources to explore several related topics, including alternatives to traditional antibiotics, the hazards of using antibiotics with livestock, and the search for novel antibiotics.
  - Have students watch the *Fecal Microbiota Transplants* video and consider how FMTs differ from traditional antibiotics, specifically as they relate to the microbiome. A transcript of the video can be downloaded from its webpage.
  - Use one or more of the following Science News articles to explore antibiotic overuse and the search for new antibiotics:
    - "Inside the Search for New Antibiotics": With no new viable antibiotics produced in over a decade, scientists are getting more creative with their methods.
    - "A Taste of Our Own Medicine": A deep dive into the controversial use of antibiotics in livestock.

        - [“The Hunt for Wonder Drugs at the North Pole”](): In a race against antibiotic resistance, a Norwegian research team sails into the Arctic darkness.
        - If using all three articles, it may be helpful to jigsaw student groupings. Have students work in “expert” groups to examine articles (noting the differences in lengths and reading levels of each article), and then debrief in groups of three where each student has engaged with a different article.
        - It may also be helpful to provide an anticipation guide, or other prereading strategy, for each article to help students focus on key content.
    - Have students revise their responses to the “Assessment” section with new information from these resources. This information will depend on which resources they engaged with and could focus on the benefits and drawbacks of traditional antibiotics versus novel treatments and/or the overuse of antibiotics.

TEACHING TIPS

- Present students with the image first, before they read the background information.
- Background information may be edited to support student proficiency, course sequence, etc.
- The image may be projected in lieu of handouts.
- Printed images can be laminated for use in multiple classes.

CREDITS

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