NATURE OF SCIENCE

Science is a Never-ending Process Lesson Set 2 of 5

NCSE National Center for Science Education

Teacher Prep

Age Levels: 9th - 12th grade

Time Commitment: 4-6 days **(if all activities completed)**

Key Vocabulary/Concepts: **The history of germ theory, cholera, epidemiology, contact tracing, fact, theory, hypothesis, law, evolution, coevolution, red queen, antibiotic resistance, variant**

Materials:

- Lesson Set Two Teacher Resources
  Note: All activities, readings, and worksheets are located in this folder
- Internet access
- Red and blue decks of playing cards (1 set/3 players)
- Coloring pencils
- Cardstock

Apps and Software:

- Google Jamboard
- Google Forms access
- Flipgrid access
- YouTube access
- Kahoot access

Introduction

This lesson is meant to bring the process of science to life by providing rich examples of how major theories have evolved with new evidence. After they are provided a historical backdrop, students will be able to compare scientific terminology with its everyday counterpart. Additionally, by participating in a historical case study, students will discard the misconception of a systematic scientific method as the only blueprint for achieving discovery.

Teacher Goals

1) The differences in the types of scientific knowledge will be thoroughly explained and compared to everyday usage by using a historical case study
2) Through examining historical examples of the scientific process, the main ideas from lesson one will be reinforced, and students will see that the scientific process is rarely linear in action
3) The lesson provides a connection between the nature of science and the overarching theme of all biology—**evolution**

Student Learning Goals

1) Examine the vital distinction between **fact** and **theory**
2) Construct an interactive example of science-in-action using the historical backdrop of epidemiology's inception
3) Develop an understanding of how evolution is the overarching theory in biology
4) Apply evidence from well-tested theories to current events and scientific research

Nature of Science Lesson Set Series

https://ncse.ngo/supporting-teachers/classroom-resources

NATURE OF SCIENCE

Lesson Set 1: Science is a Way of Knowing
Lesson Set 2: Science is a Never-Ending Process
Lesson Set 3: Science is an Inquiry-Based Process
Lesson Set 4: Science is About the Evidence
Lesson Set 5: Science Can Make You Strong

Background

Teacher Knowledge

Nature of Science

The term "scientific method" is an outdated way of referring to the scientific process (see Understanding Science: How Science Works). Despite what is found in most textbooks, continue to shift your vocabulary from this more linear motif to the more encompassing terminology—*the scientific process*.

While on the surface the differences in scientific terminology may seem very straightforward, the reality is that teachers need to understand the subtle differences among facts, hypotheses, laws, and theories. Numerous articles have been published on these topics. An excellent place to start would be either Bill McComas's "The Principal Elements of the Nature of Science: Dispelling the Myths" or Paul Strode's "Hypothesis Generation in Biology: A Science Teaching Challenge and Potential Solution." For more on this important topic, check the Lesson Set Two Background Information Folder.

Scientific Concepts:

With this lesson, the importance of theories in science is explored through a case study that focuses on the well-established, well-supported, and universally-accepted germ theory. Teachers who wish to continue forward with the COVID-19 theme from Lesson Set One: Science is a way of knowing will focus on the details of John Snow and the birth of epidemiology. Concepts that will need to be reviewed are the basics of *Vibrio cholerae* for context, coevolution (and how it applies to disease), major scientists connected to germ theory, and how germ theory applies to the wearing of masks.

Discussion Points

a) How can a theory change over time?
b) What are the definitions of critical scientific terms used in research and the scientific process?
c) How is evolution both a fact and a theory?
d) How did the field of epidemiology develop?

Science is a Never-Ending Process

(Lesson Set 2 of 5)

Core Misconceptions

MISCONCEPTION: ***Science is primarily aimed at collecting facts.***

FACT: Science involves a variety of diverse activities, including making hypotheses, testing theories, and constructing models, as well as collecting facts.

MISCONCEPTION: ***Science follows a settled formula, order, or "method".***

FACT: Science is a dynamic process that involves many different people, activities, and types of methods.

