HIGH SCHOOL **BIOLOGY**

LESSONS IN THE BIOLOGY CURRICULUM:

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BIOLOGY LESSON 1
CAN SCIENCE BE RACIST?

Suggested time: Three to five 50-60 minute class periods
Suggested units: The scientific method, biodiversity

Overview

Students are often taught to see science as an objective, morally neutral discipline. Yet science, like any other field, is influenced by bias, culture, power structures, and ideology. As a result, science has the potential both to advance social progress and also to cause harm. Throughout history, science has reinforced racism and other forms of systemic oppression, yet science can also be used to understand and dismantle structural inequities. In this lesson, students will explore these themes as they investigate the biology and the social-historical context of several different pathogens. They will also develop arguments and explanations for how science and racism interact.

Objectives

- Distinguish between scientific arguments and scientific explanations, and develop examples of each.
- Apply the claim-evidence-reasoning argument framework to analyze how science has harmed marginalized populations generally and people of color specifically.
- Develop explanations about how science and racism interact.
- Understand and apply a testable definition of racism.

Key Understandings

- Science is affected by racism and other forms of systemic oppression and cultural ideologies.

  Possible misunderstanding: Science is objective and unaffected by social and cultural beliefs.
- Science can be used to harm people based on race.

  Possible misunderstanding: All scientific "progress" is good or ethically neutral. Therefore, any experimentation done in the name of science is also good or ethically neutral.
- Racism = discrimination against people of color + unequal power.

  Possible misunderstanding: Racism is solely the consequence of bad intentions and interpersonal aggressions.

Materials

- Internet access is strongly recommended; however, if internet access is limited, students can use encyclopedias and other texts to research the biology of the pathogens listed in this lesson and how those pathogens have been used to harm people of color in the name of science.
- Disparities in COVID-19-Associated Hospitalizations. (2022). Centers for Disease Control and Prevention. Accessed April 1, 2022 at: https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/racial-ethnic-disparities/disparities-hospitalization.html.
- National Equity Project. The lens of systemic oppression. Accessed February 1, 2022 at: https://static1.squarespace.com/static/5e32157bff63c7446f3f1529/t/5f1739965f252b1d45f0cd4f/1595357599748/Lens-of-Systemic-Oppression.pdf.

- TEDx Talks. (2020). Combating Racism and Place-ism in Medicine | J. Nwando Olayiwola | TEDxKingLincolnBronzeville [video]. YouTube. Accessed October 1, 2021 at: https://www.youtube.com/watch?v=0bnm__UPTRM.
- Optional: Hutchinson, B. (2020). Black doctor dies of COVID after alleging hospital mistreatment: 'This is how Black people get killed'. abcNEWS. Accessed October 1, 2021 at: https://abcnews.go.com/US/black-doctor-dies-covid-alleging-hospital-mistreatment-black/story?id=74878119.
- Pathogen Research Datasheet handout (included at the end of this lesson)

Vocabulary

argument
discrimination
explanation
marginalized
metric
pathogen
racism

National Standards

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **JU.9-12.12** I can recognize, describe and distinguish unfairness and injustice at different levels of society.
- **JU.9-12.13** I can explain the short and long-term impact of biased words and behaviors and unjust practices, laws and institutions that limit the rights and freedoms of people based on their identity groups.
- **AC.9-12.16** I express empathy when people are excluded or mistreated because of their identities and concern when I personally experience bias.

Note to Teachers

This lesson has been structured as an inquiry-based, inductive learning lesson that prioritizes the NGSS skills of argumentation and explanation. The activities in this lesson support students in the process of inductive learning and making meaning by giving them opportunities to practice different argumentation structures, including the claim-support-question thinking routine and the claim-evidence-reasoning argument. The culminating activity in this lesson shows students how to transition from argumentation to explanation, a key distinction in the scientific process. Argumentation requires making claims from evidence and data, but does not reach the level of effectively creating an explanatory theory applicable to all situations. Explanations, on the other hand, rely upon established scientific concepts to illustrate the links between cause and effect in a given situation. Within this lesson, students will grapple with evidence to determine whether science can be racist (argument), and then be introduced to explanatory definitions of racism (explanation).

Students will spend significant time during this lesson discussing and defining racism. Before teaching this or any of the eight lessons in the Biology Curriculum, we strongly suggest educators read the Appendix to this lesson called Defining Racism, which contains details about how to develop a working definition of racism with students.

LESSON PROCEDURE

Day 1: Do Pathogens Discriminate?

1. Show students a graph or data table documenting differences in the impact of an infectious disease by race, such as the Age-adjusted Laboratory-Confirmed COVID-19-Associated Hospitalization Rates by Race and Ethnicity (scroll down for graph). In pairs or small groups, have students evaluate the data using a see-think-wonder routine, such as the one below, to help them make sense of what is shown and what questions it prompts:
   - What do you notice in these data?
   - What do these data lead you to think about?
   - What do these data make you wonder?
2. In a class discussion, engage students with the following essential question:

   Do pathogens discriminate?

   Access students' understanding of what we mean by discrimination, and how we measure discrimination. Ask students to consider the following question: What can we measure to see discrimination?
3. Introduce students to the following inquiry and argumentation activity. The purpose of this initial argumentation activity is for students to develop an initial claim which they will further revise and develop later in the lesson.

   Assign students to research the pathogens listed below. Students should work in small groups, in each group should be assigned a single pathogen to investigate.
   - Enterovirus C (polio virus)
   - Treponema pallidum (syphilis)
   - Orthomyxoviridae (influenza)
   - SARS-CoV-2 (COVID)
   - Variola (smallpox)
   - Human immunodeficiency virus (HIV)
4. Have each student group research the biology of their assigned pathogen. Sample research questions are provided in Part 1 of the handout entitled "Pathogen Research Datasheet," or you can develop your own. Useful resources for students are also available in the Additional Resources section.
5. Have students investigate the social-historical context for their assigned pathogen. This research will include both the ways in which marginalized populations, including people of color, have been intentionally or disproportionately harmed by their pathogen, as well as efforts that have been made to stop and repair for such harm. Sample research questions are provided in Part 2 of the handout entitled "Pathogen Research Datasheet."
6. Once students have completed their research, have them develop their own arguments in response to the essential question: Do pathogens discriminate? Remind or inform students that an argument must have at least two parts: a claim (e.g., "pathogens discriminate") and evidence in support of that claim. For their evidence, students should draw from the research they conducted on their assigned pathogens. You might require that arguments be structured using the claim-support-question format or the claim-evidence-reasoning format, particularly if students have never engaged in argumentation before.

Asynchronous work: Students should finish their arguments and prepare to present these in class.

Day 2: Defining Racism

1. Students should share their arguments with classmates who researched other pathogens. This could be in a jigsaw of large groups or small groups, or a in gallery walk format. Students should have the opportunity to view and understand others' arguments and investigations and to evaluate similarities and differences among these arguments and their own.
2. Facilitate a class discussion based on the following question: What would explain the discrepancies in diseases among racial groups? We suggest using the following prompts to guide this discussion:
    - What arguments did your classmates make? Was there any consensus? What important similarities or differences did you notice both within and across the different disease case studies?
    - What factors might explain the apparent discrimination in how these diseases impact different populations? Do the pathogens themselves discriminate? What factors from the environment and from society might influence how these pathogens spread, and how?
3. Ask students to consider the following question: Can science be racist? Guide them in this discussion using the prompts below. We suggest documenting students' responses on a whiteboard or in a Google Doc, Padlet, or other online discussion platform for the class to see.
    - What do we mean by "racist?" What does racism look, sound, and feel like?
    - How would students know an interaction is racist? What signs might indicate racism within an institution such as science?
    - How would you measure racism? What are some specific data you might collect in order to measure racism? What would these data tell you? What might be some challenges of collecting these data?
4. Introduce a working definition of racism as "racism = discrimination against people of color + unequal power." Ask students what kinds of power are relevant in the context of racism, and how we might measure how much power a person, company, or group has at their disposal. You can help students define power in such ways as "money," "influence," and "decision-making ability." Emphasize to students the need for a definition of racism that is measurable; this helps make it a scientific, working definition that can be evaluated as a potential cause in explaining phenomena. When investigating the issue of power, student should consider who typically holds and wields power in any given situation, including those who have decision-making and policy-making abilities in different institutions.
5. Introduce students to the different levels of racism to help them visualize the difference ways in which power and discrimination can work together. (Note that this framework is sometimes depicted as the Four I's of oppression: internalized, interpersonal, institutional, and ideological.) Ask students to discuss the following questions in small groups or as a class:
    - In your own words, how would you distinguish individual racism from interpersonal racism? How would you distinguish interpersonal racism from institutional racism?
    - In your own words, how would you explain ideological or structural racism? How does this level of racism influence each of the other three levels of racism?
    - What outcomes of "discrimination against people of color + unequal power" might we expect at each of the four levels, and might we measure these outcomes? If you were to study changes in racism over time at each level, what specific metrics would you want to track? What challenges might you face in collecting such data?
6. Now that students have discussed how racism operates generally, facilitate a class discussion about how racism might interact with science. Before or during this discussion, you might show students the video Combating Racism and Place-ism in Medicine (11:24 minutes) to help students think about concrete examples of where science and racism intersect. In addition or as an alternative, you might have students read this article about Doctor Susan Moore, whose complaints of pain and shortness of breath were initially disregarded by her White

physician, and who used her knowledge as a physician to advocate for herself in order to receive appropriate treatment. Please note that the content of this article, and the video clip within it, include descriptions of pain and racialized discrimination, and might be upsetting for students. Be sure to let students know ahead of time about the nature of this content and be ready to provide support to students who may find it upsetting.

During the discussion, consider having students respond to the following questions:

- How does power show up in science? How does discrimination generally, and discrimination against people of color, show up in science? How might we measure these forms of power and discrimination?

  Possible student responses:

  One form of power in science is the ability to decide what is studied and how it is studied. Power also shows up as having the resources (money, equipment, space, education) to conduct science and have that work be legitimized by the professional scientific community. Power even shows up as having the authority to determine what does and does not count as science.

  Discrimination based on race, gender, class, and ability can show up in science in terms of who is accepted into and mentored within the profession, as well as who has access to scientific knowledge and resources outside the profession. Discrimination might also show up in terms of whose issues are studied; for example, if an issue (such as a disease or a technological need) does not apply to the dominant group within the scientific profession or those who fund scientific research, it might not receive much attention.

  Differences in power might be measured in terms of money, space, equipment, decision-making ability, policy-making ability, and education level. Discrimination might be measured in terms of representation of both individuals and issues studied within the scientific profession, access to scientific knowledge and resources, and harm caused or reinforced because of scientific culture, practices, or policies.

- How might racism influence different people's experiences with pathogens? How might racism influence the science of pathogens? How might these influences operate at the personal, interpersonal, institutional, and/or ideological levels?

  Possible student responses:

  Racism might influence different people's experiences with pathogens if people of different races are impacted disproportionately by those pathogens (i.e., if some groups are impacted more than others), or if people of different races with the same pathogens are treated differently by medical or other scientific professionals.

  Racism might influence the science of pathogens if individuals, institutions, or policy-makers decide that pathogens that disproportionately harm people of color are not worth studying; if individuals, institutions, or policy-makers do not make treatment for or knowledge about those pathogens accessible to all people regardless of race; or if researchers or research institutions harm individuals of certain races by treating them as experimental subjects and denying them proper treatment.

- If racism = discrimination against people of color + unequal power, what role do intentions play in this process, if any? How does the difference between intention and impact help us better understand how racism and science interact?

  Possible student response: Many of the outcomes racism can have within science do not depend on the intentions of the individuals, institutions, or policies that create them. For example, as we saw in the TED Talk, doctors are often wrongfully taught that Black people have a higher pain tolerance than White people; as a result, they may cause harm to their Black patients even when they believe they are doing "good" science. As a result, measuring people's intentions (e.g., with survey data) may not give us an accurate account of whether or how much racism is operating within science, and addressing racism within science will require more than merely "fixing" people's intentions.

7. Return to the question from the beginning of class: Can science be racist? Garner initial thoughts and reactions. If necessary, allow students to continue to unpack this question if they need to; for example, they might still

need to refine what they consider "science," or how they see racism operating at any or all of the different levels (individual, interpersonal, institutional, or ideological) of science. Once they feel ready to answer the question, have students discuss, write down, and share out their answers using the claim-evidence-reasoning format. If students are unfamiliar with this format, you will need to go over it with them first.

Possible student response:

Claim: Science can be racist.

Evidence: According to the TED Talk, doctors are often taught to treat White and Black patients differently. For example, doctors are taught that Black people have a higher pain tolerance than White people.

Reasoning: Because doctors learn and believe that Black and White patients are fundamentally different, Black and White patients often receive different quality of care from doctors. Doctors use scientific reasoning, such as, "Black patients have higher pain tolerance," to justify this difference in quality. Therefore, science is being used to maintain racial inequity.

Asynchronous work: If they did not have time to write or refine their claim-evidence-reasoning responses to the question, "Can science be racist?", have students complete this before the next class.

Days 3 and 4: Developing Explanations for Racism in Science

1. Returning to their original pathogens, students should now revisit their arguments from Day 1 and consider how they might use their new understanding of racism to explain the mechanisms for their claims that pathogens do or do not discriminate. Students should be allowed to change or modify their claims at this time in response to what they have learned since they first formulated these claims. Students who choose to argue that pathogens do not discriminate should develop a counterargument involving both racism and their pathogen for which they will develop an explanation.
2. Help students understand the difference between arguments and explanations. Scientists and philosophers use arguments to convince others that a particular claim is true; scientists and philosophers develop explanations to provide clarity about the mechanisms that link scientific causes and effects. In other words, an argument offers a reason (or multiple reasons) to believe something is true, while an explanation posits the reason why something is true (Michael Gavin, 2020). Arguments and explanations have different but related purposes, and they often go hand-in-hand.
3. In their research groups, have students develop presentations about their pathogens. The requirements for these presentations are listed in the Demonstration of Learning section below.
4. Have the students present their work to the rest of the class, one group at a time. After each group presents, the rest of the class should have an opportunity to ask the presenters questions about their arguments and explanations.
5. Close by having students reflect on what they have learned about science and racism using Project Zero's I used to think... Now I think... thinking routine. You might have students use index cards to post their reflections around the classroom for others to read in a gallery walk, or you can have students post their reflections to an online discussion board.

Asynchronous work: Consider having students make infographics summarizing their arguments and explanations. These infographics could then be shared on social media, and could perhaps target local medical and scientific institutions, including universities and hospitals.

Demonstration of Learning

In their research groups, have students develop presentations about their pathogens. Each presentation should include the following elements:

- A summary of the biology of their pathogen.
- A summary of the social-historical context of their pathogen, including the historical connection to any racist science in relationship to their pathogen, and any structures or laws created to stop, curtail, or repair for racist practices associated with their pathogen.
- Their argument (and, if relevant, their counterargument) about the pathogen in response to the essential question: Do pathogens discriminate?
- Their explanation of one or more mechanisms involved in their argument.

Additional Resources

The following resources contain useful information about the medical and social history of *Enterovirus C* (polio):

Disease factsheet about poliomyelitis. (2021). European Centre for Disease Prevention and Control. Accessed January 1, 2022, at: https://www.ecdc.europa.eu/en/poliomyelitis/facts.

History of polio (2020). BBC News. Accessed January 1, 2022, at: https://www.bbc.com/news/health-17045202.

The history of vaccines. (2022). History of Polio - Timeline. The College of Physicians of Philadelphia. Accessed January 1, 2022, at: https://www.historyofvaccines.org/timeline/polio.

Van Leer-Buter, C. C., Poelman, R., Borger, R., & Niesters, H. G. (2016). Newly identified *Enterovirus C* genotypes, identified in the Netherlands through routine sequencing of all Enteroviruses detected in clinical materials from 2008 to 2015. *Journal of Clinical Microbiology*, 54(9), 2306–2314. https://doi.org/10.1128/JCM.00207-16.

The following resources contain useful information about the medical and social history of *Treponema pallidum* (syphilis):

Henao-Martínez, A. F., & Johnson, S. C. (2014). Diagnostic tests for syphilis: New tests and new algorithms. *Neurology Clinical Practice*, 4(2), 114–122. https://doi.org/10.1212/01.CPJ.0000435752.17621.48.

Mandal, A. (2019). What is syphilis? News-Medical. Accessed on January 1, 2022 at: https://www.news-medical.net/health/What-is-Syphilis.aspx.

Tampa, M., Sarbu, I., Matei, C., Benea, V., & Georgescu, S. R. (2014). Brief history of syphilis. *Journal of Medicine and Life*, 7(1), 4–10.

The following resources contain useful information about the medical and social history of *Orthomyxoviridae* (including influenza) viruses:

Barberis, I., Myles, P., Ault, S. K., Bragazzi, N. L., & Martini, M. (2016). History and evolution of influenza control through vaccination: From the first monovalent vaccine to universal vaccines. *Journal of Preventive Medicine and Hygiene*, 57(3), E115–E120.

History.com Editors. (2020). Influenza. A&E Television Networks. Accessed January 1, 2022 at: https://www.history.com/topics/inventions/flu.

Influenza (Seasonal). (2018). World Health Organization. Accessed January 1, 2022 at: https://www.who.int/news-room/fact-sheets/detail/influenza-(seasonal).

Su, S., Fu, X., Li, G., Kerlin, F., & Veit, M. (2017). Novel Influenza D virus: Epidemiology, pathology, evolution and biological characteristics. *Virulence*, 8(8), 1580–1591. https://doi.org/10.1080/21505594.2017.1365216.

The following resources contain useful information about the medical and social history of the SARS-CoV-2 (COVID) virus:

Basics of COVID-19. (2021). Centers for Disease Control and Prevention. Accessed January 1, 2022 at: https://www.cdc.gov/coronavirus/2019-ncov/your-health/about-covid-19/basics-covid-19.html.

Chaplin, S. (2020). COVID-19: A brief history and treatments in development. *Prescriber*. 31(5), 23-28. Accessed January 1, 2022 at: https://wchh.onlinelibrary.wiley.com/doi/10.1002/psb.1843.

Coronavirus History. (2021). WebMD Medical Reference. Accessed January 1, 2022 at: https://www.webmd.com/lung/coronavirus-history.

Extance, A. (2020). Explainer: The science of Covid-19 testing. Chemistry World. Accessed January 1, 2022 at: https://www.chemistryworld.com/news/explainer-the-science-of-covid-19-testing/4012078.article.

How scientists test for COVID-19. (2022). Fred Hutch. Accessed January 1, 2022 at: https://www.fredhutch.org/en/research/diseases/coronavirus/serology-testing.html.

The following resources contain useful information about the medical and social history of *Variola* (smallpox):

Colarossi, N. (2020). How American discrimination has hindered the way we've handled disease outbreaks. *Business Insider*. Accessed January 1, 2022 at: https://www.businessinsider.com/american-discrimination-impacted-how-us-handles-disease-outbreaks-2020-5.

Hussain, A. (2020). Smallpox. Medscape. Accessed January 1, 2022 at: https://emedicine.medscape.com/article/237229-overview.

Smallpox. (2017). Centers for Disease Control and Prevention. Accessed January 1, 2022 at: https://www.cdc.gov/smallpox/index.html.

The following resources contain useful information about the medical and social history of the human immunodeficiency virus (HIV):

HIV and AIDS: An origin story. (2022). PublicHealth. Accessed January 1, 2022 at: https://www.publichealth.org/public-awareness/hiv-aids/origin-story/.

HIV and gay and bisexual men: Differences in knowledge of status, prevention, treatment, and stigma exist by race/ethnicity. (2021). Centers for Disease Control and Prevention. Accessed January 1, 2022 at: https://www.cdc.gov/vitalsigns/hivgaybimen/.

Impact on racial and ethnic minorities. (n.d.). HIV.gov. Accessed January 1, 2022 at: https://www.hiv.gov/hiv-basics/overview/data-and-trends/impact-on-racial-and-ethnic-minorities.

A timeline of HIV and AIDS. (n.d.). HIV.gov. Accessed January 1, 2022 at: https://www.hiv.gov/hiv-basics/overview/history/hiv-and-aids-timeline.

Rogers, T. (2019). 8 ways to determine website reliability. ThoughtCo. Accessed April 1, 2022 at: https://www.thoughtco.com/gauging-website-reliability-2073838.

This resource offers recommendation for how students can assess website reliability.

Gonzalez, J. (2014). How to teach an inductive learning lesson [blog]. Cult of Pedagogy. Accessed February 1, 2022 at: https://www.cultofpedagogy.com/inductive-learning/.

This resource outlines the structure and goals of inductive lessons, which are a different instructional sequence than typical lessons which prioritize acquisition of knowledge first. Inductive lessons instead pose puzzles for students to develop an understanding before acquiring details and facts.

Hutchinson, B. (2020). Black doctor dies of COVID after alleging hospital mistreatment: 'This is how Black people get killed.' abcNEWS. Accessed October 1, 2021 at: https://abcnews.go.com/US/black-doctor-dies-covid-alleging-hospital-mistreatment-black/story?id=74878119.

This article is about Doctor Susan Moore, whose complaints of pain and shortness of breath were initially disregarded by

her White physician, and who used her knowledge as a physician to advocate for herself in order to receive appropriate treatment.

National Center for Science and Engineering Statistics (NCSES). (2021). Women, Minorities, and Persons with Disabilities in Science and Engineering [database]. National Science Foundation. Accessed February 1, 2022 at: https://ncses.nsf.gov/pubs/nsf21321/.

This site offers a wealth of data and analysis regarding the representation of women, people of color, and people with disabilities in science and engineering fields in the U.S.

STEM Teaching Tools. (n.d.). Is it important to distinguish between the explanation and argumentation practices in the classroom? UW Institute for Science + Math Education. Accessed February 1, 2022 at: http://stemteachingtools.org/brief/1.

This resource outlines the differences between argumentation and explanation in the scientific process, as well as why it is necessary to clearly distinguish between the two in instructions to students and in expectations by the teacher.

The Underrepresentation Curriculum Project [website], available at: https://underrep.com/.

This free curriculum contains lesson plans and facilitation tips for discussing and analyzing social injustice and underrepresentation in STEM fields.

Williams, A. P., & Gray, S. (2021). (W)holistic science pedagogy: Teaching for justice. *The Science Teacher*, 89:1. Accessed February 1, 2022 at: https://www.nsta.org/science-teacher/science-teacher-septemberoctober-2021/wholistic-science-pedagogy.

The (w)holistic science pedagogy framework presents five commitments on the part of science educators and schools that are required for socially just, restorative, and rigorous science education which supports the dignity of all learners. Access to high-quality science education is a key element of a socially just science education.

References

Michael Gavin. (2020). Explanations vs Arguments [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=y_5z-vzwD_8.

Pathogen Research Datasheet

Directions: Using reliable online and/or print sources, answer the questions below with your group.

Part 1: Pathogen Biology

1. What is the scientific name of your pathogen?
2. Does your pathogen have a common, nonscientific name? If so, what is it?
3. Are there different versions of your pathogen? What are they and how are they different from one another?
4. Can your pathogen infect any organisms other than humans? If so, when and how has it crossed species?
5. Is the pathogen living or nonliving? How do you know? Please give two resources that you have verified as reliable. Use this resource to check your sources' reliability.
6. What type of organism is your pathogen? For example, is it a fungus, a protozoa, a bacteria, an algae, a virus, a prion, or something else? How do you know? List two reliable sources.
7. Paste or print three to five images of your pathogen. Then describe and interpret these images. What do you notice? How does the pathogen's form affect its function?
8. How was your pathogen discovered? Is there a famous scientific experiment that led to its discovery? If so, describe this experiment.
9. How does your pathogen spread? How fast can it spread?
10. What type of environment does your pathogen prefer? How does its environment affect its transmission? (For example, does it spread faster during any specific seasons or in particular climates?)
11. How is your pathogen controlled and treated? Is it curable? If so, how? If not, why not?
12. How does your pathogen affect its host? What symptoms does the host exhibit?
13. Include two graphs related to your pathogen. For each graph, answer the following questions:
    a. What relationship is this graph showing?
    b. What does the x-axis represent? What does the y-axis represent?
    c. What are some observations that you can make based on the graphs?
    d. Is there a trend or pattern in the graph's data? If so, describe and interpret this trend or pattern.
    e. Are there any spikes or outliers in the graph? If so, what do these indicate?
    f. Overall, how would you interpret the data in this graph? What does this graph indicate about the past or present? What predictions can this graph help us make about the future?
14. List and define at least five vocabulary words related to the science of your assigned pathogen.