MISCONCEPTION: ***Scientific knowledge has a hierarchy of understanding (hypotheses, theories, laws, facts—in increasing order of importance).***

FACT: Hypotheses, theories, laws, facts, and other items (such as models) all play essential, if different, roles in scientific explanation.

Prerequisite Student Knowledge

Before beginning Lesson Set Two, consider introducing students to Charles Darwin by showing the HHMI video The Making of a Theory: Darwin, Wallace, and Natural Selection (31:02) to emphasize that evolution is the unifying theory of all biology and will be studied. Bozeman Science's video on The Three Domains of Life (7:28) is an excellent choice for review. The Amoeba Sisters also have an excellent video on Archaea (5:10) that references the two other domains.

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Teacher Instructions

Anchoring Phenomenon: Understanding the Importance of a Theory

Activity 1: The Broad Street Pump

- Extra History YouTube video: "England: The Broad Street Pump—You Know Nothing, John Snow—Extra History #1" (7:33)
  - Students should be introduced to John Snow and the Broad Street Pump story as it will play a significant role in Part A: Science in Action—Collecting Empirical Evidence
  - By introducing this video to the entire class, it allows for a group discussion of the historical period and acts as a teaser to future investigations

Activity 2: Vocabulary Survey Probe

- After completing the initial video and discussion, hand out the *Vocabulary Survey Probe* to students and have them individually fill it out
- At this time, do not have them share their thoughts or ideas, since want to get a baseline of their preconceptions and current understandings
- This activity was adapted from a PBS Evolution lesson titled "What is the Nature of Science" © 2001 by WGBH Educational Foundation and Clear Blue Sky Productions, Inc.

Activity 3: Scientific Terminology Homework

- Using a strategy like "Click or Clunk," "K-W-L," or "SQ3R," have students actively read either *Reading One*: "Evolution: Fact and Theory" by Richard E. Lenski or *Reading Two*: "Evolution as Fact and Theory" by Stephen Jay Gould
  Note: Reading One is geared for a regular biology classroom while Reading Two is more appropriate for gifted learners or an upper-level/AP biology course
- Then, have students answer all questions found in the *Evolution: Fact and Theory Q&A* handout provided (look for either Lenski or Gould at the start of the file name to select the appropriate one for students)

Follow-Up:

- During class, lead students through a discussion on important scientific terminology (from the vocabulary survey probe) as well as a reflection on the assigned article
- Provide students with access to the *Germ Theory Driving Questions Board* Jamboard and have them consider all activities when posing their questions
- Also, consider a formative assessment or exit ticket at this point to be sure the students can distinguish the important scientific terms discussed during the anchoring phenomenon

Storyline Activities

Part A: Science in Action—Collecting Empirical Evidence

- Introduce students to the Understanding Science Interactive Journaling Tool
- Demonstrate how students will build their concept maps by using a simple classroom experiment or the first video from the Broad Street Pump John Snow series
- Provide time for students to watch through the next two videos in the John Snow series, completing their interactive tool as they go (this can be done in groups or individually as appropriate to the classroom situation)
  Note: Video Four, The Sanitary Movement, is optional and not a part of John Snow's actual experiment.
- Have students download their interactive journaling tool as a Powerpoint or Google Slide presentation for grading purposes
- Pick one or two examples to show as evidence that the scientific process is not linear in nature and that it can take a great deal of time to get the scientific community on board with new ideas
- An example of a completed interactive tool (using the first video only) is provided in the Teacher Resources folder