Part 2: Pathogen Social and Historical Context

1. What history and relationship does your pathogen have with people of color? Does your pathogen have a particular history and/or relationship with any other marginalized groups? If so, please explain.
2. In what ways, if any, have the medical or scientific communities, or others in power, used this pathogen to take advantage of marginalized populations, including people of color? In what ways, if any, have the medical or scientific communities, or others in power, ignored or neglected marginalized populations, including people of color, with respect to this pathogen?
3. Who shed light on the particular relationship this pathogen has with marginalized groups, including people of color, and how? What strategies and tactics did they use to bring awareness to this relationship?
4. What laws, guidelines, oversight committees, or other structures, if any, have been developed to prevent continued harm to marginalized populations related to this pathogen? When were these developed, and how effective have they been in reducing harm?
5. In what ways, if any, do marginalized populations continue to be harmed disproportionately with respect to your pathogen? What are activists, lawmakers, scientists and medical professionals, or others doing to combat these injustices?

Appendix: Defining Racism

The history of biology and scientific racism is a history in which social disparities based on race have been justified as the inevitable outcomes of self-evident and immutable differences among people of differing races. According to this explanation of the social order, race is a biologically meaningful category that determines differences in people's abilities and traits, including intelligence and morality.

Modern biology has rejected race as a biological concept, leaving us to grapple with nonbiological explanations for inequality and poverty. "Great is our sin," Darwin wrote in *Voyage of the Beagle*, if human suffering "be caused not by the laws of nature" but rather by human design. If racial inequality cannot be explained by biology, then as scientists we must evaluate the alternative: that racism – not race – is responsible for racial inequality.

Several of the lessons in the Biology Curriculum require students to evaluate data and draw conclusions about whether practices and institutions perpetuate racism. To evaluate any claim, scientists require measurable, testable definitions of phenomena, and racism is no different. To effectively teach these lessons, you will need to have a working definition of racism that students can use when applying the scientific method to issues of racial disparity.

In this curriculum, we suggest starting with the following testable definition of racism:

> Racism = discrimination against people of color + unequal power

In discussing and developing this definition with students, consider the following:

- **Discrimination against people of color:** Discrimination against people of color is often made visible through people's disparate experiences and outcomes based on race. Help students determine evidence of discrimination against people of color that they can measure. These measurements could include mortality rates by race, poverty rates by race, incarceration rates by race, and so on. Help students understand the role proportionality plays in evaluating these measurements.
- **Unequal power:** Power comes in many forms. Some individuals hold large amounts of power, but often power is exerted by institutions and groups of individuals working together within those institutions. A misconception is that power is inherently bad, but power can be used to forward social justice, just as it can be used to create or maintain social inequality. Help students generate concrete examples of power that can be measured. Measurable examples of power might include funding, wealth, and other forms of money; representation within decision making bodies; and access to non-monetary resources, for example.
- **Local examples:** In developing your class's definition of racism, consider how to use the system of education or your own school as an example. What does power look like in your school, school district, or city? What are the ways that power is exerted over students or by students? Are there racist outcomes in schools that can be measured? The school-to-prison pipeline is a concrete example of policies and procedures interacting with individual prejudices to produce racist outcomes (see Figure 1 below).

A helpful framework for visualizing interactions between individual and systemic racism is the lens of systemic oppression from the National Equity Project, sometimes formulated as the Four I's of systemic oppression: individual, interpersonal, institutional, and ideological (or structural). Each of these layers reinforces the others; racist ideologies – such as meritocracy, bootstrap theory, and victim-blaming – reinforce racist policies and procedures within institutions, which in turn reinforce individual and interpersonal biases. Throughout the Biology Curriculum, teachers and students can use this framework along with the testable definition of racism to examine the ways in which institutional and structural racism relate to interpersonal and individual actions. An example using the school-to-prison pipeline is shown below (Figure 1).

Examining Racism Within the School-to-Prison Pipeline

Discrimination against people of color

Measurements of racist outcomes within the school-to-prison pipeline include:

- Increasing rates of suspension, especially for Black youth.
- Disproportionate suspensions and arrests of students by race.

Unequal power

Unequal power exists between a predominantly White teaching force and educational administrative system on the one hand, which has the power to dictate and enforce disciplinary policies for students, and a diverse body of students on the other hand, who are subject to these policies.

The Four I's of Systemic Oppression

Individual

Implicit bias influences when and how educators, administrators, and school police respond to students' behavior with disciplinary action.

Interpersonal

Educators operationalize the beliefs and policies that lead to racist outcomes within the school-to-prison pipeline through classroom management and disciplinary referrals. School police operationalize these beliefs and policies when physically restraining and arresting students.

Institutional

Examples of institutional forces that lead to discrimination against students of color within the school-to-prison pipeline include over-investment in police and under-investment in counselors, disciplinary procedures such as "zero tolerance," and suspensions and arrests of students.

Structural/Ideological

Structures and ideologies that label people of color as inherently criminal include the War on Drugs, the criminalization of Black and Brown communities, and myths about the "superpredators" and "welfare queens."

References

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BIOLOGY LESSON 2

DIRTY IS GOOD: RETHINKING MICROBES THROUGH NUTRIENT CYCLING AND CLIMATE

Suggested time: Five to six 50-60 minutes class periods
Suggested units: Ecology, biodiversity, sustainability

Overview

Climate change is the primary existential threat of our times. Nevertheless, many misconceptions exist about who is to blame for climate change and who suffers the greatest consequences of these changes, now and in the future. This lesson addresses the misconception that human overpopulation is the primary cause of climate change, and demonstrates why carbon emissions instead are the primary culprit. Not only are the predominantly Black and Brown communities of the Global South often blamed for global warming based on specious arguments about overpopulation, but also these communities – along with other marginalized communities in the Global North – are often those hardest hit by the impacts of climate change. In order to explain climate change, and to understand the role of human decisions in mitigating climate change, this lesson explores nutrient cycles and the role of diverse biological communities, specifically soil microbial communities, in perpetuating nutrient cycling.

Objectives

- Students will understand, analyze, and make predictions about nutrient cycles after exploring the carbon cycle in detail.
- Students will connect the carbon cycle to anthropogenic climate change and human activities.
- Students will investigate case studies in the sustainable management of ecosystems by humans, with a focus on cultivating the soil microbe community as a climate change mitigation strategy.
- Students will learn how diversity in biological communities is directly linked to dynamic nutrient cycling and responses to disturbances and stressors, including climate change.
- Students will learn that biological communities consist of dynamic relationships among interdependent species.

Key Understandings

- Human overpopulation is a simplistic and reductive concept for understanding sustainability, one that disproportionately targets Black and Brown communities of the Global South.

  Possible misunderstanding: Human overpopulation is a ticking time bomb for ecological collapse and is driven by population growth rates in developing countries.

- Climate change and carbon emissions are driven by the world's wealthiest individuals, the governments of wealthy countries, and wealthy corporations. These three groups are therefore disproportionately responsible for making more responsible decisions and changing their behavior in order to mitigating climate change.

  Possible misunderstanding: The responsibility falls to individuals to solve climate change through our individual purchasing decisions and individual choices and behaviors.

- The impact of climate change is disproportionately felt by frontline communities that are poor and overwhelmingly communities of color.

  Possible misunderstanding: All communities are equally impacted by climate change, and all communities are equally responsible for increasing global warming.

Materials

- Computer with access to the internet
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- The Keeling Curve. (2022). Scripps Institution of Oceanography, University of California San Diego. Accessed April 1, 2022 at: https://keelingcurve.ucsd.edu/.
- Johnson, A. E., & Blumberg, A. (2021). Soil: The dirty solution [audio podcast]. In *How to Save a Planet*. Accessed April 1, 2022 at: https://gimletmedia.com/shows/howtosaveaplanet/39h6wn7.
- Tickell, J., & Tickell, R. H. (Directors). *Kiss the Ground*. Big Picture Ranch. Accessed April 1, 2022 at: https://www.netflix.com. Note that educators can also access a free, 45-minute version of the film at https://kissthegroundmovie.com/for-schools/.
- Indigenous Peoples' Forest Tenure. (2022). Project Drawdown. Accessed April 1, 2022 at: https://drawdown.org/solutions/indigenous-peoples-forest-tenure.
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- Presnall, A. (2021). The Keystone XL Pipeline and America's history of Indigenous suppression. The University of Alabama at Birmingham. Accessed April 1, 2022 at: https://sites.uab.edu/humanrights/2021/02/15/the-keystone-xl-pipeline-and-americas-history-of-indigenous-suppression/.
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- Handouts (included at the end of this lesson):
  - How to Save a Planet KLEW Chart
  - Carbon Cycle Guided Inquiry
- Appendix: Nutrient Cycling Model

Vocabulary

biodiversity
carbon cycle
carbon emissions
carbon footprint
climate change
microbes
nutrient cycle
positive feedback loop
tilling
vicious cycle
virtuous cycle

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-ESS3-1** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- **HS-LS2-3** Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
- **HS-LS2-5** Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
- **HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **JU.9-12.12** I can recognize, describe and distinguish unfairness and injustice at different levels of society.
- **JU.9-12.13** I can explain the short and long-term impact of biased words and behaviors and unjust practices, laws and institutions that limit the rights and freedoms of people based on their identity groups.

LESSON PROCEDURE

Days 1 and 2: Whose Carbon Footprint Matters the Most?

1. Open by asking students what a carbon footprint is. What do they know about the concept, and why is it important?
2. In pairs or small groups, have students develop arguments using the claim-support-question in response to the following question: Whose carbon footprint matters the most? To develop their answers, students should consult the resources below:
   - I'm an environmental journalist, but I never write about overpopulation. Here's why.
   - How affluent people can end their mindless overconsumption
   - Revealed: the 20 firms behind a third of all carbon emissions
   - The carbon footprint sham
   - Individuals can't solve the climate crisis. Governments need to step up
   - Climate change: yes, your individual action does make a difference
   - Each Country's Share of CO2 Emissions
   - The carbon boot-print of the military

   Students may need two class periods to complete their research and develop their claim-support-question arguments.

Asynchronous work: Have students listen to the podcast How to Save a Planet: Is Your Carbon Footprint BS? for homework. As they listen, students should complete the "How to Save a Planet KLEW Chart" handout. Students should then edit their claim-support-question arguments to integrate the information they learned from the podcast and to generate new questions based on what they learned.

Day 3: Climate Change and the Carbon Cycle

1. Have students reflect on what they have learned about carbon footprints and carbon emissions by completing Project Zero's I used to think... Now I think... thinking routine. Students can then share their reflections with their classmates electronically, using Google Jamboard, Padlet, or Google Docs, or on post-it notes or a whiteboard in the classroom.
2. Ask students to consider the following questions:

   Do all people have the same responsibility for climate change? Why or why not?

   Ask students to use specific pieces of evidence when justifying their answers.
3. If you have not done so already, introduce students to nutrient cycling and the carbon cycle. In the course of your instruction, consider asking students the following questions to structure their thinking and to help them make connections to the content of this lesson:
   - How does carbon show up in the environment? How does it show up in organisms?
   - Which forms of carbon are relevant to global warming?
   - Is carbon itself bad?

   Guide students to consider the role of greenhouse gasses in climate change. In addition, help students recognize the carbon-based nature of macromolecules and centrality of carbon to organic molecules. If students have not yet learned about macromolecules, you may need to give them a brief overview.
4. Provide students with some background on climate change and carbon emissions. You will want to teach students about the greenhouse effect and the many carbon-based greenhouse gasses (e.g., CO2, CO, CH4). Then show students the Keeling curve to demonstrate the increasing amount of carbon dioxide in the atmosphere.

Ask students to consider: Where does all of the carbon in these gasses come from?

5. Distribute the handout entitled "Carbon Cycle Guided Inquiry" and have students complete the activity in small groups. From this activity, students should understand that the human use of fossil fuels requires the removal of carbon sequestered in deposits in the Earth and releases carbon gasses into the atmosphere.
6. Ask students: Is all of this increase in carbon emissions causing climate change? Exxon Mobil itself said so in the 1980s but then actively worked to disrupt scientific research documenting this relationship. This is worth sharing with students after they have completed the activity to reinforce the conclusion that carbon emissions from the use of fossil fuels are driving climate change.

Asynchronous work: Have students listen to the podcast How to Save a Planet: Soil: The Dirty Climate Solution. As before, have them take notes using the "How to Save a Planet KLEW Chart."

Day 4: Unpacking Nutrient Cycles and Biological Communities

1. Open by asking students what they learned from the podcast. What were they most surprised by? What questions do they have from the podcast? Document their questions in a class KLEW chart.
2. Show the following clips from the documentary *Kiss the Ground*, which maps the vicious cycle of soil degradation versus the virtuous cycle of soil nutrient cycling.
   - Clip 1 (12:10-15:51 minutes): This clip illustrates the vicious cycle of soil degradation. Tilling reduces soil microbe communities, leading to the need to spray more chemicals (pesticides), which further reduces soil microbial communities. This then requires the repeated application of fertilizers to the soil due to the disruption of natural inputs from livestock and soil microbes.
   - Clip 2 (41:45-43:03 minutes): This clip illustrates the virtuous cycle of soil nutrient cycling. Persistent vegetation serves as an "armor" that helps keep soils intact and able to absorb water. These soil qualities promote microbe growth, which in turn supports plant growth. Transpiration from plants increases local precipitation, perpetuating the cycle and keeping microbial communities intact and nutrients cycling.

   Identify these cycles as positive feedback loops. Make sure students understand that even the vicious cycle is a positive feedback loop, not because it has a "positive" effect on the environment, but because it is self-perpetuating.
3. If you have not already covered biological communities at this point in your ecology or biodiversity unit, be sure to do so now. Be sure to introduce community relationships, including trophic structures; symbiotic relationships such as mutualism, commensalism, and predation; and the functions of producers, consumers, and decomposers within food webs.
4. Complete a see-think-wonder thinking routine with students to analyze models of nutrient cycling involving soil communities. Choose models that emphasize the elements being cycled (such as carbon and nitrogen) and that explicitly show the place of the microbial communities in the nutrient cycles.

   This may be an opportunity to analyze models from published literature with your students. One such example, offered in the Appendix, comes from Xu, Liu, and Sayer's 2013 study of nutrient cycling and litterfall manipulation. You can unpack students' observations about this model and use their observations to scaffold further thinking, giving attention to where "microbial activities" are illustrated, and how "total C" (for total carbon) is represented in the system. Help students identify the relationship between carbon and microbial activities as well as the role microbes play in keeping carbon in the soil.
5. Introduce students to additional nutrient cycles, including the nitrogen and phosphorus cycles. Ask students to use those cycles to explain the following emergent outcomes from our agricultural system:
   - The decline in soil nitrogen and phosphorus levels when pesticides, which kill microbes such as fungi, are sprayed over crops.
   - The decline of soil nitrogen and phosphorus levels in response to tilling, which disrupts the length of

roots and thus the supply of sugar that sustains soil microbe communities.

- A decline in the ability to sequester carbon in the soil in response to tilling and pesticides, which harm microbe communities.

6. Help students make the connection between antiracism and cultivating soil communities by asking them to discuss the following questions:
   - What does it mean for humans to depend on soil microbes?
   - How does creating a diverse biological community support agriculture and climate change mitigation?
   - How can we support agency among local communities in cultivating healthy soils and healthy ecosystems?
   - How does the example of Soul Fire farms (from the podcast) show us why empowering farmers from marginalized backgrounds can provide solutions to climate change?
7. Introduce students to the Indigenous Peoples' Forest Tenure, a climate change and human rights initiative to reestablish the sovereignty of Indigenous peoples to manage and cultivate their traditional lands. Initiatives such as this one counteract the common misconception that local communities cannot effectively manage ecosystems and resources, an idea perpetuated by the concept known as the Tragedy of the Commons. For additional information on how to discuss and evaluate the Tragedy of the Commons with your students, see the Extension Opportunities section.

Day 5: Frontline Communities and the Disproportionate Impacts of Climate Change

1. Open by asking students: Is it true that "what goes around, comes around?" Unpack this colloquialism with students and make sure students can interpret what it means.
2. After they are clear on the interpretation of the colloquialism, have students generate arguments for and against the truth of this saying based on what they have learned so far about carbon emissions, climate change, nutrient cycles, biological communities, regenerative agriculture, Afro-Indigenous farming, and Indigenous sovereignty. You can list out these topics for students to jog their memories and help them create their arguments on either side. Visualize student thinking using a tug-of-war diagram from Project Zero's Tug for Truth thinking routine.
3. Introduce students to the concept of frontline communities, and to the disproportionate impacts of climate change and food scarcity on poor communities and communities of color, using the following resources. Break students into pairs or small groups and assign each pair or small group to read one of the eight resources below:

   On oil pipelines, the Missing and Murdered Indigenous Women movement, and water rights:
   - Sexual violence along pipeline route follows Indigenous women's warnings
   - The Keystone XL Pipeline and America's History of Indigenous Suppression

   On island nations and climate change:
   - Pacific Islanders have been fighting environmental crises for centuries, if only the world would notice
   - How island nations vulnerable to climate change need rich, polluting countries to act

   On climate refugees from Syria and from Central and South America:
   - The Ominous Story of Syria's Climate Refugees
   - "We have to go": Climate change driving increased migration from Central America

   On PG&E blackouts in California:
   - PG&E power outages bring darkness, stress and debt to California's poor and elderly
   - Another Rising Cost of Climate Change: PG&E's Blackouts to Prevent Wildfires
4. After reading these articles, have students add to the tug-of-war diagram. Ask students to evaluate whether

this new information tips the scales in either direction.

5. Introduce students to their final infographic project (see the Demonstration of Learning section). For this project, students will create infographics that illustrate how restoring ecosystems, preserving and restoring key biodiversity, and creating complexity in biological communities supports sustainability and climate change mitigation. As they do their research, remind students how to evaluate sources for reliability and how to document and organize their research. Possible case studies for this project include:
    - Indigenous land management practice, including Project Drawdown: Indigenous Peoples' Forest Tenure.
    - The Mayan Milpa as an alternative to plowing from European agriculture and a means of sustaining nutrients in the soil.
    - Bison as a key ecosystem engineer in North America that increase plant biodiversity.
    - Beavers as ecosystem engineers that create wetlands and promote vegetation.
    - Otters as keystone species in kelp forests.

Asynchronous work: Students will research and complete their infographics asynchronously. Consider having students provide preliminary feedback to one another on their infographic drafts before they complete and turn

Demonstration of Learning

Students will create infographics illustrating how restoring ecosystems, preserving and restoring key biodiversity, and creating complexity in biological communities supports sustainability and mitigates climate change. These infographics should include the following elements:

- Diagrams of one or more relevant nutrient cycles. These diagrams should include annotations about disruptions to those cycles as a result of human activities and about key components that can be restored through intentional management. Students should accurately describe and explain the connections within their diagrams and the role of biotic communities in perpetuating these cycles.
- Data about nutrients and biodiversity that illustrate (1) the problems of disrupted cycles and biological communities and/or (2) the improvements to these cycles and communities after successful management changes. Students should find reliable scientific data that illustrate the importance of nutrient cycles, biological communities, key species, and management practices.
- Explanations of how the illustrated management techniques, cycle restoration, and biological communities can mitigate climate change. This is another place where primary scientific data can support a robust explanation.

Extension Opportunities

- Support students in developing their climate activist identities. To do this, have students create their own climate activism venn diagrams to determine how they can best be a part of climate change solutions. Have them reflect on their strengths, their passions, and their knowledge of what work needs to be done. Then have students determine an action that aligns with their individual skills and interests. To do this, you might introduce them to Mariame Kaba's questions about community organizing:
    - What resources exist so I can better educate myself?
    - Who's already doing work around this injustice?
    - Do I have the capacity to offer concrete support and help to them?
    - How can I be constructive?

Next, have students search for climate justice initiatives in their local communities. Students can also consider their own school as a site of climate activism. Finally, have students commit to one first step in getting involved with a school- or community-based climate initiative. You can have students commit to a deadline for taking this first step and then follow up with them to see how it went.

This activity uses the following resource:

allwecansave. (2021). *@ayanaeliza's framework for figuring out what you should do about the climate crisis: Make a Venn diagram and notice what's* [tweet]. Twitter. Accessed April 1, 2022 at: https://twitter.com/allwecansave/status/1372939917861474308.

- A popular and persistent misconception – one that is often actively promoted by well-respected scientists – is that human population growth leads to the decline of natural systems. Have students consider the racist and xenophobic intentions of Garrett Hardin in formulating the concept of the Tragedy of the Commons. This metaphor is considered scientific fact despite having been debunked by Elinor Ostrom, the first woman to win the Nobel Prize in economics. Have students evaluate the validity of the Tragedy of the Commons in the context of Ostrom's work alongside case studies of successful land management by Indigenous communities. This open source textbook teaches to Ostrom's work and the work of her colleagues in showing the successful management of the commons.

This activity uses the following resources:

Anderies, J., & Janssen, M. (2016). *Sustaining the commons*. Arizona State University.

Arrow, K. J., Keohane, R. O. & Levin, S. A. (2012). Elinor Ostrom: An uncommon woman for the commons. *PNAS*, 109 (33), 13135-13136. https://doi.org/10.1073/pnas.1210827109.

Mildenberger, M. (2019). The tragedy of the tragedy of the commons. *Scientific American*. Accessed April 1, 2022 at: https://blogs.scientificamerican.com/voices/the-tragedy-of-the-tragedy-of-the-commons/.

- Black Food Justice is an organization working to create food justice and food sovereignty for Black communities. Their Impact pages include the Justice for Black Farmers Act page, which can be used to teach students how to contact their elected representatives and advocate for legislation.

This activity uses the following resource:

Black Food Justice [website], available at: https://www.blackfoodjustice.org/.

Additional Resources

Hall, Shannon. (2015). Exxon Knew about Climate Change almost 40 years ago. *Scientific American*. Accessed April 1, 2022 at: https://www.scientificamerican.com/article/exxon-knew-about-climate-change-almost-40-years-ago/.

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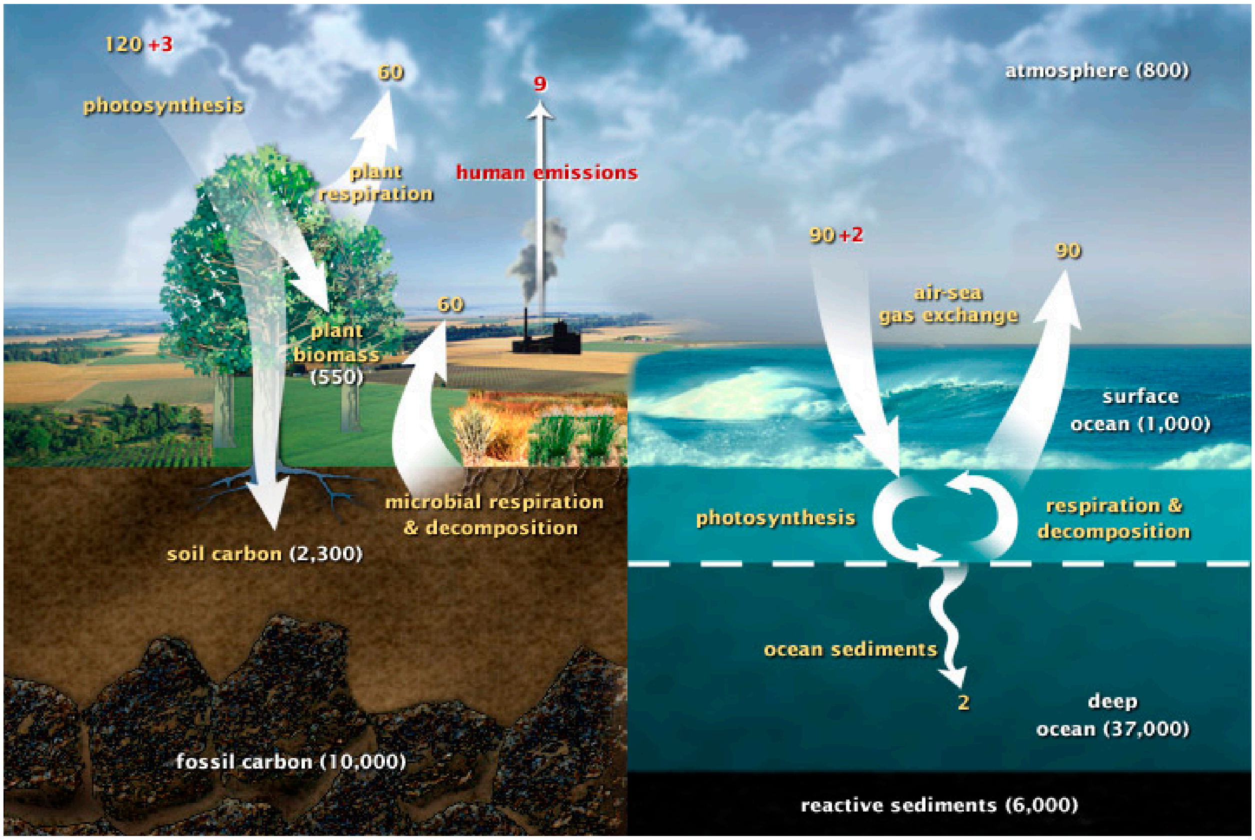
How to Save a Planet KLEW Chart

KNOW: What do you already know about climate change? Agriculture? Soil? Carbon footprints?	
LEARNED: After listening to the podcast, what are the major claims and conclusions you can make?	
EVIDENCE: What pieces of evidence illustrate and support what you have learned?	
WONDERING: What are you wondering about?	

Carbon Cycle Guided Inquiry



Model 1. The Carbon Cycle. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon. Source: U.S. DOE, Biological and Environmental Research Information System, as reproduced in Riebeek, 2011, https://earthobservatory.nasa.gov/features/CarbonCycle.

Answer the following questions about the model above:

1. What do the labels and numbers in yellow indicate? What do you think this means?
2. What do the labels and numbers in red indicate? What do you think this means?
3. What do the labels and numbers in white indicate? What do you think this means?
4. How many gigatons of carbon are moved through the carbon cycle in fluxes each year?
5. How many gigatons of carbon are stored in different places in the carbon cycle?
6. How do the numbers in your answers to Questions 4 and 5 compare?
7. How does the amount of carbon stored in the soil compare to carbon in the atmosphere? What do you think this means?

8. What is fossil carbon? How does this relate to the term "fossil fuels," which describes petroleum, coal, and natural gas?

9. Consider the "human emissions" number. Is there an equal amount of carbon going back into the cycle? How do you know?

10. What is the name for the process by which carbon enters plants?

11. What is the name for the process by which carbon leaves living things and enters the atmosphere?

12. Consider the following sources of carbon emissions. For each source, consider where they could be added to the carbon cycle shown in Model 1.
    - In order to cultivate cattle for the demand for beef, large swatches of forest are cut down, and sometimes land if burned to encourage the change to a grassland pasture.
    - Cows emit large amounts of methane (CH4) due to the presence of microbes in their rumen that help them digest food.
    - In traditional agriculture, farmers till the soil, meaning they break up and remix the soil as a means of controlling weeds and preparing the soil for planting. During this process, many live roots in the soil, which provide sugar and habitat to soil microbes, are disturbed, leading to a dramatic decrease in soil microbes.

Photosynthesis and respiration are two fundamental metabolic reactions for all living things. Photosynthesis is the capture of energy for long-term storage in carbon-based compounds such as glucose and other carbohydrates. These molecules are constitutive for plants, meaning that they make up the body of the plants.

Cellular respiration is a reaction performed by all living things. This reaction involves the breaking down of carbon molecules to transfer energy for metabolic reactions in the form of ATP.

Photosynthesis:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

carbon dioxide + water → glucose + oxygen gas

Cellular respiration:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

glucose + oxygen gas → carbon dioxide + water

The burning of gasoline in human emissions:

$$2C_8H_{18} + 25H_2O \rightarrow 16CO_2 + 18H_2O$$

iso-octane + water → carbon dioxide + water

Model 2. Chemical reactions for photosynthesis, cellular respiration, and the burning of gasoline in human emissions.

13. Examine the reactions in Model 2. What is the relationship between photosynthesis and cellular respiration? Describe this relationship in terms of the products and reactants of the reactions.

14. Compare Model 2 to Model 1. What is the illustrated relationship between photosynthesis and cellular respiration in the carbon cycle? Describe in complete sentences.

15. Compare Model 2 to Model 1. Which of the reactions in Model 2 does the carbon stored in the soil come from? How do you know?

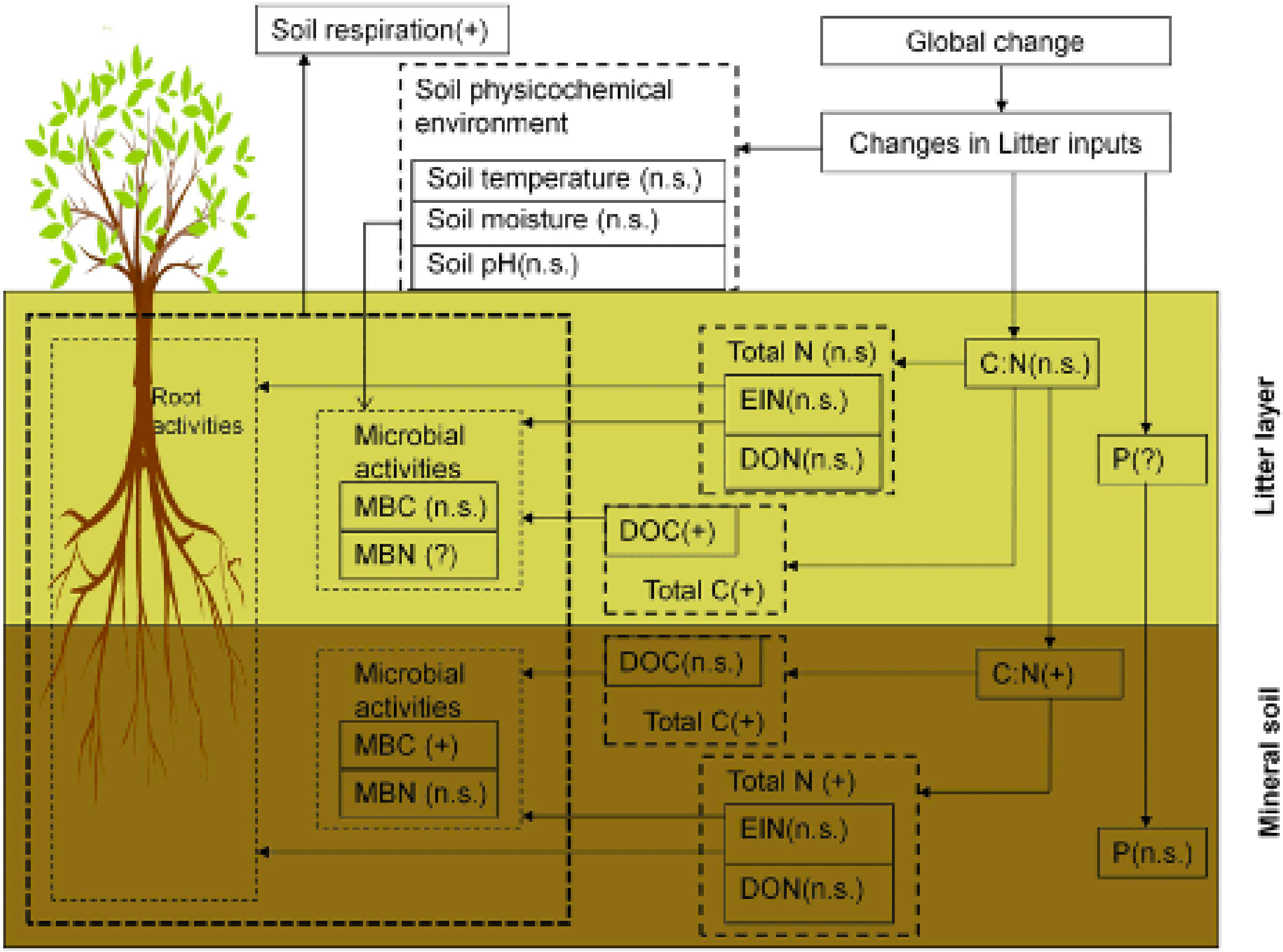
16. Compare Model 2 to Model 1. Which of the reactions in Model 2 does the carbon stored in plant biomass come from? How do you know?

17. Compare and contrast the reactions for cellular respiration and for the burning of gasoline in cars. What is similar? What is different?

18. Compare Model 2 to Model 1. Where in Model 1 is the burning of gasoline illustrated?

19. Compare Model 2 to Model 1. Does photosynthesis increase when the amount of carbon in the atmosphere increases due to carbon emissions? How do the numbers compare?

Appendix: Nutrient Cycling Model



Source: Xu et al. (2013), https://doi.org/10.5194/bg-10-7423-2013.

Description of this figure:

"The responses of soil carbon and nutrient cycling to changes in litter inputs, where MBC is microbial biomass carbon, MBN microbial biomass nitrogen, DOC dissolved organic carbon, DON dissolved organic nitrogen, EIN extractable inorganic nitrogen and P is extractable phosphorus. The relationship between the response ratio of each parameter and the quantity of litter inputs is shown in parentheses. "+" indicates a significant positive linear correlation; "–" indicates a significant negative linear correlation; n.s. is non-significant; "?" indicates an unknown relationship because of data limitations." (Xu et al., 2013, p. 7429)

BIOLOGY LESSON 3
TOXINS IN OUR COMMUNITIES

Suggested time: Five to eight 50-60 minute class periods
Suggested units: The scientific method, biodiversity, ecology

Overview

Marginalized communities, including areas where residents are predominantly people of color, people living in poverty, and/or people with lower levels of education, are often targeted as dumping grounds for toxic chemicals. These chemicals often contaminate the surrounding air and water, causing poor health outcomes for local residents. Students will learn how marginalized communities are at higher risk of exposure to toxic chemicals. They will then do an experiment using *Daphnia* to analyze the effect of toxins on organisms and ecosystems. Finally, students will share their data with local stakeholders in an effort to spread awareness of this issue and advocate for change.

Objectives

- Students will illustrate the disproportionate impact of environmental contaminants on communities of color, termed environmental racism.
- Students will follow a guided inquiry to understand the effect of road salt on living organisms.
- Students will research environmental racism in a collection of case studies and create arguments that describe the relationship between racism and disproportionate health impacts.

  Students will apply the scientific method to design a simulation of the local toxic chemicals in a mini-hydroponic system that will replicate how toxins can harm living things, including humans.

Key Understandings

- Clean air and water are not freely available to all, and, in particular, can be inaccessible to communities with marginalized identities. Many companies purposefully discard their wastes in disenfranchised communities, disproportionately harming people of color, those with less wealth and lower incomes, and those with less education, by polluting their water and air.

  Possible misunderstanding: People of color and others with marginalized identities contaminate their own communities.
- Spreading awareness about the dangers and the injustice of environmental racism can help put pressure on companies and policymakers to change practices around dumping waste in marginalized communities.

  Possible misunderstanding: Individuals and students have no power to change the actions of large corporations.

Materials

- Orum, P., Moore, R., Roberts, M., & Sanchez, J. (2014). Who's in danger? Race, poverty, and chemical disasters. Environmental Justice and Health Alliance for Chemical Policy Reform. Environmental Justice and Health Alliance for Chemical Policy Reform. Accessed October 1, 2021 at: https://comingcleaninc.org/assets/media/images/Reports/Who's%20in%20Danger%20Report%20and%20Table%20FINAL.pdf
- One 1-pint container with lid per student group (old yogurt or cottage cheese containers can work well if they are clean)
- Ten *Daphnia* (water fleas) per student group

- Algae or baker's yeast (add 1.25 teaspoons of algae or baker's yeast to a liter of warm water)
- Contaminants, such as road salt, chlorine, ammonia, formaldehyde, pesticides, oil, or grease
- One rockwool grow cube per student group
- Two plant seeds per student group, such as oregano, dill, thyme, sage, basil, rosemary, cilantro, lavender, mint, lettuce, sunflower, tomato, and/or radish
- Handouts (included at the end of this lesson):
    - How Toxins Affect Communities
    - Toxin Research Guide
    - Toxin Lab: Materials and Method

Vocabulary

environmental justice
environmental racism
toxin

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-LS2-2** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **JU.9-12.12** I can recognize, describe and distinguish unfairness and injustice at different levels of society.
- **AC.9-12.20** I will join with diverse people to plan and carry out collective action against exclusion, prejudice and discrimination, and we will be thoughtful and creative in our actions in order to achieve our goals.

Note to Teachers

This lesson includes a Toxin Lab involving *Daphnia* and a hydroponic system. By including a hydroponic system as part of this lab, students will observe the effects of toxins not only on their *Daphnia* but also on their plants and on the small ecosystems they have created. However, developing the hydroponic system takes time; you may need to begin this process several class periods before teaching this lesson. If time is limited, you might choose not to include hydroponic systems in this lab, but instead have students simply keep their *Daphnia* in small containers of water. In this case, have students skip Steps 1 and 2 from the Method section of the "Toxin Lab" handout. If you do choose to have students develop hydroponic systems, you will need to decide on a type of plant seed for students to grow.

For additional information on how to care for and teach with *Daphnia*, check out the resources linked here from Carolina Biological and Ward's Science.

You might also consider including a guided inquiry activity as part of Day 1. A guided inquiry can serve as a great first step for students to explore a model organism, learn lab techniques, practice collecting evidence, and understand experimental design before designing their own investigations. Your guided inquiry could involve having students expose a small subset of *Daphnia* to various concentrations of road salt solutions and examining how these exposures affect their *Daphnia's* heartrates. After the guided inquiry, students should be familiar with *Daphnia* and able to design an experiment with relevant dependent and controlled variables when they begin their Toxin Labs on Day 3.

LESSON PROCEDURE

Day 1: Environmental Toxins in Communities Across the U.S

Based on how frequently your class meets and whether you choose to include hydroponic systems as part of your Toxin Lab, you may need to have students set up their hydroponic systems in advance of Day 1.

1. Introduce students to the *Daphnia* they will be observing during their Toxins Lab. Have students develop and maintain a healthy environment for their *Daphnia* and teach students how to observe these creatures using a microscope. Students should observe their *Daphnia* at the start of each class period for 3-5 days, collecting data on the creatures' resting heart rates and maintaining their environments.
2. Ask students what they know about the water crisis in Flint, Michigan. You might consider keeping track of what students know and organizing their thinking in a class KLEW chart by adding students' responses to the "Know" column. If students do not know anything about Flint, Michigan, you can introduce them to the issue using this resource from the National Resources Defense Council.
3. Explain to students the cause of the water crisis. Road salt often leads to higher concentrations of chloride ions in local water sources, and these chloride ions can increase the corrosion of the lead water pipes that carry this water to residents. This corrosion can be avoided by the addition of orthophosphate to water. City officials in Flint, Michigan, however, avoided using this anti-corrosion agent after switching the source of water from the Detroit Water and Sewerage Department to the Karegnondi Water Authority, which drew from river water which is more prone to road salt runoff. This switch was made for cost reasons, but soon afterwards residents complained of contaminated and undrinkable water. The predominantly Black city saw little response to their complaints by city officials.

   Images from this teaching resource from the American Chemical Society can be useful in illustrating the chemical reactions that lead to the corrosion of pipes and the increasing concentration of lead in the water.
4. Put students in small groups and have each small group read one of the following stories from the Who's In Danger? report. Alternatively or additionally, you can have students read other stories of community efforts to combat the leaching of toxins and pollutants, such as those included in the Additional Resources section. As they read, students should fill out the handout entitled "How Toxins Affect Communities."
   - Alaska Community Action on Toxics, Savoonga, St. Lawrence Island, Alaska (p. 14)
   - West County Toxics Coalition, Richmond, CA (pp. 16-17)
   - Mossville Environmental Action Now (MEAN), Mossville, Louisiana (pp. 18-19)
   - Los Jardines Institute (The Gardens Institute), South Valley of Albuquerque, NM (pp. 20-21)
   - Texas Environmental Justice Advocacy Services (t.e.j.a.s.), Houston, Texas (pp. 22-23)
   - People Concerned About Chemical Safety, Charleston, West Virginia (pp. 24-25)
5. Have each student group present a summary of their assigned story with the rest of the class. Groups should be sure to include the information they recorded in response to the questions in the "How Toxins Affect Communities" handout. As they listen, students should take notes on each story, looking for similarities and differences across articles.
6. After each student group has presented, discuss similarities and differences from the stories they read. You can use the questions from the handout to guide this discussion, which are repeated and slightly modified here:
   - What toxin(s) are described in these stories? Where are these toxins coming from? What effects are they having on nearby communities? How are these effects similar or different across communities?
   - What do we know about the populations of the communities being affected by these toxins? What, if any, patterns exist regarding race, wealth, education level, or other demographic factors?
   - What are residents and/or local organizations doing to respond to the presence of toxins in their communities? What particular strategies are they using, and have any of these been effective?

Asynchronous work: Have students read Chapter Two: Demographic Analysis of Chemical Facility Vulnerability Zones from the Who's In Danger? report (pp. 26-34). Consider using an online discussion platform such as Padlet, Google Jamboard, Miro, or Parlay, to have students make and respond to posts about the demographic patterns described in this chapter, as well as their own hypotheses about why such patterns exist. Check that students are noticing and discussing demographic patterns related to race, wealth/income, and education, which feature prominently in the report's findings.

Day 2: Toxins and Environmental Racism

1. Students should start each class by observing and caring for their *Daphnia* and their hydroponic systems.
2. Introduce students to the term **environmental racism**. You can explain that environmental issues exist and occur within a system of racism and disproportionately impact people of color. In other words, environmental issues do not impact all communities equally, but instead disproportionately impact those already discriminated against by an unequal society. Connect the concept of environmental racism to the testable definition of racism and the Four I's of systemic oppression (see the Appendix: Defining Racism in Biology Lesson 1). Use the example of the Flint water crisis to illustrate for students how the Four I's of racism operate with respect to environmental toxins.

   The Four I's of racism in the Flint water crisis (informed by The Flint water crisis: Systemic racism through the lens of Flint):

Individual Implicit biases about people of color likely influenced government officials' choice to question, mistrust, and undervalue the complaints of the residents of Flint.	**Interpersonal** Government officials ignored complaints and criticisms from residents of Flint, who are overwhelmingly people of color.
Institutional Decades of housing discrimination has led to segregated residential areas and lower property values in those areas designated for people of color. Lower property values result in lower property taxes, resulting in underfunded communities and necessitating budget cuts and underinvestment in clean water.	**Ideological** An ideology of racism – which undervalues communities of color – likely informed the city of Flint's decision to sacrifice residents' health for cost containment, and to dismiss residents' complaints about their water.

3. Have students create a brief claim-evidence-reasoning argument to organize their thinking about the case studies they read from the Who's In Danger? report. Within their small groups, students should create arguments that answer the essential question:

   Is this case an example of environmental racism?

   Students can respond to this question on a whiteboard or posterboards, in short written responses, or with slide decks. Have students share these initial claim-evidence-reasoning arguments with short presentations to the rest of the class.
4. Have students examine Appendix C from the Who's In Danger? report (pp. 50-200), in which students will find a table of the Vulnerability Zones of 3,433 chemical facilities throughout the country by state, county, and city. Students should determine whether any of these chemical facilities exist in their own county (or, if not, then in nearby counties), which main chemicals are at risk of becoming contaminants from these facilities, and the size – both in miles and in population – of these Vulnerability Zones.
5. Have students research the chemical(s) made by the factories in their county to find out how these agents

can be harmful to organisms. Once again, you might break students into small groups, this time having each group research a different toxin. Students can use the handout entitled "Toxin Research Guide" to guide their research. You might also consider partnering with the teacher and students from a chemistry class, allowing chemistry students to teach their peers about the chemical agents from the Who's In Danger? report, and biology students to teach their peers how those chemicals are harmful to biological organisms.

Asynchronous work: Have students write short reports about the toxins they researched. This report should include all the information they gathered in the "Toxin Research Guide," as well as recommendations about how to prevent the toxin they researched from harming communities.

Days 3-5: Using *Daphnia* to Evaluate Environmental Toxins

1. Explain to students that they will be using their hydroponic ecosystems to study the effects of chemical toxins on living organisms. Guide students to consider contaminants they can study for their investigations. Students should choose contaminants that have relevance to environmental racism and the effects of toxins on living things. You should also curate a list of available materials that students can choose from.
2. Students will follow the procedure in the Toxins Lab: Materials and Method handout. Beforehand, have students develop an appropriate research question and hypothesis for their experiment. Consider maintaining at least one control hydroponic system as a class for comparison.
3. Have students maintain daily observations in a lab notebook. Once the experiment is complete, consider having students write a formal scientific research poster (see Demonstration of Learning) analyzing the results of their experiment.
4. Close by having students compile and organize their data into scientific posters, making connections between the effect of their toxin on *Daphnia* and the effect of toxins on humans. As a class, choose local companies, political representatives, and/or community groups to share their presentation or report with.

Asynchronous work: If assigned a lab report, students should work on the different sections of their reports outside of class, throughout the testing period.

Demonstration of Learning

Have students create a scientific research poster that includes the following sections and elements:

- Title
- Introduction with relevant background information from their toxin reports, as well as a clear research question and hypothesis
- A visual diagram of their experimental design that clearly communicates their independent and dependent variables
- Results
- Conclusion
- Citations

Students' introduction and conclusion sections should be sure to make connections between the data they collected with *Daphnia* and the data they read about from the Who's In Danger? report. This resource outlines key pieces of an academic research poster and can serve as a guide for students.

Additional Resources

Baker, K. (2021). La. grandma takes on chemical companies in cancer alley 'like a roaring lion' — and succeeds. *People*. Accessed October 1, 2021 at: https://people.com/human-interest/louisiana-grandma-takes-on-chemical-companies-in-cancer-alley/.

This article describes the efforts of Louisiana resident Sharon Lavigne to combat environmental racism affecting her community.

Denchak, M. (2018). Flint water crisis: Everything you need to know. National Resource Defense Council. Accessed April 1, 2021 at: https://www.nrdc.org/stories/flint-water-crisis-everything-you-need-know.

This resource provides a thorough overview of the Flint water crisis and may be useful for students unfamiliar with the issue.

Dhillonm, J. (2017). What Standing Rock teaches us about environmental justice. Social Science Research Council. Accessed October 1, 2021 at: https://items.ssrc.org/just-environments/what-standing-rock-teaches-us-about-environmental-justice/

This essay argues that environmental injustice on Indigenous lands is intertwined with a long history of settler colonialism and gender violence against Indigenous peoples.

Dingle, A. (2016). The Fling water crisis: What's really going on? American Chemical Society. Accessed April 1, 2022 at: https://www.acs.org/content/dam/acsorg/education/resources/highschool/chemmatters/issues/2016-2017/December%202016/chemmatters-dec2016-flint-water-crisis.pdf.

This resource explains the chemistry behind Flint's water crisis.

The Flint water crisis: Systemic racism through the lens of Flint. (2017). Michigan Civil Rights Commission. Accessed April 1, 2022 at: https://www.michigan.gov/-/media/Project/Websites/mdcr/mcrc/reports/2017/flint-crisis-report-edited.pdf?rev=db527d0e6c404254892c84c907988934.

This report assesses the role of systemic racism in producing the Flint water crisis.

Gross, J. (2022). Road salt works. But it's also bad for the environment. *The New York Times*. . Accessed April 1, 2022 at: https://www.nytimes.com/2022/01/07/climate/road-salt-water-supply.html.

This resource describes the numerous impacts road salt has on the environment and on biological communities. This resource can be assigned to students to read prior to or after class to help clarify these connections.

Gundogan, B., Koshy, K., Kurar, L., & Whitehurst, K. (2016). How to make an academic poster. *Annals of Medicine and Surgery,* 11, 69-71.

This resource outlines key elements of an academic research poster and can be useful to provide to students as they prepare their Demonstration of Learning posters.

History.com Editors. (2018). The Flint water crisis begins. A&E Television Networks. Accessed April 1, 2022 at: https://www.history.com/this-day-in-history/the-flint-water-crisis-begins.

This resource provides a brief overview of the Flint water crisis.

Let's talk about sacrifice zones. (2021). The Climate Reality Project. Accessed April 1, 2022 at: https://www.climaterealityproject.org/blog/lets-talk-about-sacrifice-zones.