Part B: The History of Germ Theory

- Now that students have explored an in-depth case study on epidemiology, they are ready to learn about how our understanding of the microscopic world and "germs" have changed over time
- Provide students with the *Claim-Evidence-Reasoning Tool* and an example—either by taking them through the scenario found at the end of the C-E-R worksheet or by applying it to the John Snow sample slide of this activity
- Assign each student one slide of the The History of Germ Theory C-E-R Activity to research
  Note: Not all slides must be used, and the presentation can be tailored only to feature the biggest highlights of germ theory's evolution. The slides are organized chronologically. The depth and requirements of students' research can be altered as appropriate for grade level and student ability.
- As a formative assessment, have students take their C-E-R information and ask them to become the scientist or idea they researched—role-playing a skit about their place in the timeline (or generating a Flipgrid video), making a poster of their significant findings, or writing letters to the scientists about their discoveries
- **Important Note:** At this end of this activity, a discussion about how a theory can evolve while still maintaining its core ideas is needed.
  - By referencing *humoral theory* and *miasma theory*, you can also discuss how the evidence collected by John Snow and other scientists did not support these ideas—making both these (mainly superstitious) theories obsolete
  - Additionally, critical examination of *humoral theory* and *miasma theory* eventually led to our current understanding of germ theory, which has held up over the test of time as well as through rigorous experimentation and volumes of evidentiary support

Storyline Activities (continued)

Part C: Germ Theory Goes Down the Rabbit Hole

Note: Now that students have a thorough understanding of germ theory's past, it is time for students to gather new evidence and apply this long-standing theory to both the present and the future. Additionally, germ theory has intimate ties to one of science's most important theories – evolution. The following set of activities forms a strong segue to this more societally controversial theory using bacterial and viral evolution as examples. In order for this storyline segment to be more effective, some scaffolding is needed to make the appropriate connections as seen below.

Activity 1: Mini-Anchoring Phenomenon: Toxic Newts (5:28)

- A classic example of coevolution presented in *PBS's Evolution* series: *The Evolutionary Arms Race* that provides a macroscopic-level scenario in order to promote student interest
  Note: The Activity 1 folder contains the original research on toxic newts, "Tetradoxin Resistance in Garter Snakes: An Evolutionary Response of Predators to Dangerous Prey", and current research, "The Geographic Mosaic of Arms Race Coevolution is Closely Matched to Prey Population Structure".
- This video is meant to serve as a scaffold for students in understanding the basics of coevolution. This example is easily understood and should be used before attempting to understand how coevolution applies to bacterial and viral evolution

Activity 2: The Red Queen Coevolution Card Game

- A simple, but thought-provoking card game that will help students understand how coevolution (and evolutionary theory) is playing a role in germ theory
- Directions for teachers and students are provided in *The Red Queen Coevolution Card Game* handout
- During gameplay, one student assumes the role of the parasite (bacteria/virus), and one student takes the part of the host (vector or human)
- A third student will record data into the provided Red Queen Coevolution Spreadsheet
- Upon completion, students should understand the following main ideas: (1) coevolution can be rapid; (2) that which is most fit may not always stay that way; (3) that when rare genotypes have an advantage, genetic variation will be maintained through time; and (4) that using simple models can often be used to represent complex processes
- Provide students the opportunity to discuss how the Red Queen effect could be playing a role in the current pandemic by completing their assignment or writing a reflection comparing the activity to current events
- This activity was adapted from Amanda K. Gibson's work on coevolution with her permission to reconfigure the activities for remote learning
- **Teacher Tip:** Gibson also made a video, The Red Queen Game (6:19), that demonstrates gameplay

Storyline Activities (continued)

Part C: Germ Theory Goes Down the Rabbit Hole (continued)

Activity 3: Bacterial Antibiotic Resistance and Introduction to Virus Evolution

- Have students watch the following two videos about antibiotic resistance (a human-driven version of coevolution):
  - TED-Ed Video: What Causes Antibiotic Resistance? (4:34)
  - YouTube Video: I Contain Multitudes—Superbugs that Resist Antibiotics Can Evolve in 11 Days (8:50)
- Then have students watch this video about viral evolution during the 2013-2016 Ebola outbreak in West Africa (a mutation that led to higher virulence in a virus):
  - HHMI Biointeractive: Think Like a Scientist—Natural Selection in an Outbreak (7:30)
  - Pose the following question to your students: *What are the similarities and differences between the 2013-2016 Ebola outbreak and the current SARS-CoV-2 outbreak?*
  - Whiteboard their responses as a group and discuss before completing the last activity