This resource defines the term "sacrifice zone," which refers to the intentional positioning of polluting industries beside marginalized residential areas, particularly those that include low-income residents and residents of color.

Srikanth, A. (2021). How a pastor in South Carolina is fighting environmental racism with a sustainable water farm. *The Hill*. Accessed October 1, 2021 at: https://thehill.com/changing-america/sustainability/infrastructure/539947-how-a-pastor-in-south-carolina-is-fighting.

This article describes how pollution generally, and water contamination specifically, disproportionately affects communities of color, and highlights locally led efforts to combat water contamination.

Wilkins, B. (2021). 'Stand with us': Indigenous line 3 opponents seek allies to fight tar sands pipeline. Common Dreams. Accessed October 1, 2021 at: https://www.commondreams.org/news/2021/08/05/stand-us-indigenous-line-3-opponents-seek-allies-fight-tar-sands-pipeline

This article describes the efforts of a group of Indigenous-led water protectors in Minnesota opposing a pipeline that runs through Indigenous lands ostensibly protected by U.S. treaties. Please note that this article contains descriptions of police brutality and racialized violence.

How Toxins Affect Communities

In your small group, read the story assigned to you. Then answer the questions below. Be prepared to present these answers and a summary of your article to the rest of your class.

1. What toxin(s) are described in this story? Where are they coming from? What effect(s) are they having on community members?

2. What do you know about the population of the community being affected by these toxins? Does the article note any trends regarding race, wealth, education level, or other demographic factors?

3. What are residents and/or local organizations doing to respond to the presence of toxins in their community? What particular strategies are they using, and have any of these been effective?

Toxin Research Guide

Use the questions below to guide your research about your toxin.

1. What is the name of your toxin?

2. Why is your toxin produced? When, where, and how is your toxin typically used? If your toxin is a byproduct of another process, describe that process.

3. How was your toxin discovered? When and why did it first become widely used or produced?

4. What are the physical and chemical properties of your toxin?

5. What effect does your toxin have on living organisms? Which organisms have been studied or shown to be at high risk regarding this toxin?

6. Are there any notable events or accidents that have occurred involving contamination by this toxin? If so, please describe these.

7. What regulations, if any, exist with respect to your toxin?

Toxin Lab: Materials and Method

Materials

- 1 1-pint container with lid
- 1 rockwool growing cube
- 2 _______________ seeds
- 10 Daphnia
- Water
- Pipette
- Algae or baker's yeast

Method

1. Set up your hydroponic system by placing the rockwool growing cube on the container lid. Use a marker to trace the bottom of the rockwool on the center of the container lid. Cut just inside the traced line so that you create a tight space into which you can securely wedge your rockwool. Insert the rockwool into the cutout in your lid.

2. Fill your container with enough water that the bottom of the rockwool growing cube is immersed; this contact will allow the rockwool to absorb the water and keep it moist for seed germination. Set the seeds in the moistened rockwool. Set the system aside and monitor it daily to ensure the water is touching the rockwool to keep it moist for the seeds to grow. Allow this to continue until the seed has developed into a young plant with small, exposed leaves.

3. Introduce 10 *Daphnia* into your hydroponic system. Feed the *Daphnia* once a day with the reconstituted solution of algae or baker's yeast. When feeding your *Daphnia*, add 2 to 3 teaspoons of your feeding solution to the water in your hydroponic system. Continue this process until your plant is mature.

4. Every day, remove two *Daphnia* from the hydroponic ecosystem and observe them under the microscope. Measure and record their heart rates in beats per minute and draw your observations of the *Daphnia* in your lab notes. After making observations, return your *Daphnia* to the container. In addition, record any observations you make of your hydroponic system. This step establishes the resting heart rate of the *Daphnia* before you apply any contaminant.

5. When your plant is mature and your *Daphnia* colony is thriving, start adding small microdoses of the agreed-upon contaminant to the water in your hydroponic system. Your teacher will let you know the correct amount of contaminant to add to your system.

6. Continue to remove two *Daphnia* from the hydroponic ecosystem every day after adding the contaminant and observe them under the microscope. As before, measure and record their heart rates in beats per minute and record your observations of the *Daphnia* in your lab notes. In addition, record any observations you make of your hydroponic system.

BIOLOGY LESSON 4

MACROMOLECULES: THE BUILDING BLOCKS OF US

Suggested time: Four to six 50-60 minute class periods
Suggested units: Macromolecules, properties of water

Overview

This lesson explores the essential nutrients of life: water and the four macromolecules. Students will learn about these molecules and their roles within the body in the context of culturally nourishing foods. In completing a macromolecules detection lab, students will investigate what makes cultural dishes nourishing and celebrate diverse lived experiences. In addition, students will grapple with the history of nutrition-based experimentation on Indigenous children in boarding schools and on incarcerated people. This lesson provides opportunities for teaching to introduce or review biochemical processes within the body – including osmosis, hydrolysis, and dehydration synthesis – in the context of racial justice and cultural diversity.

Objectives

- Use everyday experiences with water and food to build an understanding of why these molecules are necessary for living things.
- Explain the need for water using hydrolysis reactions and access to nutrition from macromolecules.
- Introduce the four major macromolecules and investigate qualitative methods for determining the presence or absence of macromolecules in foods.
- Celebrate cultural dishes as nourishing from both biological and cultural perspectives.

Key Understandings

- Food is nourishing and nutritious. There is no one correct cuisine or diet but instead a diversity of cuisines and diets that reflect social, cultural, and religious values.

  Possible misunderstanding: There is one optimal, healthy diet that we should all ascribe to.

- The daily values of nutrition labels and nutrition science is founded on unethical human experimentation conducted on Indigenous children and incarcerated populations. Understanding and learning from these historical examples of unethical experimentation illustrates how systemic racism influences science.

  Possible misunderstanding: Science is objective and morally neutral.

Materials

- Smith, P., & Zagorsky, J. L. (2020). Poorest Americans drink a lot more sugary drinks than the richest – which is why soda taxes could help reduce gaping health inequalities. *The Conversation*. Accessed April 1, 2022 at: https://theconversation.com/poorest-americans-drink-a-lot-more-sugary-drinks-than-the-richest-which-is-why-soda-taxes-could-help-reduce-gaping-health-inequalities-142345.
- Amoeba Sisters. (2016). Biomolecules (Updated) [video]. YouTube. Accessed April 1, 2022 at: youtube.com/watch?v=YO244P1e9QM.

- Macdonald, N. E., Stanwick, R., & Lynk, A. (2014). Canada's shameful history of nutrition research on residential school children: The need for strong medical ethics in Aboriginal health research. *Paediatrics & Child Health*, 19(2), 64. https://doi.org/10.1093/pch/19.2.64.
- Mosby, I. (2013). Administering Colonial Science: Nutrition Research and Human Biomedical Experimentation in Aboriginal Communities and Residential Schools, 1942–1952. *Histoire sociale / Social History*, 46(1), 145-172. https://hssh.journals.yorku.ca/index.php/hssh/article/download/40239/36424/0.
- Carpenter, K. J. (2006). Nutritional studies in Victorian prisons. *The Journal of Nutrition*, 136, 1, 1–8. https://doi.org/10.1093/jn/136.1.1.
- Kolata, G. (2018). The ideal subjects for a salt study? Maybe prisoners. *The New York Times*. Accessed April 1, 2022 at: https://www.nytimes.com/2018/06/04/health/prisoners-salt-study.html.
- Kaljur, L. (2020). Sharing food, building resilience. *Hakai Magazine*. Accessed April 1, 2022 at: https://hakaimagazine.com/features/sharing-food-building-resilience/.
- Godley, L. (Producer). (2017). The cooking gene: Michael Twitty. PBS. Accessed April 1, 2022 at: https://www.pbs.org/video/the-cooking-gene-michael-twitty-baqmq2/.
- About the right to food and human rights. (2022). United Nations. Accessed April 1, 2022 at: https://www.ohchr.org/en/special-procedures/sr-food/about-right-food-and-human-rights.

Vocabulary

carbohydrates: monosaccharides, polysaccharides
dehydration synthesis
food desert
human experimentation
hydrolysis
Indigenous boarding schools
lipids
macromolecules
monomers
nucleic acids
osmosis
polymers
proteins and amino acids
tonicity (hypotonic, hypertonic, isotonic)

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-LS1-6** Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **ID.9-12.1** I have a positive view of myself, including an awareness of and comfort with my membership in multiple groups in society.
- **ID.9-12.2** I know my family history and cultural background and can describe how my own identity is informed and shaped by my membership in multiple identity groups.
- **ID.9-12.4** I express pride and confidence in my identity without perceiving or treating anyone else as inferior.
- **DI.9-12.10** I understand that diversity includes the impact of unequal power relations on the development of group identities and cultures.
- **DI.9-12.8** I respectfully express curiosity about the history and lived experiences of others and exchange ideas and beliefs in an open-minded way.

LESSON PROCEDURE

Day 1: How Is Water Nourishing for Us?

1. Let students know that, throughout this lesson, they will be considering the following question: What foods and drinks do we consume, and why?
2. Introduce students to the KLEW chart you will be using as a class to organize students' thinking and learning over the course of this lesson. Have students discuss the prompts below with a partner, then share out with the class. Use students answers to these questions to fill in the Know column of your class KLEW chart.
    - How do different foods and drinks affect our health and wellbeing? What do you think makes a food or drink healthy or unhealthy, and how do you know?
    - How do different foods and drinks relate to our preferences, identities, and communities?
    - Why might we choose to consume sugary drinks or fast food even when we know these may not be as good for us as other drinks and foods? What factors determine how a person chooses what to drink or eat?
3. Have students reflect on the popularity of sugary drinks such as juices, sodas, and energy drinks. Ask students to discuss with a partner: Why do many of us choose to drink sugary drinks instead of water? What is in these drinks, and how do these ingredients affect us?
4. Create an osmosis demonstration using dialysis tubing. You can choose any solute that will cause dehydration of bags when placed in a hypertonic solution; salt and sugar will both demonstrate the necessary results, though sugar is more relevant to the opening case study. Create one bag with only distilled water inside the bag and place it in a solution that is hypertonic to the contents of the bag. Create a second bag which is the opposite (solute inside, distilled water outside) to model a hypotonic solution. For more guidance on how to set up an osmosis demonstration, see the Additional Resources section.
5. Return to the KLEW chart and add what students learned from the osmosis investigation. Have students generate comparisons, observations, and trends from this demonstration and record these in the Evidence column.

    After accumulating and discussing evidence, guide students in generating a conclusion from the evidence: what happened and why?
6. Introduce the concepts of osmosis, diffusion, and tonicity; if you have not already covered these concepts in your course, this would be a great opportunity to teach these phenomena to students. Help students connect the observations they made during the osmosis demonstration with each of these concepts. Generate a conclusion for the "Learned" column that connects the evidence from the investigation to the concepts of osmosis and tonicity.
7. Connect the concepts of osmosis, diffusion, and tonicity to what happens in our cells. The cells in our bodies are using and producing water in metabolism constantly, but there is a net output of water as the body gets rid of urea by diluting it in urine. For this reason, we have a continuous need to consume water.
8. Given the path of solutes in our bodies, ask students:

    Based on the concepts presented, why are sugary drinks less hydrating than pure water for our cells? Explain using osmosis and tonicity.
9. Introduce hydrolysis reactions with diagrams and examples and help students construct an explanation for why we need water to break down large molecules in the foods and drinks we consume. Simple diagrams showing hexagons of glucose being liberated from starch should be sufficient to get across the idea that water is a necessary reactant for this to happen.
10. Given the function of hydrolysis in our bodies, ask students: Why are sugary drinks dehydrating, even when they feel satisfying to drink?

Possible student response: Sugary drinks are dehydrating because not only do they contain less water than pure water, but also because water is then necessary for hydrolysis to break down the sugar molecules consumed as part of those drinks.

11. Have students revisit their KLEW chart. In pairs, have students discuss what to add to the "Learned" column, and then generate questions they are wondering about for the "Wondering" column. As a class, have students share out their learnings and wonderings. The questions they identify should be noted and returned to throughout the remainder of the lesson as a way of building their understanding out of the guided inquiry.

Asynchronous work: Have students read the article "Poorest Americans drink a lot more sugary drinks than the richest – which is why soda taxes could help reduce gaping health inequalities" and respond in writing to the following questions:

- People with less wealth are disproportionately Black, Indigenous, and people of color. Given this information, how is regulating sugary drinks a racial justice issue?
- The Navajo Nation has had significant issues with access to clean water for decades. In 2015, the Navajo Nation also introduced a sugary drinks tax in response to significant rates of obesity and diabetes. How could a lack of clean water and reliance on sugary drinks be related? How might a lack of clean water reflect systemic racism?

Day 2: Introducing and Investigating Macromolecules

1. Open by reviewing the previous class. Have students complete the thinking routine I used to think... Now I think... when it comes to why water is nourishing and necessary for all living things.
2. Show students a nutrition label and ask them to evaluate it. Have students add to the "Know" column of their existing KLEW chart to organize their thinking, using the following questions to guide them:
   - What do you know about nutrition labels?
   - What do you know about food and why we need it?
3. Next, ask students to take a closer look the nutrition label, making observations and drawing inferences from what they see. Have students discuss the following questions:
   - What do you see as evidence that this food is nourishing? (Add these observations in the "Evidence" column.)
   - What conclusions can you make about what makes food nourishing, based on the evidence you have gathered? (Add these conclusions to the "Learned" column).
   - What questions are you still wondering about? (Add these questions to the "Wondering" column.)
4. Introduce students to macromolecules. Explain that macromolecules are the major building blocks of all living things. Be sure to provide an overview of the four major macromolecules – carbohydrates, lipids, proteins, and nucleic acids – including their monomers and polymers. Describe the functions of these macromolecules in our bodies. For a brief overview, consider showing students the video Biomolecules (8:12 minutes) by the Amoeba Sisters. As they watch, students should take notes using the template provided in the handout "Macromolecules Fact Sheet;" students will need four copies of this handout, one for each macromolecule.
5. Review with students the important role water plays in our bodies, particularly with respect to macromolecules. Some major points to include in your instruction are:
   - **Hydrolysis:** our bodies need water to split apart what we eat so that we can access the building blocks and nutrients to use in our own bodies. This can review and reinforce what was covered in Day One.
   - **Dehydration synthesis/condensation reactions:** Our bodies can also synthesize or put together molecules to create macromolecules. Consider using the example of glucose to glycogen and back again to show why this is useful for us for short-term storage of sugars.

6. Return once again to the nutrition labels. Ask students:
   - What can we better understand in this nutrition label now that we know about macromolecules?
   - Look at the daily values. What does these mean? How do you think these amounts were calculated? How might the first "daily values" have been determined?

   Have students make conclusions about macromolecules and nutrition and add these to the "Learned" column of the class KLEW chart.

7. Share with students that much of the research on nutrition has involved unethical human experimentation. Divide students into four groups and assign each group one of the four articles below. As students read their assigned articles, they should take notes on what they read in the handout entitled "Nutrition Experiments." Then have each group present their findings to the rest of the class. As they listen to these presentations, students should take notes on what they are learning.
   - Canada's shameful history of nutrition research on residential school children: The need for strong medical ethics in Aboriginal health research
   - Administering Colonial Science: Nutrition Research and Human Biomedical Experimentation in Aboriginal Communities and Residential Schools, 1942–1952
   - Nutritional Studies in Victorian Prisons
   - The Ideal Subjects for a Salt Study? Maybe Prisoners

8. After they have heard the presentations, ask students: How do these case studies reflect racism? Have students generate explanations using the testable definition of racism (racism = discrimination against people of color + unequal power) and the Four I's of systemic oppression. (See the Appendix in Biology Lesson 1 for a complete introduction to the testable definition of racism and the Four I's of oppression.) You can have students work in groups to create this explanation, or you can work on this together in a class discussion.

Days 3 and 4: What Makes Food Nutritious?

1. Have students review their initial answers to the questions "What makes food nutritious? What makes food nourishing?" from their KLEW charts and consider any additions or ways in which they now know more. Are there questions from their "Wondering" column they can now answer?

2. If it does not come up naturally in the class discussion, ask students to extend their thinking beyond the molecular science of food to consider the role of food in social and cultural traditions. Ask students the following questions:
   - What is the cultural value of food?
   - How do cultural dishes and cuisines carry social, cultural, and religious meanings?
   - Do you have any foods, dishes, or cuisines that carry social, cultural, and/or religious meanings for you, and, if so, what are these?

3. Food is a deeply person expression of our individual identities, community values, and ancestry. Consider sharing one or both of the following resources, which demonstrate the cultural value of food:
   - Article: Sharing Food, Building Resilience
   - Video: The Cooking Gene: Michael Twitty (7:39 minutes)

4. Project or distribute the following statement from the United Nations on the right to food:

   > The right to food is the right to have regular, permanent and unrestricted access, either directly or by means of financial purchases, to quantitatively and qualitatively adequate and sufficient food corresponding to the cultural traditions of the people to which the consumer belongs, and which ensure a physical and mental, individual and collective, fulfilling and dignified life free of fear.

   Have students discuss why "cultural traditions" are included in this definition and why food is more than just the nutrients it contains.

5. Introduce students to the Macromolecules Lab they will complete over the next couple of class periods. In this lab, students will use chemical indicators to test for the presence of each of the four macromolecules in different samples of foods. Consider providing a diversity of foods for students to investigate in addition to the positive controls. If possible, for example, consider having students bring major ingredients of their own favorite cultural dishes to investigate. Alternatively, you might create a selection of ingredients based on a survey of students' favorite foods, cultural dishes, and cuisines.
6. Distribute the "Macromolecules Lab" handout and have students complete the lab investigation. Note that this investigation may take more than one class period to complete.
7. After students have completed the Macromolecules Lab, introduce students to their final project (see Demonstration of Learning) by asking them to consider: What makes my cultural foods nourishing, both biologically and culturally? For this assignment, students will conduct independent research to investigate ingredients and nutrition labels for a cultural dish that is meaningful for them, and this information will be collated into a class zine. Students may need help exploring the concept of culture as it applies to them. Let students know they may be part of multiple cultures, whether these be the cultures of their ancestors, the regional cultures that pervade where they live, or even their family cultures. Encourage students to think expansively about the meaning of culture as they choose a dish to investigate for the class zine.
8. Students should complete their zine page in class or for homework. When complete, all students should receive copies of the class zine. You might consider having a zine publication party where students present their pages.

Demonstration of Learning

Students will complete a zine page in response to the question: What makes my cultural food nourishing? Students should consider both the nutrition the dish provides biologically as well as the cultural significance of the dish. Each student should create a one-page, data-driven zine page that includes:

- Pictures and diagrams of the dish, the preparation of the dish, and its macromolecule components.
- A recipe, if relevant.
- An explanation of the dish's macromolecule components and how these macromolecules are used in the body. Students should incorporate diagrams of monomers and polymers as they relate to the components of the dish.
- Data on the cultural dish, if possible. These data could be economic statistics if the cultural dish is also sold commercially, the sale of the ingredients or other necessary materials such as kitchen equipment. It could also be data about when the cultural dish is found in historical records, or data about nutrition as well.

An exemplar zine page is provided at the end of this document.

Special considerations for this final assignment:

- White students might not feel the relevance of the question "my cultural food" due to the purposeful loss of ethnicity required by assimilation into Whiteness in America. This can be a place to prompt White students to reconnect with their ethnic background or to explore comfort food for them. You might ask students: Is there American food? Where does American food come from?
- Transracial and transnational adoptees might also feel disconnected from the notion of cultural dishes. Help these students define a culture they connect with that is not necessarily grounded in their ethnic identity but more proximate (i.e., regional culture or family culture) while also providing the space for them to research a cultural dish from their ethnic or racial identity or birth nationality.

Notes about creating zines:

- You will need a special long-arm stapler to put the zine together. Many public libraries have long arm staplers.
- A special role for students in the class might be to create the zine cover; this is also an opportunity to partner with art educators.
- Zines are meant to be messy and not crisp or picture-perfect! Students should be encouraged to be creative and break free from perfectionist formatting for their zine page.

Extension Opportunity

A possible extension is to complete a calorimetry lab, which can be used to explore the question: How do we determine the energetic value of food?

This activity uses the following resource:

Jennings, L. (2022). Food calorimetry: How to measure calories in food. Carolina Biological. Accessed April 1, 2022 at: https://www.carolina.com/teacher-resources/Interactive/food-calorimetry+/tr23949.tr.

Additional Resources

Barclay, E. (2015). Navajos fight their food desert with junk food and soda taxes. NPR. Accessed April 1, 2022 at: https://www.npr.org/sections/thesalt/2015/04/01/396607690/navajos-fight-their-food-desert-with-junk-food-and-soda-taxes.

Buss, J. (2020). Diffusion of Water, Glucose, and Starch through a Dialysis Bag [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=0V5Zodwf4K4.

Navajo Nation Department of Water Resources [website], available at: https://www.nndwr.navajo-nsn.gov/.

What is a zine? (2021). University of Texas Libraries. Accessed April 1, 2022 at: https://guides.lib.utexas.edu/c.php?g=576544&p=3977232.

POLLYANNA
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Nutrition Experiments

As you read your assigned article, organize your learning by completing the Four C's below:

What **connections** do you draw between the text and your own life or your other learning?	
What key **concepts** or ideas do you think are important and worth holding on to from the text?	
What **challenges** are presented in the text? What is **challenging** about the text?	
What **changes** in attitudes, thinking, or action are suggested by the text, either for you or others?	

Macromolecules Fact Sheet

Macromolecule:	
Monomer(s):	Polymer(s):
Function(s) in the body:	
Examples:	

Macromolecules Lab

Chemical energy is the fuel that allows the 30 trillion cells in the human body to function so effectively. To store and utilize chemical energy, humans and other living things require four types of large molecules called macromolecules: carbohydrates, proteins, lipids, and nucleic acids. In this lab, you will detect macromolecules in known samples and identify macromolecules in an unknown sample.

Materials

Each lab group will need the following materials:

- 12 test tubes
- Pipettes
- Tube rack
- Glass stirring rod
- Biuret's solution indicator
- Lugol's iodine indicator
- Benedict's solution indicator
- Sudan III solution indicator
- Distilled water
- Vegetable oil
- Protein shake solution
- Pasta juice solution (the liquid that remains after cooking pasta)
- Powerade or Gatorade
- Hot water bath
- Test tube tongs
- Cultural food sample (blended with distilled water)

Method

Create negative controls:

1. Get a test tube rack and place four test tubes in the rack. Label each of the test tubes with one of each of the four indicators and the words Negative Control.

2. Add 1 mL of each type of indicator to its respective test tube.

3. Add 1 mL of distilled water to each test tube.

4. Gently stir the contents of each test tube with a glass stirring rod. Clean off the stirring rod between uses so you do not contaminate the different test tubes. For the sample with Benedict's solution, immerse the bottom of the test tube in a hot water bath for 3-5 minutes after stirring it. (For Benedict's Solution to work, the solution requires heat.) Record what you see in each tube.

Create positive controls:

1. Get a test tube rack and place four test tubes in the rack. Label each of the test tubes with one of each of the four indicators and the words Positive Control.

2. Add 1 mL of each type of indicator to its respective test tube.

3. Sudan III tests for lipids. In the test tube with Sudan III, add 1 mL of vegetable oil and stir the contents of the tube with the glass rod. Record the results and wash the glass rod before the next step.

4. Biuret's solution tests for proteins. In the test tube with Biuret's solution, add 1 mL of protein shake solution and stir the contents of the tube with the glass rod. Record the results and wash the glass rod before the next step.

5. Lugol's solution tests for starch, a type of carbohydrate. In the test tube with Biuret's Solution, add 1 mL of pasta juice solution and stir the contents of the tube with the glass rod. Record the results and wash the glass rod before the next step.

6. Benedict's solution tests for glucose, another type of carbohydrate. In the test tube with Benedict's solution, add 1 mL of Powerade or Gatorade and stir the contents of the tube with the glass rod, then, using the test tube tongs, immerse the bottom of the test tube in a hot water bath for 3-5 minutes. Record what you see in each tube.

Testing your cultural food sample for macromolecules

1. Get a test tube rack and place four test tubes in the rack. Label each of the test tubes with one of each of the four indicators and the words Cultural Food Sample.

2. Add 1 mL of each type of indicator to its respective test tube.

3. Add 1 mL of the cultural food sample water to each test tube.

4. Gently stir the contents of each test tube with a glass stirring rod. Clean off the stirring rod between uses so you do not contaminate the different test tubes. For the sample with Benedict's solution, immerse the bottom of the test tube in a hot water bath for 3-5 minutes after stirring it. Record what you see in each tube.

Results

Based on your test results from this investigation, complete the data table below with your written and drawn observations:

Macromolecule	Negative test result description	Positive test result description	Cultural food sample
Carbohydrates - Simple Sugars			
Carbohydrates - Starch			
Proteins			

Analysis

1. What was the importance of having control groups in this lab?

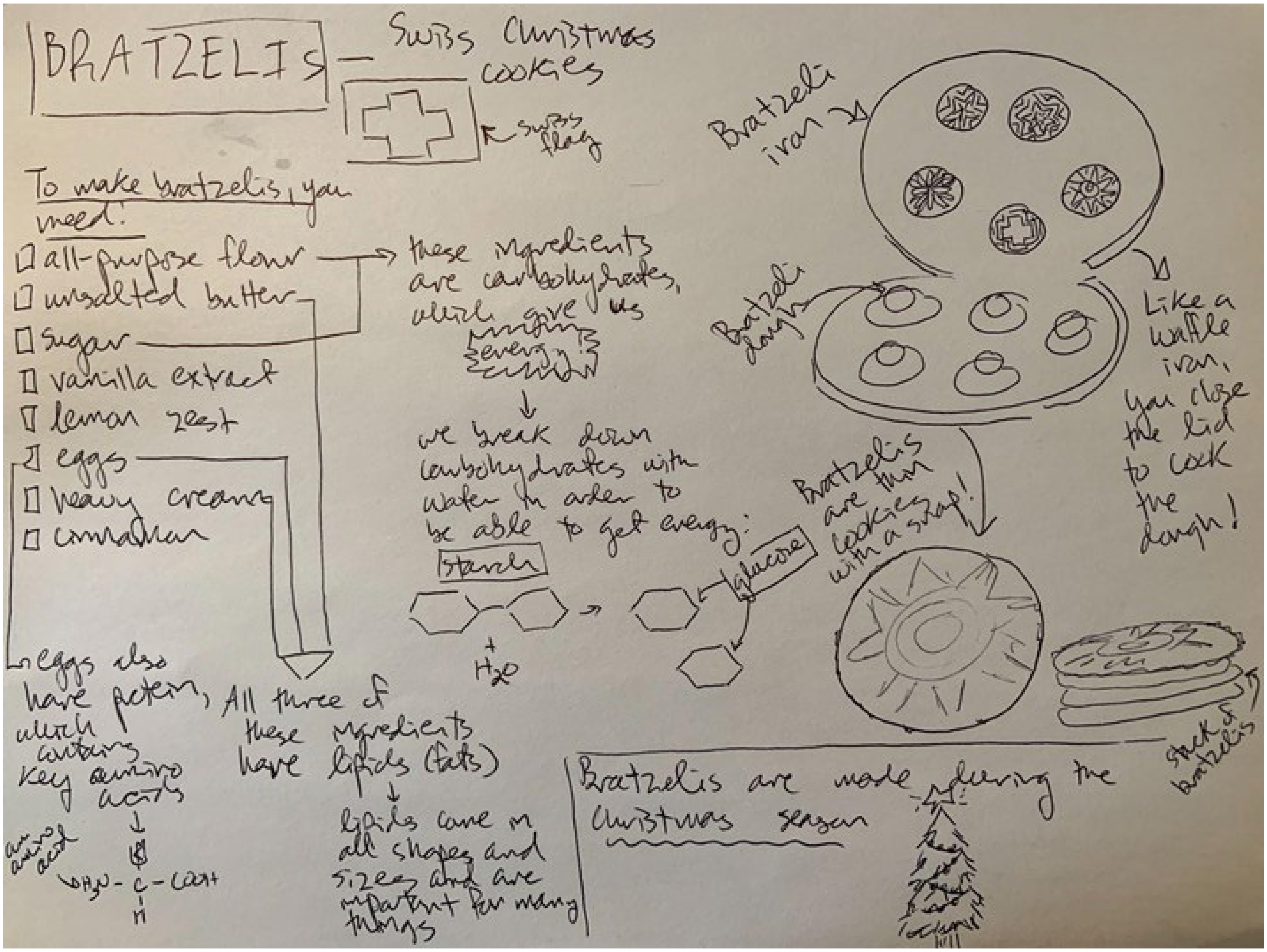
2. Why did we not test for the presence of nucleic acids? Explain.

3. How are macromolecules related to nutrition?

4. What makes the foods evaluated in this lab nutritious? Cite specific evidence to justify your answer.

Appendix: Zine Exemplar Page

This zine page is created with a typical letter size page which can be folded in half to incorporate into the larger zine.



BIOLOGY LESSON 5

EVOLUTION, RACE, AND GENETIC DIVERSITY

Suggested time: Three to four 50-60 minute class periods
Suggested units: Evolution, biodiversity

Overview

In this lesson, students are introduced to phylogenies as a tool for modeling evolutionary relationships, and to the use of molecular data in developing phylogenies. In the opening case study, students will use molecular data to uncover the truth about Thomas Jefferson's relationship with Sally Hemings and her children, exploring topics of race and racism in the process. Students will also use molecular data to explore genetic variation among five human individuals representing three races, discovering along the way that race cannot be determined based on genetic variation. Throughout the lesson, students will use concepts from evolutionary biology to debunk race as a biological concept and consider how we have created social institutions that justify and perpetuate racial inequality.

Objectives

- Students will analyze and interpret phylogenies to understand common ancestry and evolutionary relationships.
- Students will practice constructing phylogenies.
- Students will explore the discrepancies between common definitions of race and the realities of human genetic diversity.

Key Understandings

- Understanding how genes evolve helps us understand why race is a social construct and not a biological concept.

  Possible misunderstanding: Phenotypic traits are coded by genes, and racial categories are based on phenotypic traits; therefore, race is based in biology.

  Possible misunderstanding: If race is not a biological concept, then racism must not be real.
- Science can and should be antiracist. Science is antiracist when it is used to challenge the differential treatment of people of color. When not antiracist, science can be and has been used to harm people of color.

  Possible misunderstanding: Science is neutral and therefore has no relevance to issues of social justice.

Materials

- The life of Sally Hemings. (No date). The Jefferson Monticello. Accessed April 1, 2022 at: https://www.monticello.org/sally-hemings/.
- Internet access
- UniProt [database], available at: https://www.uniprot.org/.
- Chou, V. (2017). How science and genetics are reshaping the race debate of the 2st century [blog]. Harvard University Graduate School of Arts and Sciences. Accessed April 1, 2022 at: https://sitn.hms.harvard.edu/flash/2017/science-genetics-reshaping-race-debate-21st-century/.
- Handouts (included at the end of this lesson):
  - Who Was Sally Hemings?

- Did Thomas Jefferson Father Sally Hemings's Children?
- Creating Phylogenies: Which Differences Matter?

Vocabulary

bi-allelic markers
common ancestry
descent with modification
genome
microsatellites
minisatellites
outgroup
phylogeny
single-nucleotide polymorphisms

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-LS4-1** Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **ID.9-12.2** I know my family history and cultural background and can describe how my own identity is informed and shaped by my membership in multiple identity groups.
- **DI.9-12.10** I understand that diversity includes the impact of unequal power relations on the development of group identities and cultures.
- **DI.9-12.8** I respectfully express curiosity about the history and lived experiences of others and exchange ideas and beliefs in an open-minded way.
- **JU.9-12.13** I can explain the short and long-term impact of biased words and behaviors and unjust practices, laws and institutions that limit the rights and freedoms of people based on their identity groups.

Background Information

Carl Linnaeus, in his attempt to categorize and classify the variation of living things, is famous for categorizing the human species, *Homo sapiens*, into four distinct groups. These groups reflect the beginning of the scientific enterprise of justifying race as a biological concept. Race as a meaningful and significant characteristic took on new life with the adoption of Darwin's theory of natural selection. Darwin did much to encourage this with his explicit proposals of the use of his theory to explain racial differences in *The Descent of Man, and Selection in Relation to Sex*. Natural selection was further used by scientists for decades to come to justify a hierarchical ranking of the races that positioned "Caucasians" at the top of the hierarchy at a time when colonialism required racial divisions to justify the subjugation of those being colonized.

Ever since, there have been exhaustive and thorough debunkings of race as a meaningful biological concept for describing human variation. According to a summary for educators written by Kay Young McChesney, there are six scientifically accepted arguments that reject race as a biologically meaningful and significant classification scheme for humans. These arguments are:

1. People cannot be reliably divided into racial groups.
2. There are no relationships between traits that are used to categorize people into races (like skin color) and associated stereotypes.
3. Over time, geography and environment influence the genetic structures of human populations through natural selection.

4. There is more diversity within racial groups than between racial groups.
5. All people living today are descended from populations that originated in Africa.
6. All people living today are one biological species. (McChesney, 2015)

This lesson introduces and evaluates the first and fourth arguments from this list.

In the handout "Did Thomas Jefferson Father Sally Hemings's Children?" students will examine data from study using genotyping to explore claims about the paternity of Sally Heming's son Eston Hemings (Foster et al., 1998). The following information helps explain these data:

- To explore claims about Eston Hemings's paternity, the researchers genotyped the Y chromosomes of living male-line relatives of Hemings and of each of the possible fathers. Y chromosomes undergo very few changes as they do not experience recombination with homologous chromosomes during meiosis, making Y chromosomes very reliable for tracking paternal lineage. (For tracking maternal lineage, mitochondrial DNA is similarly used, as it also is relatively slow to change and does not experience recombination). Based on these genotypes, the researchers concluded that Thomas Jefferson did in fact father Eston Hemings.
- Additionally, Thomas Jefferson's Y chromosome belongs to a rare European lineage, which makes for an especially important piece of evidence supporting the conclusion that Thomas Jefferson fathered Eston Hemings.
- In genotyping the Y chromosomes, the scientists quantified several bi-allelic genes as markers. The zeros and ones indicate if the genotype of the individual matched the ancestral state (0) or a derived state (1) for the allele.
- The second string of numbers represents the microsatellite short tandem repeats (STRs) which are repeating sequences in the DNA. The number of repeats of each microsatellite sequence is quantified as the genotype or allele of the individual, and these numbers represent the number of repeats for several microsatellite sequences.
- Minisatellite MSY1 quantifies repeating sequences that are longer than microsatellites. As the figure legend in the original paper states "Each number in brackets represents the sequence type of the repeat unit; the number after it is the number of units with this sequence type. For example, J41 has 5 units of sequence type 3, 14 units of sequence type 1, 32 units of sequence type 3, and 16 units of sequence type 4" (Foster et al., 1998).

Note to Teachers

The case study in this lesson involves issues of consent and the nature of the sexual relationship between Thomas Jefferson and Sally Hemings. These issues can be triggering for students who are victims themselves, or who are close to victims, of sexual assault and abuse. Make sure to provide modifications to the assignment if necessary, such as allowing students to read select portions of the resource on The Life of Sally Hemings, or allowing students to take breaks during class when discussing the case study. If you have not already, create community agreements and support those community agreements with regular check-ins and relationship building. For additional guidance on creating classroom norms, see Lesson 1 of the Advisory Curriculum.

Note that for ease of analysis and construction by students, the phylogenies in the "Creating Phylogenies: Which Differences Matter?" handout are constructed as monophyletic trees. For the activity involving elephants, cetaceans, bony fishes, and sharks, a monophyletic tree is not necessarily the most accurate presentation of these relationships, as students will see when they use UniProt to create a tree for these animals using cytochrome b data. However, monophyletic trees are the natural extension of racist human classifications made by early naturalists such as Linnaeus, and therefore are useful for evaluating biological claims about race in the activity investigating human variation. If you feel comfortable and confident in discussing the construction of different types of trees, this is a great place to do so, but otherwise the goal of the activity is to help them understand molecular evidence as considered the more valuable form of data for creating phylogenies and that phylogenies are created by comparing similarities in sequences.

Finally, note that Part 1 of the handout "Creating Phylogenies: Which Differences Matter?" is constructed to reveal the limitations of using morphological and environmental information to construct accurate phylogenies. As a result, students should not be expected to construct accurate phylogenies in this part of the handout, as long as they can explain their reasoning for why they constructed the phylogenies they did.

LESSON PROCEDURE

Day 1: Did Thomas Jefferson Father Sally Hemings's Children?

In advance of this lesson, assign students to review the multimedia presentation The Life of Sally Hemings and fill in the handout entitled "Who Was Sally Hemings?" A brief content warning is included on the webpage, but make sure to prepare yourself and your students for reading about a nonconsensual sexual relationship between Thomas Jefferson and Sally Hemings. For more information, see the Note to Teachers.

1. Open by having students reflect on The Life of Sally Hemings. With a partner or as a class, have students share their responses to the handout entitled "Who Was Sally Hemings?" The prompts from this handout, based on Project Zero's Connect-Extend-Challenge thinking routine, are repeated below:
   - Connect: How does this reading connect to what you have already learned or what you already know?
   - Extend: How does this reading extend your thinking? What new things did you learn from this reading?
   - Challenge: What are challenges presented in this reading? These can be challenges to our thinking and beliefs, challenges to common narratives we have in our culture and society, or challenges to specific ideas.
2. Help students use the case study of Sally Hemings to interrogate the relationship between race and biology. Facilitate a class discussion based on the following prompt:

   What makes a person White, Black, or any other race? Recall that Beverly and Harriet Hemings were able to "pass" as White, and that Sally, Madison, and Eston Hemings were listed as "free white people" in the 1830 census. In addition, note that all the Hemings (including Sally) were parented by a father considered to be White and a mother considered to be Black. What do these facts reveal about how racial categories operate?
3. Explain that, in 1998, researchers performed genetic testing to evaluate whether Thomas Jefferson did indeed father Sally Hemings's son Eston. Students will examine the results of that testing during this class.
4. Distribute the handout entitled "Did Thomas Jefferson Father Sally Hemings's Children?" Carefully review the Background Information section of this handout together as a class, including Figure 1. To complete the activity, students do not need to understand the details of how the bi-allelic genes are coded, but simply that, if two individuals share the same male-line ancestry, they should share the same or very similar sequences for these bi-allelic genes.
5. Once students understand the Background Information, have them work in pairs to answer the Data Analysis questions. Once all students have completed these questions, review their answers as a class.
6. Have students complete the activity in the handout by developing an evidence-based argument in response to the question: Did Thomas Jefferson father Sally Hemings's children?
7. Close by asking students to consider the following questions about the implications of what they have learned in class:

   How does the DNA evidence linking Sally Jennings to Thomas Jefferson require that we re-evaluate cultural narratives about Thomas Jefferson? Why is knowing the full truth about Jefferson important for us as people who live in the United States?

Asynchronous work: Have students complete their argument for homework if they did not do so during class.

Day 2: Introduction to Phylogenies

1. Have students share their arguments from the handout "Did Thomas Jefferson Father Sally Hemings's Children?" with a partner. Then discuss students' arguments as a class and see if you can solicit consensus about whether Thomas Jefferson fathered Sally Hemings's children. In addition, solicit and document questions that arose for students as they worked on their arguments. In response to questions that will not be addressed later in the lesson, provide clarification. For questions that will be addressed later in the lesson, keep them in a "parking

lot" and be sure to return to them when they come up again in the lesson content.

2. If you have not already done so in your biology course, introduce and outline the major concepts related to constructing phylogenies and determining evolutionary relationships. Key concepts to cover include:
    - **Common ancestry:** Descent with modification from a common ancestor is a fundamental assumption of phylogenies. Taxa that are more closely related are said to have a more recent common ancestor compared to groups that are more distantly related. Because of descent with modification, there will be differences even among closely related groups; however, the degree of change matters for constructing how recent the common ancestor of the taxa existed. Phylogenies assume a relatively constant rate of change (sometimes quantified as a molecular clock).
    - **Outgroup:** Phylogenetic trees, and monophyletic trees in particular, are constructed with an outgroup that serves as a point of comparison. Typically the outgroup is so different that it helps to clarify the similarities among the "in-group" taxa.
    - **Phylogenetic evidence:** Many types of evidence have been used to construct phylogenies. Before the availability of biotechnology, morphology, behavior, and fossils were used to assess evolutionary relationships; however, these forms of evidence have sometimes led scientists to make many false based on convergent evolution and analogous structures. Molecular data can reveal unintuitive relationships, such as that between elephants and cetaceans, who diverged only very recently from a common ancestor.
    - **Species:** The most widely used species concept is the biological species concept, which defines a species based on its reproductive isolation. If two individuals cannot produce viable, fertile offspring, those individuals are considered to be two different species. Horses and donkeys creating mules are a classic example of viable but not fertile offspring.
    - **Subspecies:** Populations of the same species with significant genetic variation and with distinct geographic isolation count as subspecies. These are populations that are in some sense on their way to becoming distinct and separate species given enough time and consistent isolation.
3. Distribute the handout entitled "Creating Phylogenies: Which Differences Matter?" In pairs or small groups, have students complete the activities in the handout, checking their answers with you and asking questions along the way. After each section of the activity, students are instructed in the handout to stop and check their work with you.

Asynchronous work: If students do not complete the activities in the handout "Creating Phylogenies: Which Differences Matter?" during class, have them complete these activities for homework.

Day 3: Analyzing Phylogenies

1. Review the major concepts from the previous class, including what phylogenies are, how they are created, how morphological and molecular data compare for constructing phylogenies, and common ancestry.
2. Have students reflect on their work in Part 3 of the handout "Creating Phylogenies: Which Differences Matter?" and ask them to discuss whether they can tell which individuals share the same race, and what predictions they have for shared races among the samples.
3. Show students the people behind three of the samples and discuss what it means for Kim (SJK in the data) to be more closely related to Watson than Venter (HuRef in the data) is. Can we reliably know a person's race from their genetics? What does this mean for whether or not race is a meaningful and significant way of describing human variation?
4. Have students read the article How Science and Genetics are Reshaping the Race Debate of the 21st Century. Then have students turn and talk with a partner, using the information in this article and their work from the handout "Creating Phylogenies: Which Differences Matter?" to explain to their partner why, as Vivian Chou writes, scientists prefer the concept of ancestry to the concept of "race" for understanding human diversity.

5. Introduce students to the Demonstration of Learning activity, which students will complete asynchronously. Then have students summarize their learning from this lesson with a short reflection using Project Zero's I used to think... Now I think... thinking routine.

Demonstration of Learning

Have students write an essay responding to the following prompt:

> Sally Hemings was an enslaved woman, but Eston Hemings went on to enter White society in Madison, Wisconsin. Similarly, Sally Hemings's daughters entered White society. How is it possible that a Black woman can have children who pass as White? How does this complicate what we think determines a person's race? Our goal is to better understand the extent to which race is a biologically meaningful and significant way of classifying populations of humans. In order to be a meaningful and significant way of classifying populations of humans, race needs to be able to consistently and reliably explain human variation and have a usefulness in predicting the race of an individual. What does this case study tell us about the reliability and usefulness of race as a biological category?

Students should support any claims they make using evidence from the activities they completed during this lesson. In particular, students should be sure to describe and explain why ancestry is not synonymous with race, and why simple morphological traits, such as skin color (a proxy for race), do not predict how closely related individuals are.

Extension Opportunities

- For advanced biology courses, students can engage in an argumentation activity using primary literature that evaluates the distribution of genetic variation among populations and among races. Consider providing students with sources such as published literature on genetic variation and on the subspecies definition of race. This activity extends students' learning beyond NGSS but can be useful for practicing key science and engineering skills, especially in evaluating data and constructing arguments.

  Suggested primary literature includes:

  Barbujani, G., Magagni, A., Minch, E., & Cavalli-Sforza, L. L. (1997). An apportionment of human DNA diversity. *Proceedings of the National Academy of Sciences,* 94: 4516-4519; https://doi.org/10.1073/pnas.94.9.4516.

  Lewontin, R. C. (1972). The Apportionment of Human Diversity. In: T. Dobzhansky, M. K. Hecht & W. C. Steere (Eds), *Evolutionary Biology.* Springer. https://doi.org/10.1007/978-1-4684-9063-3_14.

  Templeton, A.R. (2013). Biological races in humans. *Studies in History and Philosophy of Biological and Biomedical Sciences*, 44: 262–271. https://dx.doi.org/10.1016%2Fj.shpsc.2013.04.010.

- Students can investigate the use of "blood quantum" by the federal government for defining American Indian identity. Students can write persuasive essays describing why blood quantum is neither a biologically meaningful description of Native identity nor an ethical approach to determining Native affiliation. The following resources may be useful for this activity:

  Chow, Kat. (2018). So what exactly is 'blood quantum'? Code Switch, NPR. Accessed April 1, 2022 at: https://www.npr.org/sections/codeswitch/2018/02/09/583987261/so-what-exactly-is-blood-quantum.

  Harmon, M. (2021). Blood quantum and the White gatekeeping of Native American identity. California Law Review. Accessed April 1, 2022 at: https://www.californialawreview.org/blood-quantum-and-the-white-gatekeeping-of-native-american-identity/.

  Hilleary, C. (2021). Some Native Americans fear blood quantum is formula for 'paper genocide'. Voice of America. Accessed April 1, 2022 at: https://www.voanews.com/a/usa_some-native-americans-fear-blood-quantum-formula-paper-genocide/6208615.html.

Additional Resources

Understanding Evolution [website], available at: https://evolution.berkeley.edu/evolution-101/.

This website provides accessible explanations for a variety of evolutionary concepts.

Torres J. B., Doura M. B., Keita S. O. Y., Kittles R. A. (2012). Y chromosome lineages in men of West African descent. *PLOS One* 7(1): e29687. https://doi.org/10.1371/journal.pone.0029687.

This study indicates that 30-40% of Black men in America have Y chromosomes of European ancestry, indicating the extensive rape of enslaved women by White slave owners.

King, T. E., Bowden, G. R., Balaresque, P. L., Adams, S. M., Shanks, M. E., & Jobling, M. A. (2007). Thomas Jefferson's Y chromosome belongs to a rare European lineage. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, 132(4), 584-589. https://doi.org/10.1002/ajpa.20557.

References

Ahn, S. M., Kim, T. H., Lee, S., Kim, D., Ghang, H., Kim, D. S., Kim, B. C., Kim, S. Y., Kim, W. Y., Kim, C. & Park, D. (2009). The first Korean genome sequence and analysis: full genome sequencing for a socio-ethnic group. *Genome research*, 19(9), 1622-1629. https://doi.org/10.1101/gr.092197.109.

Foster, E. A., Jobling, M. A., Taylor, P. G., Donnelly, P., de Knijff, P., Mieremet, R., Zerjal, T., & Tyler-Smith, C. (1998). Jefferson fathered slave's last child. *Nature*, 396: 27-28. https://doi.org/10.1038/23835.

McChesney, K. Y. (2015). Teaching diversity: The science you need to know to explain why race is not biological. *SAGE Open*. https://doi.org/10.1177/2158244015611712.

Who Was Sally Hemings?

Read and explore: The Life of Sally Hemings. As you read, fill in the table below with your responses to the prompts.

Please note: This resource evaluates issues of consent and the nature of the sexual relationship between Thomas Jefferson and Sally Hemings. Though academic in nature, it is important acknowledge that the violence inherent to such a sexual relationship can be triggering to many, especially if unexpected. Please connect with your teacher in approaching this reading and discuss any needed support or modifications.

Connect: How does this reading connect to what you have already learned or what you already know?	
Extend: How does this reading extend your thinking? What new things did you learn from this reading?	
Challenge: What are challenges presented in this reading? These can be challenges to our thinking and beliefs, challenges to common narratives we have in our culture and society, or challenges to specific ideas.	

Did Thomas Jefferson Father Sally Hemings's Children?

Background Information

Researchers pursued the claims that Thomas Jefferson was the father of Sally Hemings's last child, Eston Hemings. To do this, they compared three sets of genetic sequences on the Y-chromosomes of (1) the living male-line descendant of Eston Hemings and (2) the living relatives who share male-ancestry with Thomas Jefferson.

Y-chromosomes undergo very little change over time and are passed from father to son. Thomas Jefferson had no male offspring. However, Jefferson's brother's male-line descendants were sampled as they reliably have the same Y-chromosome sequence that Thomas Jefferson himself had. It is also documented that the Jefferson family have an incredibly rare Y-chromosome sequence (called a haplotype), that is present in a frequency of approximately 0.1% of the population.