Activity 4: Applying Germ Theory to COVID-19: The Battle of the Variants

- Ask students the following probing questions:
  - *What is a variant?*
  - *What is a mutant?*
  - *What do you already know about viruses in regards to variants and mutations?*
- Formative Assessment Probe: Sit/Stand
  - *Sit* if the student answer is "no", *stand* if the student answer is "yes."
  - *Should variants be considered when deciding if masks should be worn in schools?*
  - *Should community mask mandate policies change when a SARS-CoV-2 variant is showing a significant increase in infection rates across a population?*
- Create groups of four and provide them with access to the Our World in Data *SARS-CoV-2 Sequences by Variants Slideshow*
- Allow them five minutes to interpret the 2021 variant data
- While they are analyzing the data, pose the following questions:
  - *What do you notice about variants over the 2021 year?*
  - *What do you wonder about the 2021 variants?*
  - *Which variant appeared most frequently in 2021?*
  - *Do you think we will see similar patterns in the future with the same variants or similar patterns with new variants? Or something completely different?*

Storyline Activities (continued)

Part C: Germ Theory Goes Down the Rabbit Hole (continued)

- Jigsaw Activity
  - Assign each group of students one article about masks and one article about variants.
  - Have students use *The Battle of the Variants Four Square* handout to organize the information from their assigned articles.
  - After students read and analyze their articles, recreate groups to include one "expert" from each original group. The experts will share information they learned about masks, variants, and the current research being conducted on the topics.
  - Suggested articles include (but are not limited to):

    Masking/Safety Precautions:
    - Article: the *Washington Post*—The discovery of germs changed American life, especially parenting. Will COVID-19 do the same?
    - Article: *cnn.com*—Why you should upgrade your mask as the Omicron variant spreads
    - Article: *verywellhealth.com*—Will we wear masks forever?
    - Article: cnet.com—Eight COVID-19 mask myths to stop believing today
    - Article: *deseret.com*—To mask or not to mask? Here's what 2 years and hundreds of COVID-19 experts say
    - Article: *Science Daily*—Face masks cut distance airborne pathogens could travel in half, new study finds

    COVID-19 Variants:
    - Article: the *San Francisco Chronicle*—Omicron is now the dominant U.S. COVID variant. Is it as contagious as measles?
    - Article: *Science*—Where did 'weird' Omicron come from?
    - Article: *Scientific American*—Why is Omicron so contagious?
    - Article: *Science News*—Why the coronavirus's delta variant dominated 2021
    - Article: *verywellhealth.com*—Where do COVID variants come from?
    - Article: *verywellhealth.com*—What's a subvariant? What you should know about Omicron BA.2
    - Article: *livescience.com*—Omicron's not the last variant we'll see. Will the next one be bad?
    - **Teacher Tip:** These articles cover information on variants up until January 2022. They will routinely be updated.
  - Allow students the opportunity to complete another Sit/Stand formative assessment probe, posing the same two questions from the beginning of the activity, but taking into consideration all the information processed throughout the activity:
    - *Should variants be considered when deciding if masks should be worn in schools?*
    - *Should community mask mandate policies change if the SARS-CoV-2 variant is showing a significant increase in infection rates among a population?*

Storyline Activities (continued)

Part C: Germ Theory Goes Down the Rabbit Hole (continued)

- Add the following questions (now based on the evidence):
  - *Did your ideas change from the first sit/stand activity to the second?*
  - *If they did, what caused that change? If they did not, why didn't they?*
  - *Do you think variants are important to consider when developing mandates and policies? Why or why not?*
  - *If you don't think that variants should be taken into consideration during decision-making policies, what do you think should be considered instead?*
  - **Teacher Tip:** Be careful not to indicate if there is a right or wrong answer – the sit/stand questions are a part of a socratic discussion and students should feel safe to answer freely and without prejudice