A counterclaim by historians who do not believe that Thomas Jefferson fathered Sally Hemings's children is that her children were instead fathered by one of Jefferson's nephews, his sister's sons, Samuel and Peter Carr. Note that these sons would not share a Y-chromosome with Jefferson since they inherited their Y-chromosomes from their father, who was not related to Jefferson. To test this counterclaim, the researchers also included the genetic sequences from the Carr's male-line descendants in their comparisons.

In genotyping the Y-chromosomes, the researchers sequenced (1) seven bi-allelic markers (genes with two possible alleles), (2) eleven microsatellites (repeating DNA sequences, where the number of repeats is measured), and (3) a small genetic sequence termed a minisatellite, named MSY1, also containing multiple repeating sequences. None of these sequences are coding sequences, meaning they do not actually code for proteins.

The figure below shows the results of the Y-chromosome genotyping.

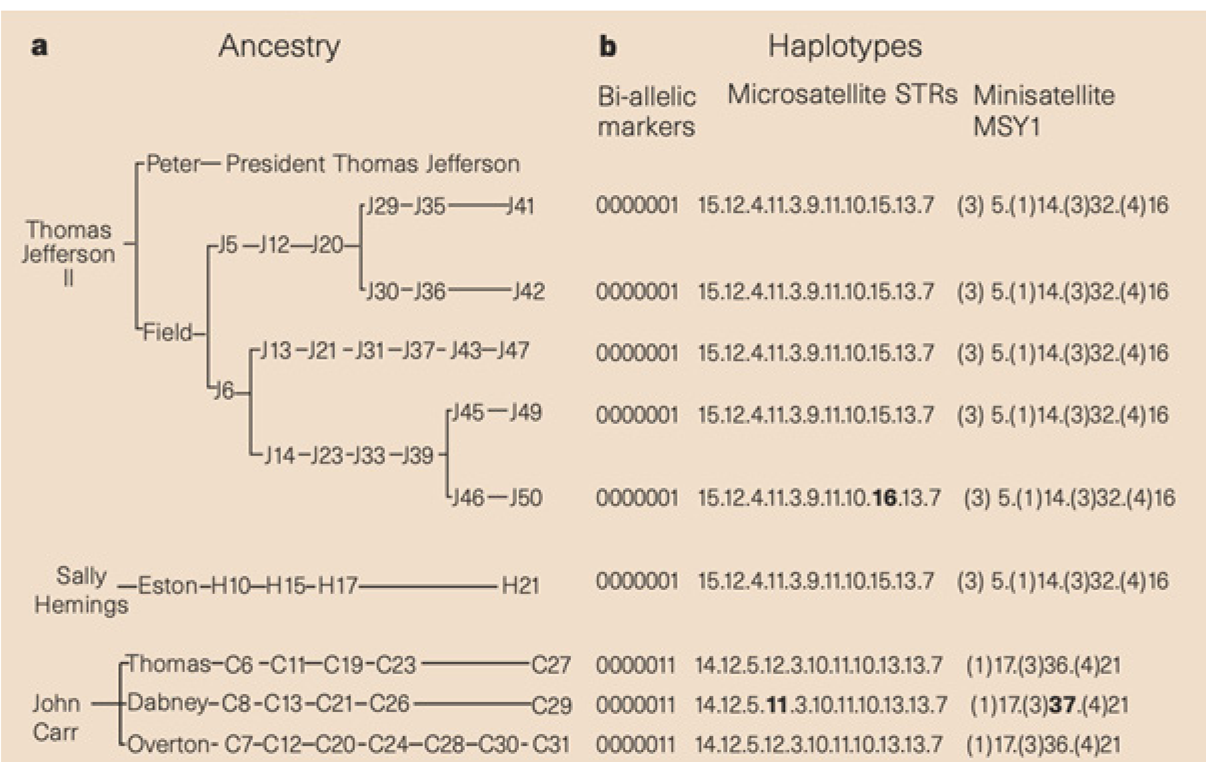


Figure 1 Male-line ancestry and haplotypes of participants. **a**, Ancestry. Numbers correspond to reference numbers and names in more detailed genealogical charts for each family. **b**, Haplotypes. Entries in bold highlight deviations from the usual patterns for the group of descendants. **Bi-allelic markers.** Order of loci: YAP-SRYm8299-sY81-LLY22g-Tat-92R7-SRYm1532. 0, ancestral state; 1, derived state. **Microsatellite short tandem repeats (STRs).** Order of loci: 19-388-389A-389B-389C-389D-390-391-392-393-dxys156y. The number of repeats at each locus is shown. **Minisatellite MSY1.** Each number in brackets represents the sequence type of the repeat unit; the number after it is the number of units with this sequence type. For example, J41 has 5 units of sequence type 3, 14 units of sequence type 1, 32 units of sequence type 3, and 16 units of sequence type 4.

Data Analysis

Use the figure above to answer each of the following questions.

1. H21 is the male descendent of Sally Hemings and Eston Hemings. Of the two potential paternal lines (Jefferson versus Carr), H21's bi-allelic markers match which family lines? How do you know?

2. Of the two potential paternal lines (Jefferson versus Carr), H21's microsatellite markers match which family lines? How do you know?

3. Of the two potential paternal lines (Jefferson versus Carr), H21's minisatellite MSY1 matches which family lines? How do you know?

4. Since Y-chromosomes are only inherited from one's father, where did the Y-chromosome of H21 come from?

5. How do these data support or reject the claim that Thomas Jefferson was the father of Eston Hemings?

Develop an Evidence-Based Argument

Respond to the question below using the claim-support-question argument template provided:

Question: Did Thomas Jefferson father Sally Hemings's children?

Claim Develop a one-sentence answer to the question:
Support Provide evidence and scientific reasoning to support your claim:
Questions List any questions you still have:

Data source: Foster, E. A., Jobling, M. A., Taylor, P. G., Donnelly, P., de Knijff, P., Mieremet, R., Zerjal, T., & Tyler-Smith, C. (1998). Jefferson fathered slave's last child. *Nature*, 396: 27-28. https://doi.org/10.1038/23835.

Creating Phylogenies: Which Differences Matter?

Biological classification involves determining the evolutionary relationships between organisms. Scientists determine how similar or different organisms are, and then use those similarities and differences to create models that represent the evolutionary relationships among these organisms. These models are called phylogenies.

We can create evolutionary relationships for different scales of organisms. We can represent evolutionary relationships between species, subspecies, populations, and even families and individuals (often shown as family trees or pedigrees). Phylogenies represent evolutionary relationships by representing common ancestry. Common ancestry is the concept that two organisms descend from a common ancestor that lived at some point in the past. For species, this means that at some point in the past, there was one species of the common ancestor but, since then, distinct populations from that original species have evolved and diverged into two separate species. Populations of the same species with significant genetic variation and with distinct geographic isolation are considered subspecies. Subspecies are populations that in some sense are on their way to becoming distinct and separate species, given enough time and consistent isolation.

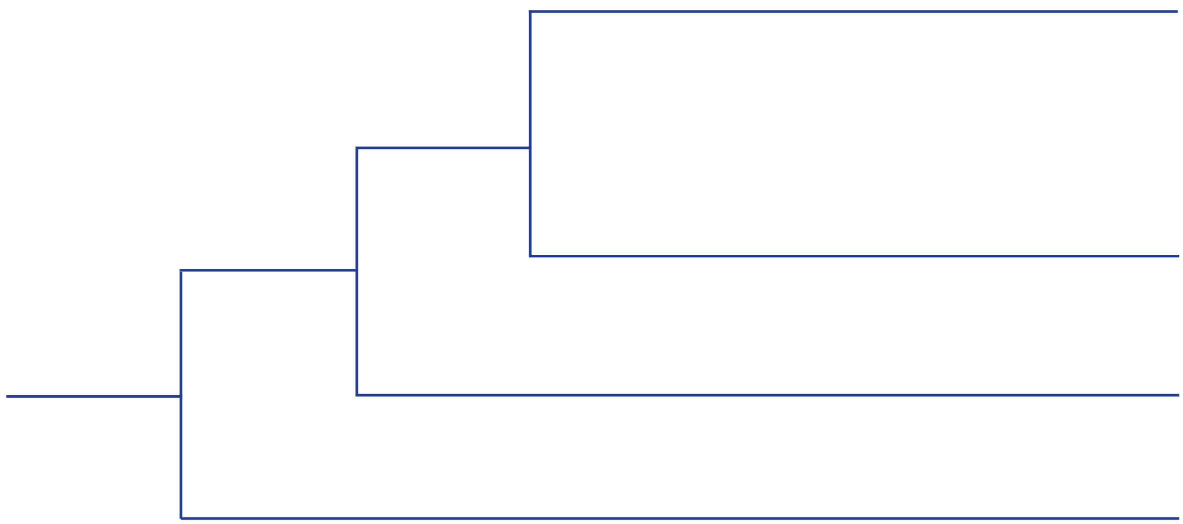
Part 1: Creating a Phylogenetic Tree Using Morphological and Ecological Traits

How do we know how to classify organisms? We have to recreate evolutionary relationships using our best available data and the assumption that the more closely related two organisms are, the more they will share similar features due to their more recent common ancestor. Biologists have grappled with how to know which kinds of data are most reliable and which phylogenies are the most accurate. Before scientists had access to molecular data, biologists would classify organisms based on information about their environments and morphologies.

Consider the following groups of organisms, example organisms from each group, and their environments and morphologies:

Elephants	Cetaceans	Bony fish	Sharks (cartilaginous fish)
• *Loxodonta africana* (African elephant) • Elephas maximus (Indian elephant) • Live on land • Have four legs and a trunk • Can swim for up to six hours at a time • Internal fertilization • Birth live offspring • Asian elephants undergo menopause, but African elephants do not	• *Tursiops truncatus* (Atlantic bottle-nosed dolphin) • Hyperoodon ampullatus (Northern bottlenose whale) • Orcinus orca (Killer whale) • Live in salt water • Have fins and flippers • Internal fertilization • Birth live offspring • Orcas undergo menopause but other whales and dolphins do not	• *Salmo salar* (Atlantic salmon) • Thunnus albacares (Yellowfin tuna) • Tuna live in salt water, salmon live in both salt water and fresh water depending on reproductive stage • Have fins • Reproduce by laying eggs with external fertilization	• *Galeocerdo cuvier* (Tiger shark) • Ginglymostoma cirratum (Nurse shark) • Live in salt water • Have fins • Internal fertilization • Birth live offspring

Your task: Use the information from the table above to label where you think the four groups of organisms go on the phylogeny below:



Part 1 Analysis Questions

1. Which two groups are the most closely related in the phylogeny you constructed? Which traits did you use to place organisms together as sister taxa on your phylogeny?

2. If you made a phylogeny based on habitat only (i.e., live on land versus in the water), which groups would be the most closely related to each other? What do you see as the pros and cons of such a phylogeny?

---------------------STOP: Check your work with your teacher before moving on---------------------

Part 2: Creating a Phylogenetic Tree Using Sequence Alignment With UniProt

These days, most phylogenies are created using molecular data: DNA sequences, RNA sequences, and protein sequences.

Cytochrome b is a key protein of the electron transport chain and is critical to cellular respiration. We can use the amino acid sequence of cytochrome b to construct a phylogeny using BLAST alignment tools. BLAST alignments compare amino acid sequences and align those most similar together into clades on a tree.

Your task: Make a phylogenetic tree using molecular data by following the steps below:

1. Go to the homepage for UniProt (https://www.uniprot.org/).
2. Using the search bar at the top of the UniProt homepage, look up the cytochrome b sequence for orcas (also called killer whales) using either the entry or the entry name listed in the first row of the table below.
3. On the entry page you can view lots of information, including the amino acid sequence for this protein, a model of its structure, and other references. At the top of the page, under the entry name, click the button labeled "Add to basket."

4. Repeat this process for each of the remaining sequences in the table below.
5. Once all sequences have been added to your basket, click “Basket” in the top right-hand corner of the screen. Using the checkmark box to the left of each entry in your basket, check all the entries and then click “Align.”
6. You will be taken to a new screen showing that the alignment is “running.” The algorithm is working to match bases and create a webpage of the data analyzed. This may take a several minutes to complete.
7. Once the completed job has loaded, you can view the sequences side-by-side, including where their bases align or where some sequences are missing bases compared to other species.
8. Scroll down to the section labeled “Tree” and evaluate the phylogenetic tree created from the cytochrome b sequences. If helpful, take a screenshot of the tree to use for analysis.

Table 1. Entry code, entry name, and description for cytochrome b sequences to be used in UniProt activity.

Entry	Entry name	Description
Q9TDM5	CYB_ORCOR	Cytochrome b sequence for *Orcinus orca* (Killer whale)
Q9TDK1	CYB_TURAD	Cytochrome b sequence for *Tursiops aduncus* (Indo-pacific bottle-nosed dolphin)
P34868	CYB_GALCU	Cytochrome b sequence for *Galeocerdo cuvier* (Tiger shark)
P24958	CYB_LOXAF	Cytochrome b sequence for *Loxodonta africana* (African elephant)
Q9TDJ9	CYB_TURTR	Cytochrome b sequence for *Tursiops truncatus* (Atlantic bottle-nosed dolphin)
Q35925	CYB_SALSA	Cytochrome b sequence for *Salmo salar* (Atlantic salmon)
O48885	CYB_ELEMA	Cytochrome b sequence for *Elephas maximus* (Indian elephant)
Q36560	Q36560_THUTH	Cytochrome b sequence for *Thunnus thynnus* (Atlantic bluefin tune)
A0A342KAX5	A0A342KAX5_GINCI	Cytochrome b sequence for *Ginglymostoma cirratum* (Nurse shark)

Part 2 Analysis Questions

1. How does the cytochrome b phylogeny compare to the phylogeny you created without molecular data? What is similar and what is different between the two trees?

2. Which groups of species (elephants, cetaceans, bony fish, and sharks) are most closely related to each other, according to the cytochrome b phylogeny?

3. The molecular data reflects the proteins created from DNA sequences. DNA sequences are altered due to evolutionary changes such as mutations, but the fact that all living things contain DNA is considered evidence of common ancestry. How do similarities in DNA, RNA, and protein sequences indicate common ancestry? Why does this make molecular data so valuable for creating phylogenies?

----------------------STOP: Check your work with your teacher before moving on----------------------

Part 3: Creating Phylogenies of Human Genomes

Since the sequencing of the first human genome, sequencing entire genomes has proven fruitful for understanding the architecture of the human genome and the organization of genetic diversity among populations of humans.

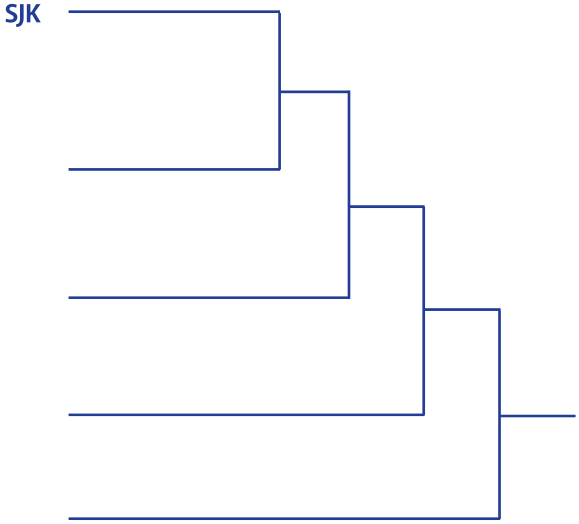
In genome research, single nucleotide polymorphisms (SNPs) are a meaningful form of diversity for evaluating human genetic diversity and the reconstruction of human migration and evolution patterns. SNPs are differences in genetic sequences at single nucleotides and are the most common form of genetic variation among people. In a study of representative genomes from three different races, the following table shows the number of SNPs in common between the genomes evaluated. We can use the number of common SNPs as a proxy for the degree of overlap among DNA sequences (called sequence similarity).

Table 2. Number of sequences of single-nucleotide polymorphisms shared among representative full genomes of five individuals (SJK, HuRef, Watson, NA18507, and YH). Adapted from Ahn et al. (2009), https://doi.org/10.1101/gr.092197.109.

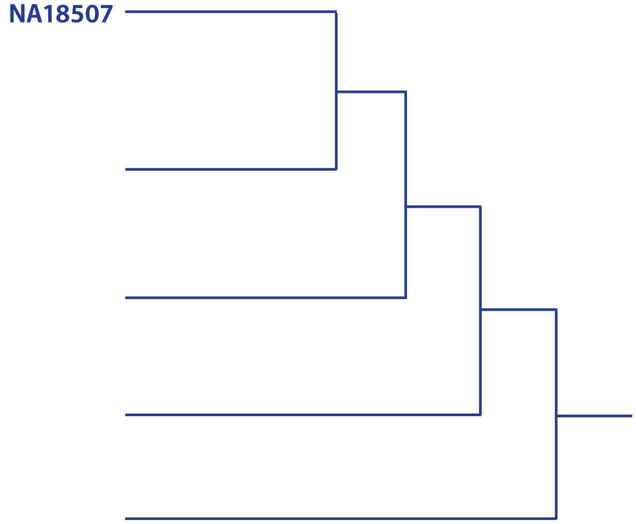
	SJK	**HuRef (Venter)**	**Watson**	**NA18507**	**YH**
SJK		1,736,340	1,824,482	1,920,025	2,039,636
HuRef (Venter)			1,715,851	1,625,971	1,586,616
Watson				1,689,234	1,660,234
NA18507					1,762,775
YH					

Your task: Organize the information from Table 2 into phylogenies. To create a phylogeny, you need a starting point. In this case, we start with one of the sample genomes and work backwards from most related genomes to least related genomes. For each of the phylogenies below, your starting sample is given. Complete the rest of each phylogeny using the data from Table 2.

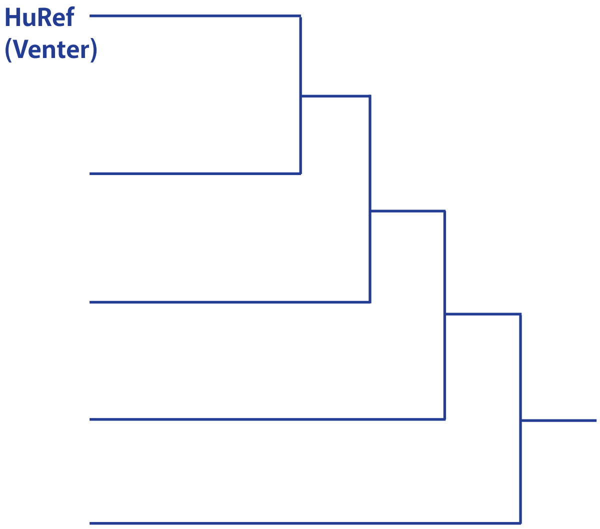
Phylogeny A



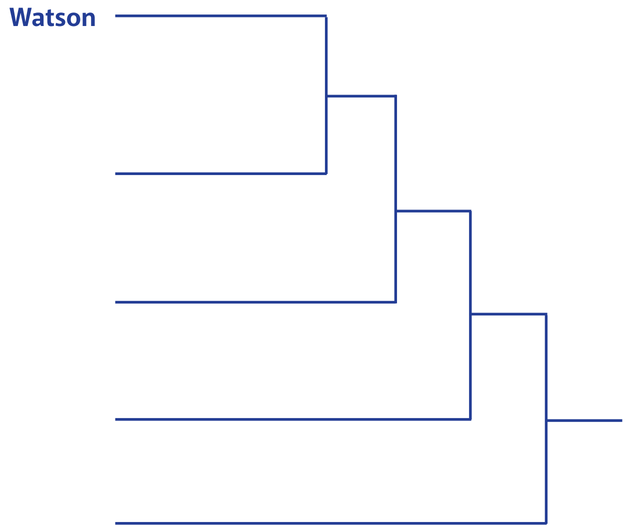
Phylogeny B



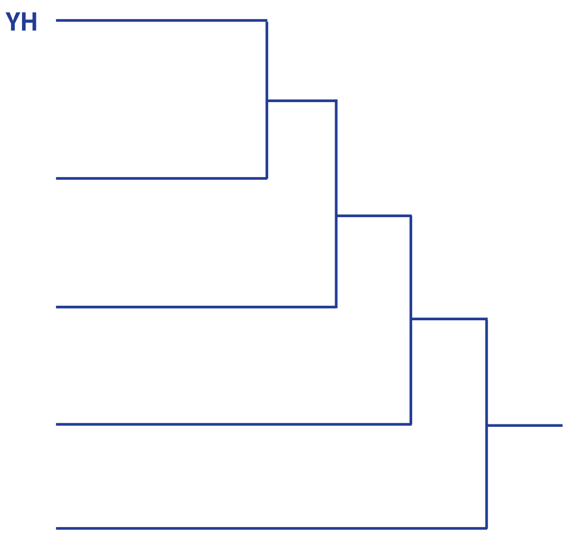
Phylogeny C



Phylogeny D



Phylogeny E



Part 3 Analysis Questions

1. Do these phylogenies agree with each other? How do you know?

2. Given the total number of SNPs in common among these five individuals, which phylogeny would you expect to be the most meaningful and significant in determining similarities? Explain your reasoning.

3. The five genomes represent five humans who we would socially and culturally assign to three races. Based on the phylogenies you created, would you be able to accurately group together the samples into three distinct groups? Why or why not? What criteria would give you a sense of which samples to group together?

BIOLOGY LESSON 6

HUMAN EVOLUTION, POPULATION GENETICS, AND ADAPTATION

Suggested time: Three to four 50-60 minute class periods
Suggested units: Evolution, biodiversity

Overview

In this lesson, students will investigate the evolution of skin color along clines and discover how both convergent evolution and the widespread migration of humans throughout the planet account for the phenotypic diversity we see among humans today. Students will explore examples of microevolution among human populations due to unique selection pressures and understand how microevolution is different from macroevolution. Students will learn that the phenotypic traits we associate with race are examples of microevolution, not of macroevolution, and thus why race is problematic as a biological construct for understanding the human species. Students will also learn how to determine whether a trait meets the biological standards required to be designated as an adaptation. Finally, students will disentangle skin color and the other phenotypic traits we associate with race from the evolution of genetic diseases such as sickle-cell anemia, cystic fibrosis, and heritable cancers due to BRCA mutations.

Objectives

- Students will learn that skin color is not a fixed trait but instead represents the evolution of human populations as they migrated out of Africa and met unique selection pressures.
- Students will analyze and evaluate the convergent evolution of adaptive traits that can be found in human populations across different races and continents.
- Students will use principles of natural selection to construct arguments about whether certain traits qualify as adaptations.
- Students will disentangle ancestry from race and use biological principles to refute racialized assumptions about diseases.

Key Understandings

- Understanding how genes evolve helps us understand why race is a social construct and not a biological concept.

  Possible misunderstanding: Phenotypic traits are coded by genes, and racial categories are based on phenotypic traits; therefore, race is based in biology.

  Possible misunderstanding: If race is not a biological concept, then racism must not be real.

- Evolution is a slow process that allows organisms to adapt to their environments due to mutations that can be inherited through sexual reproduction. This process is not driven by a purpose or a conscious force acting to create perfection, but simply reflects traits that have been successful in the past. Natural selection does not follow moral standards or rules.

  Possible misunderstanding: Evolution is intent in selecting the best organisms to survive. Populations with high amounts of one race are selected to live because they are the best suited to survive. Natural selection produces perfection and "more" evolution is a good thing.

- Science can and should be antiracist. Science is antiracist when it is used to challenge the differential treatment of people of color. When not antiracist, science can be and has been used to harm people of color.

Possible misunderstanding: Science is neutral and therefore has no relevance to issues of social justice.

Materials

- McKie, R. (2018). Cheddar Man changes the way we think about our ancestors. *The Guardian*. Accessed April 1, 2022 at: https://www.theguardian.com/science/2018/feb/10/cheddar-man-changed-way-we-think-about-ancestors.
- Vox. (2015). The myth of race, debunked in 3 minutes [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=VnfKgffCZ7U.
- A fish of a different color. (2013). UC Museum of Paleontology Understanding Evolution. Accessed April 1, 2022 at: https://evolution.berkeley.edu/evo-news/a-fish-of-a-different-color/.
- TED-Ed. (2019). How this disease changes the shape of your cells [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=hRnrIpUMyZQ.
- Sickle cell disease (SCD): Mimi's story. (2021). Centers for Disease Control and Prevention. Accessed April 1, 2022 at: https://www.cdc.gov/ncbddd/sicklecell/stories/mimi.html.
- Hebda, D. (2021). Free at last: One medical mystery solved, a couple turns to helping others. *Arkansas Democrat Gazette*. Accessed April 1, 2022 at: https://noaacf.org/wp-content/uploads/2021/12/Free-at-last-One-medical-mystery-solved-a-couple-turns-to-helping.pdf.

Vocabulary

adaptation
ancestry
cline
convergent evolution of traits
macroevolution
microevolution
natural selection
phenotype
race

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-LS4-2** Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- **HS-LS4-3** Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- **HS-LS4-4** Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **DI.9-12.10** I understand that diversity includes the impact of unequal power relations on the development of group identities and cultures.
- **DI.9-12.8** I respectfully express curiosity about the history and lived experiences of others and exchange ideas and beliefs in an open-minded way.

- **JU.9–12.13** I can explain the short and long-term impact of biased words and behaviors and unjust practices, laws and institutions that limit the rights and freedoms of people based on their identity groups.

Background Information

While biological ideas about race continue to persist, there have been exhaustive and thorough debunkings of race as a meaningful biological concept for describing human variation. According to a summary for educators written by Kay Young McChesney, there are six scientifically accepted arguments that reject race as a biologically meaningful and significant classification scheme for humans. These arguments are:

1. People cannot be reliably divided into racial groups.
2. There are no relationships between traits that are used to categorize people into races (like skin color) and associated stereotypes.
3. Over time, geography and environment influence the genetic structures of human populations through natural selection.
4. There is more diversity within racial groups than between racial groups.
5. All people living today are descended from populations that originated in Africa.
6. All people living today are one biological species. (McChesney, 2015)

This lesson introduces and evaluates the second and third arguments from this list.

Notes to Teachers

This lesson expects students have already learned the elements of evolutionary theory. Specifically, students will need to understand the following concepts:

- Adaptation
- Convergent evolution
- Genetic drift
- Founder events
- Negative selection
- Selection pressure

It is also important to be aware of and actively address misconceptions about evolution while students are completing this lesson. Common misconceptions about evolution include:

- *Organisms are "trying" to evolve.* You can counter this claim with questions such as: Do we see these traits in all geographic locations where relevant selection pressures are present? Why not? What does this tell us about natural selection? Here it is important to reiterate that existing variation is needed for natural selection to occur.
- *Some populations are "more evolved" and therefore "more advanced" than others.* Note that this kind of logic is often used by white supremacist groups. Remind students that evolution is just a reflection of past fitness, not a reflection of some objective standard of perfection.
- *All traits are adaptations.* Traits can evolve for many reasons and due to many factors. Sometimes, traits do not evolve as adaptations but later become advantageous when appropriated for new functions and purposes in an organism. For more on adaptationism, we recommend reading Stephen Jay Gould and Richard Lewontin's paper "The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme."

LESSON PROCEDURE

Day 1: What Is Race?

1. Open by having students discuss and consider what we look for to classify someone as a certain race. Guide them through this discussion by asking the questions below and documenting their responses on a whiteboard or digital platform, such as Google Docs or Padlet.
   - What is race? How would you define race?
   - What information do we use to determine a person's race? Note that two people might have the same skin color, yet we might classify them as different races (e.g., one as Black and the other as South Asian, one as Pacific Islander and the other as Latinx, one as White and the other as East Asian, and so on). In addition to skin color, what other traits do we look for when making these distinctions?
   - Where do these features "come from?" Why do different populations of humans have different phenotypes? Why do different populations of humans have different skin colors?
   - How constant have these phenotypes been throughout human history? Have humans always looked this way and been able to be distinguished from each other by these traits?
   - What do these phenotypic traits tell us about a person? Beyond their race, what else do we assume?
   - Are ancestry and race the same thing? If they are different, how are they different? How are these concepts related to geography, if at all?

   This conversation may serve as an opportunity to discuss why the question "Where are you from?" can serve to alienate people of color by casting them as "other."
2. Tell students about Cheddar Man, a fossil of a male human found in Cheddar Gorge in England. Found in 1903, Cheddar Man is approximately 10,000 years old. DNA was successfully extracted from Cheddar Man in 2018. Researchers were able to analyze the genome and determine the skin color and eye color of Cheddar Man by comparing known genes to current human populations. Using this method to create a forensic facial reconstruction of the fossil, anthropologists can get a sense of Cheddar Man's appearance. Based on this information, ask students to predict what Cheddar Man will look like. Have students draw or write down their predictions about Cheddar Man's phenotype.
3. After students have made their predictions, show them the forensic reconstruction of Cheddar Man. Point out that, based on correlations to modern-day phenotypes, Cheddar Man likely had blue or green eyes, lactose intolerance, dark curly or wavy hair, and very dark skin. The discovery of Cheddar Man challenged what biological anthropologists previously believed about the evolution of certain human traits. We now know that these features were typical of humans in Western Europe at the time. Lighter skin evolved in the Middle East with the advent of agriculture and settled communities, in contrast to the nomadic, hunter-gatherer lifestyle of people like Cheddar Man.
4. Have students read the Cheddar Man changes the way we think about our ancestors in small groups and answer the following questions:
   - What advantage does light skin give people living in places like modern-day England? How were British ancestors such as Cheddar Man able to survive in these places with dark skin?

     Possible student response: The major challenge of darker skin at higher latitudes is the inability to synthesize vitamin D from UV light. It is likely that Cheddar Man was a part of hunter-gatherers who relied heavily on fishing. Fish are a source of large amounts of vitamin D, thus darker skin would not be selected against at these latitudes if able to acquire vitamin D from food.
   - Cheddar Man, together with other evidence, helps demonstrate that constant migration and admixture among human populations has been the norm throughout most of human history. Why is this important?

     Possible student response: Human traits such as skin color follow gradual clines that mirror the gradual *changes of environment factors, not sharp boundaries. The evolution of skin color is not due to genetic isolation but rather constantly in flux for populations as alleles are introduced or leave a population.*

- Modern-day British people share about 10% of their genetic ancestry with Cheddar Man. What does this fact tell us about the differences between ancestry and race, and about how these two concepts relate to geography?

  Possible student response: Cheddar Man helps demonstrate how race and ancestry are not the same thing. The dark-skinned people of the British Isles are ancestors to modern day British people but we would not consider them the same race. Ancestry describes the regional, local population from which one's ancestors came, but those populations are forever shifting in their boundaries and identities. Ancestry is not a fixed identity or concept. The example of Cheddar man helps demonstrate how both ancestry and race are not permanently tied to geography, even if geography does influence changes in phenotype over time.

5. Ask students to return to the question: What is race? How would they define Cheddar Man's race? Is it possible to assign Cheddar Man a race, and, if not, what does that tell us about what race is?
6. Show students the video The myth of race, debunked in 3 minutes (3:07 minutes). As they watch, have students write down any information they hear that can help them define race, as well as any information that challenges how race is typically defined. After watching the video, help students understand that race is not a meaningful biological category; there is no single gene or set of genes that we can use to determine a person's race. Rather, race is a social concept, and its definition and usage has changed throughout history.
7. Gather a collection of relevant evidence for students to examine as they consider an explanation for the evolution of skin color. Such evidence might include a map of UV radiation exposure around the world, a diagram showing the relationship between UVB radiation and the synthesis of Vitamin D, and so on. Have students examine the evidence and try to construct an explanation using the Explanation Game thinking routine. As they play, ask students to consider the question: What explains the skin color of local populations by latitude?

   To use this routine, solicit responses from students that complete the sentence stems "I notice that..." and then have them ask each other "Why is it that way?" in response. You will need to complete several rounds of these responses to construct a class explanation.

   Sample student response:

   Student 1: I notice that UV radiation is strongest at the equator and gets weaker farther from the equator.

   Student 2: Why is it that way?

   Student 1: UV radiation is strongest at the equator because areas along the equator receive the most direct sunlight.

8. Have students read the article A fish of a different color, which explains the migration of humans into Europe and the evolution of lighter skin colors. Then ask them to discuss the question: Does success in one environment guarantee success in another?
9. Guide students toward a discussion of evolutionary trade-offs using skin color as a case study. Variation in human skin color shows that it is not possible to adapt such that an organism is equally prepared for every environmental condition. Instead, adapting to high UVB exposure and maintaining folate levels comes at a cost when in higher latitudes, where less UVB is available for synthesizing vitamin D. Help students see that what makes for success in terms of evolution is unique to a particular environment and that any one adaptation is not better than any other, but simply reflects a particular set of environmental conditions.

Day 2: Microevolution of Human Populations

1. Review the major outcomes of the previous class: reiterate that skin color evolved along gradients in the environment (clines) and represents a trade-off between what is most successful in different environments.
2. Introduce the distinction between microevolution and microevolution. Microevolution is the evolution of local

populations of a large species, defined by changes in gene frequencies within a population over time, whereas macroevolution is the evolution of unique species with reproductive isolation from similar species. Ask students to answer the following question and defend their thinking: Do evolutionary variations in skin color and in other phenotypic traits of race represent microevolutionary changes or macroevolutionary changes?

Possible student response: Evolutionary variations in skin color and other phenotypic traits of race represent microevolutionary changes because these changes do not define populations that are meaningfully isolated from one another. All humans, regardless of skin color, are one species.

3. Explain that while, historically, the concept of race has been used to designate groups of humans "on their way" to becoming separate species, in fact, human populations do not show this isolation and genetic differentiation into subspecies. Rather, any visible variation human populations have is due to microevolution among a limited set of traits. Stereotypes and assumptions about people of different races are based on the belief that race is a biological concept, and the misconception that race and ancestry are the same thing. These misconceptions have had a profound impact on the ways people of different races are treated by scientific and social scientific fields such as medicine, anthropology, and sociology.
4. Let students know that they will be investigating microevolutionary traits among humans and analyzing whether these traits are adaptations. Distribute the handout entitled "Human Adaptations Investigation and Fact Sheet" and have them look it over. Then project or distribute the handout "Example Human Adaptations Investigation for Red Hair and Pale Skin," and review the example investigation as a class. As you talk through the example, ask students to consider the following questions:
   - Do we see red heads at all high latitudes? What does this tell us about what is needed for an adaptation to occur?

     Possible student response: Red heads exist at some high latitudes but not at all high latitudes. Instead, they are limited to northern Europe. This tells us that there must be a selection pressure from the environment that traits are responding to. In this case the selection pressure is limited availability of sunlight.
   - What does it mean that red hair is considered an example of lack of negative selection?

     Possible student response: Red hair emerged but was not selected against by the environment, even though being a red head carries much higher risks of melanoma. The trait is likely to be a reflection of genetic drift following a founder event that increased the frequency of the allele to higher amounts without any selection against the alleles.
   - Why isn't red hair considered an adaptation?

     Possible student response: Red hair does not confer any environmentally based survival advantages to those who have it. Therefore, red hair is not an adaptation, but simply a mutation that is not selected against in the environment.

   You might let students know that there are also populations that have evolved red hair with dark skin, illustrating the convergent evolution of traits. If not correlated with pale skin as the variant in northern Europe is, red hair is a neutral trait.
5. Break students into four groups and assign each group to investigate one of the four traits from the handout: lactase persistence, high altitude adaptation, sickle cell anemia, or extreme cold tolerance and diet. Suggested resources for each trait are provided in the Additional Resources section for students to use as a starting point, but we recommend empowering students to do additional research in order to more thoroughly complete the activity.

Asynchronous work: Have students complete their fact sheets for homework if not able to do so during class time. This is necessary preparation for jigsaw presentations in the next class period.

Day 3: Why Assumptions About Race and Biological Traits Are Harmful

1. Organize students into teams of four such that each member of the team investigated a different trait from the "Human Adaptations Investigation and Fact Sheet" on Day 2. Have each student share their investigations with their teammates.
2. After they have finished presenting, have students discuss the following questions, first in their teams and then as a class:
   - How does natural selection help us explain these traits in local human populations? How are the distinct traits of different populations a result of natural selection?
   - Why are these traits *not* examples of macroevolution?
   - What does it take to show that a trait is an adaptation? How is an adaptation more than simply a trait that is beneficial?
   - Are these traits racial? In other words, do these traits correlate to a person's race?
   - Can these traits be used to determine a person's race? Why or why not?
3. Help students understand the dangerous consequences of racializing biological traits by considering the impact of "racialized diseases," a false concept based on the belief that certain diseases exist only among those of the same race. This belief rests on the assumption that race is biological and that population-specific traits define racial categories. Students will look at several examples that illustrate the dangers of this belief.
4. As their first example, have students consider sickle cell anemia. Solicit what students already know about this disease, then show them the video How this disease changes the shape of your cells (4:40 minutes). After they watch the video, have students talk in pairs about the evolutionary pressures that gave rise to the trait responsible for sickle cell anemia, and how this disease is related to ancestry.
5. Explain that because the trait for sickle cell anemia originated in Africa, the majority of people who develop sickle cell anemia have African ancestry and are considered Black. For this reason, the medical field previously made the false assumption that only people categorized as Black could develop sickle cell anemia. This assumption, of course, is not true, and, until the United States added sickle cell anemia to the list of diseases tested for among all newborns, it led to the underdiagnosis of sickle cell anemia in patients who were not considered Black.

   Have students read the story of Mimi, a 37-year-old woman with Middle Eastern ancestry who still encounters medical practitioners who question her sickle cell anemia diagnosis. Then ask students:

   > Why is it important that doctors reevaluate their assumptions about who can get sickle cell anemia? What harm continues to persist for people like Mimi because of the misunderstanding that sickle cell anemia is a "racialized" disease?

6. Contrast sickle cell anemia with the example of cystic fibrosis. Cystic fibrosis is a genetically inherited disease that has been stereotyped as a "White" disease because it is most common among White patients. However, as outlined in this call to action from the Cystic Fibrosis Foundation, Black and Latinx individuals with cystic fibrosis are more likely to go undiagnosed due to rare mutations. As a result, these individuals are nearly twice as likely as White people are to die of the disease before the age of 18. Furthermore, some of the treatments developed for cystic fibrosis are designed to treat the mutation more common among White patients than among patients of color.

   Have students read the story of Terry Wright, a man who suffered from cystic fibrosis for 54 years without a diagnosis because his doctors did not believe a Black man could have the disease. Then ask students:
   - How does Terry Wright's story demonstrate the dangers of a biological understanding of race?
   - Given the differences between ancestry and race, why can't we rule out that a Black person could have cystic fibrosis?

- Based on current research, Black and Hispanic individuals with cystic fibrosis have a mutation considered to be "rare" among individuals with the disease. However, Black and Hispanic individuals with cystic fibrosis have also been underrepresented within the research on this disease. How might their underrepresentation in the research effect what we know about the genetic basis of cystic fibrosis?

7. Remind students of the testable definition of racism: racism = discrimination against people of color + power. (For more information about the testable definition of racism, see the Appendix: Defining Racism from Biology Lesson 1). Then ask students: How does the assumption that race is biological reinforce systemic racism?

    Possible student responses:

    Doctors who have been taught that race is biological may misdiagnose or underdiagnose certain patients for particular diseases and conditions based on their race.

    Doctors who have been taught that race is biological might assume that their patients of color need different medical treatment from their White patients.

    Regardless of doctors' intentions in treating patients differently based on race, these differences in treatment are examples of systemic racism, because they are examples people being treated differently and not having their needs met because of their race.

8. Introduce students to the persuasive essay they will write, in class or for homework, about the potential consequences of a biological belief in race on screening patients for the BRCA mutation (see the Demonstration of Learning section). You might share this video with them about how Once students have completed these essays, consider having them film Public Service Announcements based on their arguments, and uploading these announcements to YouTube or to your school website.

Demonstration of Learning

Have students write a persuasive essay in response to the following prompt:

> BRCA mutations are associated with a higher risk for certain cancers. BRCA mutations are also associated with having Ashkenazi Jewish ancestry, yet these mutations have been found in those without Ashkenazi Jewish ancestry, as well. Using what you have learned in this and other lessons, write an argument for why a doctor's belief in race as a meaningful biological concept could lead to racist health outcomes for her patients when counseling them on whether to get tested for BRCA mutations. Then describe the role public health education can play in helping individuals of all races understand their risks regarding the BRCA variants.

Additional Resources

The following resources contain useful information about lactase persistence:

Early man 'couldn't stomach milk'. (2007). BBC News. April 1, 2022 at: http://news.bbc.co.uk/2/hi/health/6397001.stm.

Got lactase? (2007). UC Museum of Paleontology Understanding Evolution. Accessed April 1, 2022 at: https://evolution.berkeley.edu/evo-news/got-lactase/.

Ségurel, L., & Bon, C. (2017). On the evolution of lactase persistence in humans. *Annual review of genomics and human genetics,* 18, 297-319. https://doi.org/10.1146/annurev-genom-091416-035340.

The following resources contain useful information about high altitude adaptation in humans:

Bigham, A. W., & Lee, F. S. (2014). Human high-altitude adaptation: forward genetics meets the HIF pathway. *Genes & Development*, 28(20), 2189-2204. https://doi.org/10.1101/gad.250167.114.

Evolving high altitude aptitude. (2014). UC Museum of Paleontology Understanding Evolution. April 1, 2022 at: https://evolution.berkeley.edu/evo-news/evolving-altitude-aptitude/.

Understanding Evolution Team. (2022). High altitude adaptations: The work of Emilia Huerta-Sánchez. UC Museum of Paleontology Understanding Evolution. April 1, 2022 at: https://evolution.berkeley.edu/high-altitude-adaptations/.

The following resources contain useful information about sickle cell anemia:

biointeractive. (2014). Malaria and Sickle Cell Anemia — HHMI BioInteractive Video [video]. YouTube. April 1, 2022 at: https://www.youtube.com/watch?v=Zsbhvl2nVNE&feature=youtu.be.

A case study of the effects of mutation: Sickle cell anemia. (2022). UC Museum of Paleontology Understanding Evolution. April 1, 2022 at: https://evolution.berkeley.edu/a-case-study-sickle-cell-anemia/.

Piel, F. B., Patil, A. P., Howes, R. E., Nyangiri, O. A., Gething, P. W., Williams, T. N., Weatherall, D. J., & Hay, S. I. (2010). Global distribution of the sickle cell gene and geographical confirmation of the malaria hypothesis. *Nature Communications*, 1(1), 1-7. https://dx.doi.org/10.1038%2Fncomms1104.

The following resources contain useful information about extreme cold tolerance and diet:

Torgan, C. (2015). Genetic adaptations to diet and climate. National Institutes of Health. April 1, 2022 at: https://www.nih.gov/news-events/nih-research-matters/genetic-adaptations-diet-climate.

University of California - Berkeley. (2015). Adaptation to high-fat diet, cold had profound effect on Inuit, including shorter height: Greenlanders developed unique mutations to deal with diet high in omega-3 fatty acids. *Science Daily*. Accessed April 1, 2022 from www.sciencedaily.com/releases/2015/09/150917160034.htm.

Abul-Husn, N. S., Soper, E. R., Odgis, J. A., Cullina, S., Bobo, D., Moscati, A., Rodriguez, J. E. , CBIPM Genomics Team, Regeneron Genetics Center, Loos, R. J. F., Cho, J. H., Belbin, G. M., Suckiel, S. A., & Kenny, E. E. (2020). Exome sequencing reveals a high prevalence of BRCA1 and BRCA2 founder variants in a diverse population-based biobank. *Genome Medicine*, 12(1), 1-12. https://doi.org/10.1186/s13073-019-0691-1.

CF Foundation Seeks Input from Communities of Color. (2020). Cystic Fibrosis Foundation. April 1, 2022 at: https://www.cff.org/news/2020-11/cf-foundation-seeks-input-communities-color.

Detecting microevolutionary change. (2022). UC Museum of Paleontology Understanding Evolution. April 1, 2022 at: https://evolution.berkeley.edu/evolution-101/microevolution/detecting-microevolutionary-change/.

Evolution in the fast lane? (2008). UC Museum of Paleontology Understanding Evolution. Accessed April 1, 2022 at: https://evolution.berkeley.edu/evo-news/evolution-in-the-fast-lane/.

A common misconception regarding human evolution is that humans are no longer evolving. This misconception comes from the assumption that evolution takes hundreds of thousands or millions of years. While such assumptions are true of macroevolution, microevolution takes place over shorter timescales. This source highlights evidence of repeated micro-evolution of human populations over the past 80,000 years.

Gould, S. J., & Lewontin, R. C. (1979). The spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme. *Proceedings of the Royal Society of London. Series B. Biological Sciences, 205*(1161), 581-598. https://doi.org/10.1098/rspb.1979.0086.

Lotzof, K. (No date). Cheddar Man: Mesolithic Britain's blue-eyed boy. Natural History Museum, London. April 1, 2022 at: https://www.nhm.ac.uk/discover/cheddar-man-mesolithic-britain-blue-eyed-boy.html.

McGarry, M. E., & McColley, S. A. (2021). Cystic fibrosis patients of minority race and ethnicity less likely eligible for CFTR modulators based on CFTR genotype. *Pediatric Pulmonology, 56*(6), 1496–1503. https://doi.org/10.1002/ppul.25285.

Ravishankar, R. A. (2020). What's wrong with asking "where are you from?" Harvard Business Review. April 1, 2022 at: https://hbr.org/2020/10/whats-wrong-with-asking-where-are-you-fromreally from?".

References

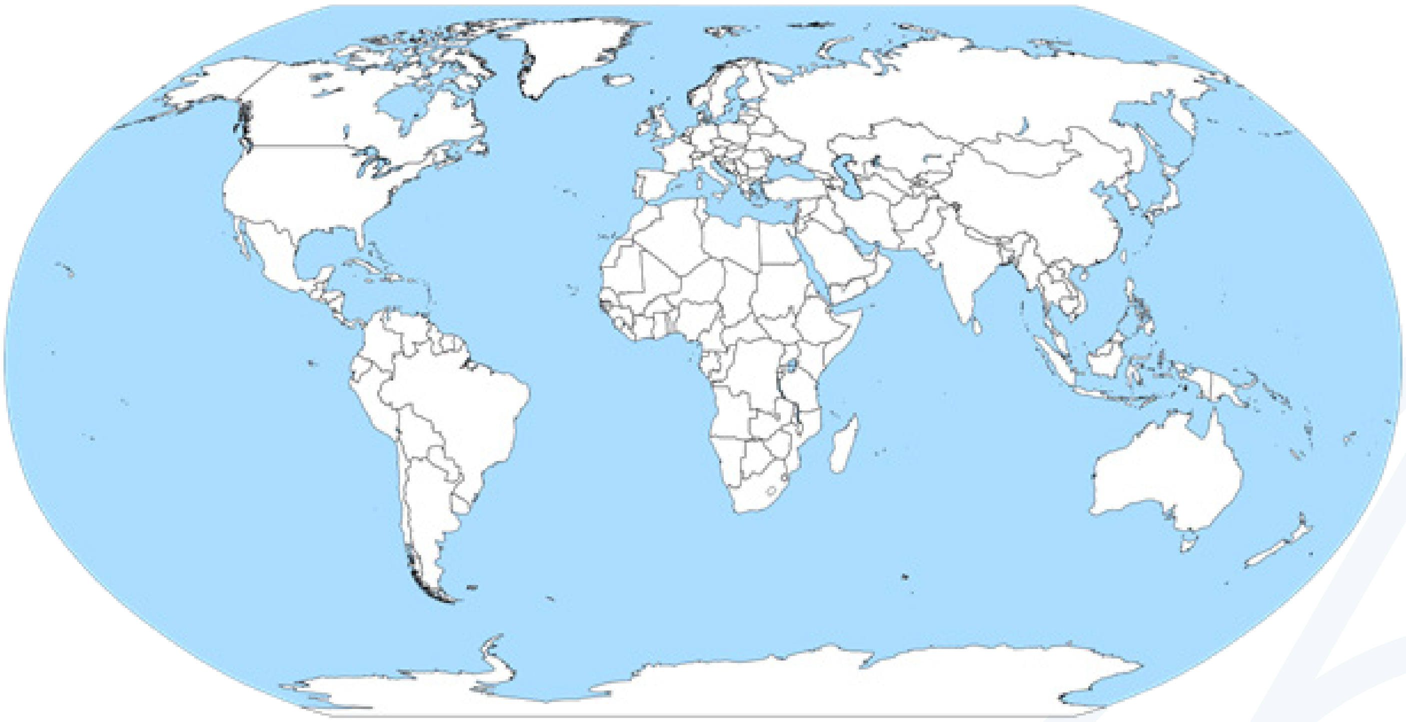
McChesney, K. Y. (2015). Teaching diversity: The science you need to know to explain why race is not biological. *SAGE Open*. https://doi.org/10.1177/2158244015611712.