- **Tying it All Together:**
  - Now that students have explored many facets of germ theory, coevolution, and viruses, ask the following **culminating questions**:
    - *How do current events surrounding COVID-19 fit into what we know about germ theory?*
    - *How do current events surrounding COVID-19 connect to what we know about the Red Queen hypothesis?*
    - *How does germ theory apply to the issue of whether or not we wear masks two years after the discovery of the SARS-CoV-2 virus?*
  - Have students return to the *Germ Theory Driving Questions Board* Jamboard and reflect on what they have learned throughout the storyline
  - Ask students to define the following terms—**fact**, **hypothesis**, **theory**, and **law** – in their own words, then challenge students to develop a metaphor that describes the relationships between these terms
  - Consider having students fill out the *Vocabulary Survey Probe* worksheet again to check for any lingering misconceptions

Extension Activities

Deeper Dive

- Evolution as Fact, Theory, and Path by T. Ryan Gregory
- The Molecular Ecologist Blog: Population genetics takes the "co" out of snake-newt coevolution (maybe)
- The Shape of Life "Science in Action" Activities
  - An alternative to John Snow videos
  - Note: Uses outdated terminology: scientific method vs. scientific process (reinforces linear misconception, so consider modifying)
- Co-evolution Video Extras:
  - SciShow—Attack of the Superbug (10:04)
  - NBC News Learn: Science Behind the News—Drug-Resistant Bacteria (4:45)
- Coronavirus Variants:
  - Livescience.com – Coronavirus variants: facts about Omicron, Delta, and other COVID-19 mutants

Online Resources

- **Extra History YouTube video series: "You Know Nothing, John Snow"**
- **Reading One: Richard Lenski's "Evolution—Fact and Theory"**
- **Reading Two: Stephen Jay Gould's "Evolution as Fact and Theory"**
- ***Understanding Science* Interactive Journal Tool**
- **PBS Learning Media "Toxic Newts"**
- **"The Red Queen's Race" blog article**
- **Amanda Gibson's The Red Queen Game**
- **I Contain Multitudes YouTube video: "Superbugs That Resist Antibiotics Can Evolve in 11 Days" (8:50)**
- **Ted-Ed YouTube video: "What causes antibiotic resistance?" (4:34)**

Primary Literature/Works Cited

Evolution: Online Lessons for Students: Activity 1- Teacher Notes. (2001). Retrieved August 30, 2020, from https://www.pbs.org/wgbh/evolution/educators/lessons/lesson1/act1notes.html.

Extra Credits. (2018, July 3). *Extra History: The Broad Street Pump & John Snow* [Video Playlist]. Retrieved August 30, 2020, from https://www.youtube.com/playlist?list=PLhyKYa0YJ_5A1enWhR5Ll3afdyhokVvLv.

Gould, S. J. (1994). Evolution as Fact and Theory. In 911409136 717216260 S. J. Gould (Author), *Hen's teeth and horse's toes* (pp. 253-262). New York, NY: Norton.

Gregory, T.R., (2008). Evolution as Fact, Theory, and Path. *Evo Edu Outreach* 1, 46–52. https://doi.org/10.1007/s12052-007-0001-z.

Lenski, R. E. (2020, July 30). *Evolution: Fact and Theory*. Evolution: Fact and Theory | National Center for Science Education. https://ncse.ngo/evolution-fact-and-theory.

Strode, P. K. (2015). Hypothesis Generation in Biology. *The American Biology Teacher*, 77(7), 500-506. doi:10.1525/abt.2015.77.7.4.

Mccomas, W. F. (2002). The Principal Elements of the Nature of Science: Dispelling the Myths. *The Nature of Science in Science Education Science & Technology Education Library*, 53-70. doi:10.1007/0-306-47215-5_3.

Mccomas, W. F., Clough, M. P., & Almazroa, H. (n.d.). The Role and Character of the Nature of Science in Science Education. *The Nature of Science in Science Education Science & Technology Education Library*, 3-39. doi:10.1007/0-306-47215-5_1.

The University of California Museum of Paleontology (Ed.). (2010). Understanding Science. Retrieved August 3, 2020, from https://undsci.berkeley.edu/