Human Adaptations Investigation and Fact Sheet

Our group is investigating (circle your assigned trait):			
• Lactase persistence	• High altitude adaptation	• Sickle cell anemia	• Extreme cold tolerance and diet

Description of trait: What is this trait and how is it considered unique?

Distribution of trait: Where in the world is this trait present in populations indigenous to that location? Mark these locations on the map below.



Source: https://commons.wikimedia.org/wiki/File:World_Map_Blank_-_with_blue_sea.svg

Is this trait an adaptation? Scientists will infer that a trait is an adaptation if it meets the following criteria:

- Presentation of the trait overlaps with existence of a selection pressure (a set of environmental conditions that challenge survival).
- The trait provides a survival advantage that would increase the organism's fitness given the known selection pressures.
- The trait presents in significantly higher frequencies in the population compared to populations in different environments.

Using the sources for your given trait, determine the extent to which this trait counts as an adaptation. Record notes for each criterion in the space below:

Overlaps with a selection pressure	
Provides a survival advantage in response to the selection pressure	
Is present in significantly higher frequencies in some populations	

Develop your conclusion: Is this trait an example of adaptation? Given what you know about the process of natural selection, write an explanation in support of your answer.

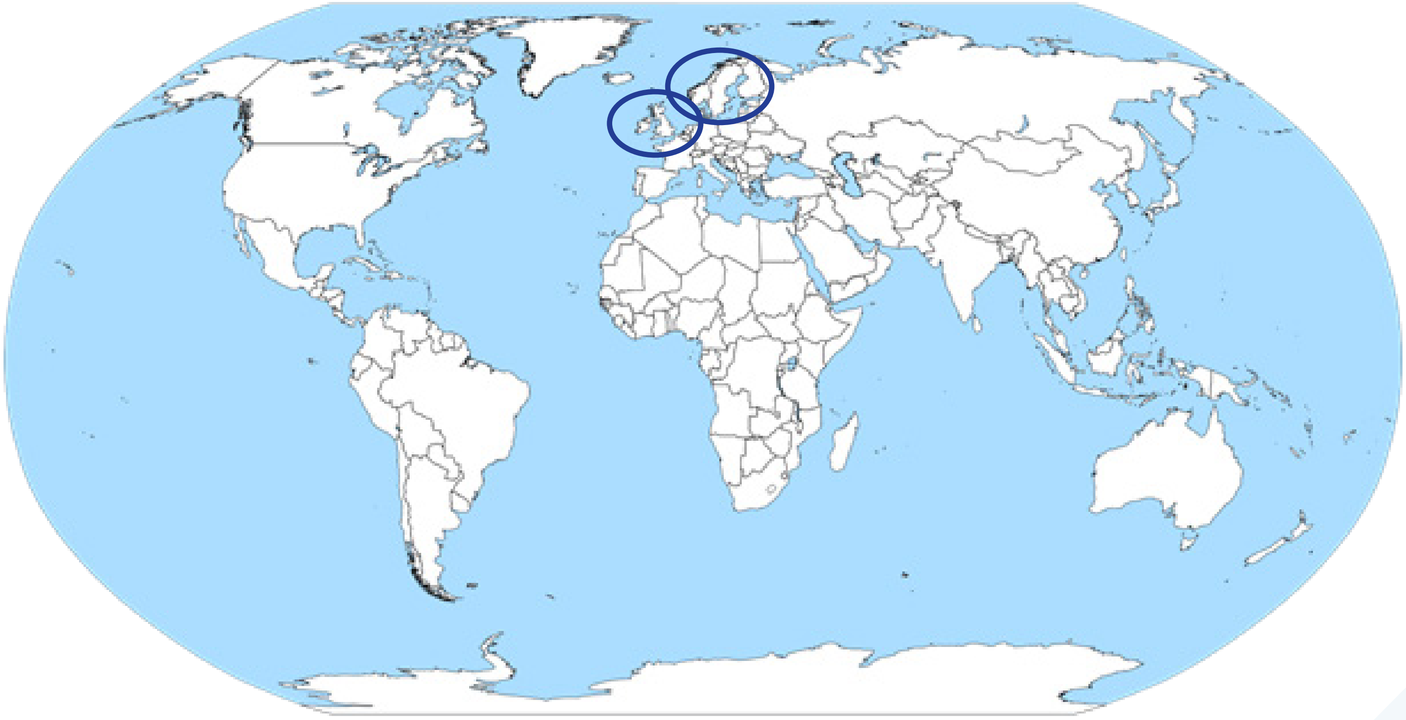
Example

Human Adaptations Investigation for Red Hair and Pale Skin

Description of trait: What is this trait and how is it considered unique compared to those without the trait?

Red hair creates a distinctive hair color but also often is correlated with pale skin due to a mutation in the eumelanin gene which makes the pheomelanin pigment present in much higher concentrations and show through without the masking by eumelanin. People with red hair and pale skin are very sensitive to UV radiation and prone to sunburns with little exposure.

Distribution of trait: Where in the world is this trait present in populations indigenous to that location? Mark these locations on the map below.



Is this trait an adaptation? Scientists will infer that a trait is an adaptation if it meets the following criteria:

- Presentation of the trait overlaps with existence of a selection pressure (a set of environmental conditions that challenge survival).
- The trait provides a survival advantage that would increase the organism's fitness given the known selection pressures.
- The trait presents in significantly higher frequencies in the population compared to populations in different environments.

Using the sources for your given trait, determine the extent to which this trait counts as an adaptation. Record notes for each criterion in the space below:

Overlaps with a selection pressure	*There is a strong selection pressure against red hair and pale skin in Africa, but it seems like there isn't any selection for red hair in northern Europe (Harding et al., 2000).*
Provides a survival advantage in response to the selection pressure	*There is a higher incidence of melanoma among redheads, even in northern latitudes, indicating this does not provide a selection advantage. Instead, this is likely due to genetic drift (a founder effect is likely) or a lack of negative selection against red hair if melanoma appears after reproduction (Harding et al., 2000).*
Is present in significantly higher frequencies in some populations	*Worldwide, 1-2% of the global population has red hair (Barnes, 2013), but the trait is more concentrated in northern Europe; approximately 5% or more of the populations in Ireland, Scotland, England, and Scandinavian countries have red hair, with the frequencies for the recessive alleles being even higher due to heterozygous carriers (Gerstenblith et al., 2007).*

Develop your conclusion: Is this trait an example of adaptation? Given what you know about the process of natural selection, write an explanation in support of your answer.

Red hair is not an adaptation, but instead it is a mutation that becomes visible due to a combination of a lack of negative selection and genetic drift (founder effect) in northern latitudes.

References

Barnes, H. (2013). How many redheads are there in the world? BBC News. Accessed April 1, 2022 at: https://www.bbc.com/news/magazine-24331615.

Gerstenblith, M. R., Goldstein, A. M., Fargnoli, M. C., Peris, K., & Landi, M. T. (2007). Comprehensive evaluation of allele frequency differences of MC1R variants across populations. *Human Mutation*, 28(5), 495-505. https://doi.org/10.1002/humu.20476.

Harding, R. M., Healy, E., Ray, A. J., Ellis, N. S., Flanagan, N., Todd, C., Dixon, C., Sajantila, A, Jackson, I. J., Birch-Machin, M. A., & Rees, J. L. (2000). Evidence for variable selective pressures at MC1R. *The American Journal of Human Genetics, 66*(4), 1351-1361. https://doi.org/10.1086/302863.

BIOLOGY LESSON 7

GENE TECHNOLOGY AND PRISON EXONERATION

Suggested time: Two to three 50-minute class periods
Suggested units: Genetic technology, genetics, molecular and cellular biology

Overview

In this lesson, students will learn about the role of DNA fingerprinting in exonerating individuals wrongfully sentenced by the criminal justice system. Students will also examine racial and other inequalities among those incarcerated in the U.S. and discuss the role that race and systemic racism play with respect to criminal justice in this country. Students will then conduct a gel electrophoresis lab to determine whether a fictional incarcerated individual should be exonerated based on DNA evidence. Students are then asked to demonstrate what they have learned by writing a formal lab report on their findings from the gel electrophoresis lab, including making a recommendation about the fictional incarcerated individual and relating these recommendations to what they have learned about racism and racial equity. Students will also learn about the cases of real individuals who have been exonerated using DNA evidence and share these stories with their classmates.

Objectives

- Apply knowledge of enzymes, the structure of DNA, and genetics to an understanding of DNA fingerprinting.
- Weigh the pros and cons of using DNA fingerprinting in forensic analysis.
- Acquire lab skills and familiarity with gel electrophoresis.

Key Understandings

- Science can be used to dismantle systemic racism and other forms of injustice.

  Possible misunderstanding: Science is morally neutral and therefore has no role in relation to social justice.
- People of color, and Black and Latino men and boys in particular, are disproportionately targeted by the criminal justice system in the U.S.

  Possible misunderstanding: People of color are more likely to end up incarcerated because they are more likely to commit crimes.

Materials

- The case of Malcolm Alexander. (2022). The Innocence Project. Accessed April 1, 2022 at: https://innocenceproject.org/cases/malcolm-alexander/.
- Criminal Justice Facts. (2022). The Sentencing Project. Accessed April 1, 2022 at: https://www.sentencingproject.org/criminal-justice-facts/.
- The Atlantic. (2015). The enduring myth of Black criminality [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=cQo-yYhExw0.
- NakedScientists. (2011). How does DNA fingerprinting work? - Naked Science Scrapbook [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=ZxWXCT9wVoI.

- Innocence staff. (2020). How eyewitness misidentification can send innocent people to prison. Innocence Project. Accessed April 1, 2022 at: https://innocenceproject.org/how-eyewitness-misidentification-can-send-innocent-people-to-prison/.
- Norrgard, K. (2008). Forensics, DNA fingerprinting, and CODIS. *Nature Education*, 1(1):35. Accessed April 1, 2022 at: https://www.nature.com/scitable/topicpage/forensics-dna-fingerprinting-and-codis-736/.
- Innocence Project: All Cases (webpage), available at: https://innocenceproject.org/all-cases/.
- Exploratorium Teacher Institute. Gel Electrophoresis: Biotechnology on a budget to dye for. Accessed November 1, 2021 at: https://www.exploratorium.edu/snacks/gel-electrophoresis?media=11062.
- Restriction Mapping of Plasmid DNA Kit, DNA Only (from 8-Station Kit), available for purchase from https://www.carolina.com/dna-gel-electrophoresis/restriction-mapping-of-plasmid-dna-kit-dna-only-from-8-station-kit/211176.pr.
- Food coloring
- Glycerin
- Microcentrifuge tubes (six per group)
- Agar-agar powder
- Pipettes
- TAE Buffer
- Handouts (included at the end of this lesson):
    - Malcolm Alexander: Wrongfully Imprisoned for 38 Years
    - DNA Fingerprinting Lab: Materials and Method

Vocabulary

criminal justice system
DNA fingerprinting
electrophoresis
exoneration

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **JU.9-12.12** I can recognize, describe and distinguish unfairness and injustice at different levels of society.
- **JU.9-12.13** I can explain the short and long-term impact of biased words and behaviors and unjust practices, laws and institutions that limit the rights and freedoms of people based on their identity groups.
- **JU.9-12.14** I am aware of the advantages and disadvantages I have in society because of my membership in different identity groups, and I know how this has affected my life.
- **AC.9-12.16** I express empathy when people are excluded or mistreated because of their identities and concern when I personally experience bias.

Note to Teachers

Before engaging with this lesson, we strongly recommend that educators familiarize themselves with how exoneration operates within the U.S. criminal justice system. Note, for example, that inaccurate eyewitness identifications account for the majority of wrongful convictions, and that it is on the appellant – not the court system – to provide evidence of their innocence. You can learn more about the exoneration process from organizations such as the Innocence Project and the Equal Justice Initiative, both of which provide a wealth of information and data on their websites. We also recommend checking out the Sentencing Project and the Prison Policy Initiative for information about the criminal justice system more broadly, and how individuals in the U.S. are disproportionately affected by this system based on race, age, and gender.

During this lesson, you may hear students suggest that people of color are incarcerated at higher rates because they commit felonies at higher rates. Remind students that due to over-policing in BIPOC communities, higher rates of being stopped by police, unfair drug laws, and other forms of structural racism within the criminal justice system, people of color are more likely to be surveilled, criminalized, arrested, and impacted by that system. This could also be an opportunity to introduce students to the issue of confirmation bias, or to the fact that fraud and corporate crime is often not prosecuted at the same rates as other forms of crime.

On Day 2 of this lesson, students will conduct a gel electrophoresis lab. If your classroom is equipped with professional materials for gel electrophoresis, students can use those to conduct the experiment. If not, you can improvise a gel electrophoresis setup with some common household items. This resource from the Exploratorium Teacher Institute provides instructions for one such setup.

You should prepare the gels in advance of Day 2 of this lesson. Gels should be kept in the fridge to preserve the results, both before and after they have been run with DNA or food dye.

DNA is prepared using PCR, but this requires expensive equipment that can be difficult to access. Instead, you can perform gel electrophoresis with pre-cut DNA samples available from Carolina Biological, or by adapting the process to use food coloring dyes as mock genetic samples in order to mimic the process of DNA fingerprinting.

To prepare the samples with food coloring dye, mix three drops of glycerin with 1-2 drops of food coloring per sample. Samples can be mixed and distributed using microcentrifuge tubes. Prepare enough samples for each group to get its own set and, for the purposes of this lesson, ensure that the incarcerated person has a color that does not match the colors from the samples being used as evidence in the case.

For either method, consider preparing and labeling the samples below for each group. Suggested combinations of food dye are listed in parentheses.

- Unknown DNA from the knife handle (red and blue dye)
- Mr. Jones's DNA (green dye)
- Victim's DNA (yellow and green dye)
- Boyfriend's DNA (yellow dye)
- Victim's cousin's DNA (red and blue dye)
- Unknown DNA from underneath the victim's fingernail (red and blue dye)

Finally, please note that this lesson presumes that students already have acquired a basic understanding of genetics.

LESSON PROCEDURE

Day 1: DNA Fingerprinting and the Criminal Justice System

1. Open by having students read the case of Malcolm Alexander's wrongful sentencing and eventual exoneration from the Innocence Project's website. Alternatively, you can assign this article as asynchronous work in advance of class. Then have students answer the questions in the handout entitled "Malcolm Alexander: Wrongfully Imprisoned for 38 Years." You might have students discuss their answers in small groups or complete the handout in advance of class before discussing these questions as a whole group. Please note that this case involves rape and violence; be sure to warn you students ahead of time, and offer support and accommodation for students who may find this content triggering or otherwise upsetting.
2. Project or distribute the Sentencing Project's Criminal Justice Facts. Have students look at each of the info-graphics, and spend some time contemplating the Lifetime Likelihood of Imprisonment for U.S. Residents Born in 2001. In a notebook or worksheet, have students complete the following sentence starters, based on Project Zero's see-think-wonder thinking routine:
   - In these data I see....
   - These data make me think....
   - These data make me wonder....
3. Show students the video The Enduring Myth of Black Criminality (3:15 minutes) and ask students to discuss: How do the arguments Ta-Nehisi Coates makes in this video influence or change how you make sense of the data in the Lifetime Likelihood of Imprisonment for U.S. Residents Born in 2001? Explicitly tell students that there is no "criminal gene" or biological basis for criminality or violence.
4. Review the testable definition of racism and the Four I's of systemic oppression (see the Appendix: Defining Racism in Lesson 1 for more information). In small groups or as a class, have students discuss:
   - How might we use the idea that racism = discrimination against people of color + unequal power to understand and evaluate the data in these infographics? Where in the criminal justice system might people of color experience discrimination? Where and how might they experience unequal power? How would we measure each of these elements?

     Possible student response: Some of the ways that people of color experience discrimination in the criminal justice system include being more likely to be arrested due to over-policing and implicit bias among police officers and being more likely to be wrongfully convicted because of implicit bias among jurors. In the first situation, police have the power to make decision about whether to arrest the people of color they encounter; in the second situation, jurors have the power to decide whether to convict people of color who are being tried for crimes.
   - In the class discussion, consider the interactions between the criminal justice system and each of the four levels of racism. How might individual, interpersonal, institutional, and ideological racism impact people of color throughout this system? How can the unconscious biases of legal professionals and jurors be a form of interpersonal racism? When combined with the institutional power of the legal system, how do these unconscious biases lead to racist outcomes?

     Possible student response: The individual bias of a judge can become interpersonal bias during a sentencing hearing. If the judge has a bias against Black people or people of color, they will deny bail for the person, even before being charged. The institution of the justice system gives judges this power without any accountability for their sentencing. Three-strikes laws and "zero tolerance" laws for sentencing operate at the institutional level and can lead to imprisonment for life.
5. If you have not already introduced DNA fingerprinting at this point in your genetics unit, be sure to do so now. Consider showing students the video How does DNA fingerprinting work? (5:26 minutes) to introduce them to the topic.

- Have students compare, discuss, and weigh the pros and cons of eyewitness identification and DNA fingerprinting as evidence in a criminal court. In class or for homework, have students read the resource How Eyewitness Misidentification Can Send Innocent People to Prison from the Innocence Project and Forensics, DNA Fingerprinting, and CODIS. As they read these articles, students should write down what they see as the pros and cons of each type of evidence.

Possible student responses:

	Pros	**Cons**
Eyewitness identification	• Using eyewitnesses does not involve expensive technologies • Eyewitness identification may be the only form of identifying evidence if no biological material was found at the crime scene	• Our memories are often not reliable, especially when recalling stressful situations • People tend to be less accurate when identifying someone of another race • Suggestive practices can unconsciously alter witnesses' testimony
DNA Fingerprinting	• DNA fingerprinting does not rely on memory, which is often not reliable • There is a very, very low chance of two people sharing the same DNA fingerprints	• DNA testing relies on STR sequences being different between people of different races • DNA testing is expensive • DNA fingerprinting requires that there be biological material available at the crime scene • DNA fingerprinting is less reliable if the material is contaminated or an incomplete sample or when there are DNA from multiple sources • There are ethical issues of privacy in the collection of DNA evidence and creating DNA databases

Day 2: Gel Electrophoresis Lab

1. Have students review and discuss their pros and cons lists for using eyewitness identifications and DNA fingerprinting as criminal evidence, especially if they completed these lists outside of class. Review the pros and cons as a class.
2. Let students know that, in today's class, they will conduct a gel electrophoresis lab to determine whether a fictional person incarcerated for a murder case should be exonerated. Students will be presented with the following scenario:

   Casey Jones has been in prison for 10 years for a murder he claims he did not commit. He is a Black, 36-year-old male. He has no physical evidence to support his whereabouts other than personal testimonies from his family. However, three witnesses say they saw someone who fits his description at the crime scene. DNA evidence from the murder scene matches the victim and there is preserved, unidentified DNA evidence taken from the weapon and from underneath the victim's fingernails of the crime scene. You are the forensic scientists tasked with analyzing the unidentified DNA samples.

3. Before students begin the lab, discuss how to frame the objective of this investigation. This is not a hypothesis-driven investigation, but instead the application of biological concepts in the form of a technology. For this investigation, students should develop an objective that involves determining if the accused person's DNA matches the unknown DNA samples from the crime scene.
4. Students will then follow the procedure in the "DNA Fingerprinting Lab: Materials and Method" handout. If this is your students' first time conducting an experiment using gel electrophoresis, you may want to demonstrate how to add samples to a gel. You might have students practice pipetting the correct amount of water or food dye before pipetting samples into the gels. Throughout the experiment, have students record their observations and results in a lab notebook. Once the experiment is complete, consider having students write a formal lab report (see Demonstration of Learning) that analyzes the results of their investigation.
5. While the gels are running, students should prepare their lab notebooks with the title of the lab, the objective of the lab, and space for recording data. After the gels are completed, students should make a sketch of their results or, depending on cell phone use policies, take a picture with their cell phones to incorporate into their lab reports.
6. Close by having students visit the Innocence Project website and select "The Cases" to read about the stories of real individuals who have been exonerated. Instruct students, individually or in small groups, to choose stories of exoneration to present to the class. During each presentation, students should describe how science was used, misused, or could have been applied to their selected case. Finish with a discussion about what role science should play in the criminal justice system, and what implications the use of forensic science can have with respect to racial inequity within this context.

Demonstration of Learning

Have students write a formal lab report that includes the following sections:

- Introduction (including background information and the objective of the investigation)
- Methods (including materials used)
- Results
- Discussion (including a clear conclusion that addresses the objective of the investigation)

Students' discussion sections should include an argument regarding the exoneration of Casey Jones using the claim-evidence-reasoning structure. Students should be sure to incorporate the testable definition of racism and the Four I's of systemic oppression into their analyses.

Additional Resources

DNA Exonerations. (2022). Fred Hutch. Accessed April 1, 2022 at: https://www.fredhutch.org/en/about/education-outreach/science-education-partnership/sep-curriculum/dna-exonerations.html.

Equal Justice Initiative [website], available at: https://eji.org/.

Innocence project [website], available at: https://innocenceproject.org/.

Lewis, J., & Stevenson, B. (2014). On the Presumption of Guilt. *Human Rights Magazine*, 40:1. Accessed November 1, 2021 at: https://www.americanbar.org/groups/crsj/publications/human_rights_magazine_home/2014_vol_40/vol_40_no_1_50_years_later/presumption_of_guilt/.

Nellis, A. (2021). The color of justice: Racial and ethnic disparity in state prisons. The Sentencing Project. Accessed April 1, 2022 at: https://www.sentencingproject.org/wp-content/uploads/2016/06/The-Color-of-Justice-Racial-and-Ethnic-Disparity-in-State-Prisons.pdf.

Prison Policy Initiative [website], available at: https://www.prisonpolicy.org/.

The Sentencing Project [website], available at: https://www.sentencingproject.org/.

Wald, J., & Losen, D. J. (2003). Defining and redirecting a school-to-prison pipeline. *New Directions for Youth Development*, 2003(99), 9-15.

Wilson, H. (2014). Turning off the school-to-prison pipeline. *Reclaiming Children and Youth*, 23(1), 49.

Malcolm Alexander: Wrongfully Imprisoned for 38 Years

Read through the Innocence Project's report on Malcolm Alexander, then respond to the questions below. Please note that this report involves the mention of rape and other forms of violence.

1. List each of the factors from this case that contributed to the wrongful conviction of Malcolm Alexander.

2. How was Malcolm Alexander eventually exonerated? What steps had to happen for this exoneration to take place, and what barriers did he face along the way?

3. How do you think Malcolm Alexander's wrongful imprisonment affected his life? Who else's lives might have been affected? How would you propose preventing wrongful sentences such as Alexander's, and how would you suggest repaying and repairing wrongful imprisonments once someone is exonerated?

DNA Fingerprinting Lab: Materials and Method

Casey Jones has been in prison for 10 years for a murder he claims he did not commit. He is a Black, 36-year-old male. He has no physical evidence to support his whereabouts other than personal testimonies from his family. However, three witnesses say they saw someone who fits his description at the crime scene. DNA evidence from the murder scene matches the victim and there is preserved, unidentified DNA evidence taken from the weapon and from underneath the victim's fingernails of the crime scene. You are the forensic scientists tasked with analyzing the unidentified DNA samples.

Materials

- Electrophoresis setup (including gel and power source)
- TAE buffer
- DNA samples
- Pipettes

Method

1. Gently remove the comb from your gel. Add TAE buffer into the container with your gel until the gel is entirely, but just barely, submerged in the buffer.
2. Using a pipette, carefully place a small amount of each DNA sample (10 microliters, or one large drop) into each of the wells in your gel. Be sure to write down which samples you have added to which wells.
3. Connect your electrophoresis setup to the power source. Make sure to connect the negative end toward the side of your gel with the DNA samples, and the positive end toward the opposite side of the gel. Track the movement of your samples through the gel and turn off the power once your samples have moved about halfway across the gel.
4. In your lab notebook, record what you see on the gel.

BIOLOGY LESSON 8

GENE TECHNOLOGY AND THE RISE OF GARAGE WHITE SUPREMACIST GENETICISTS

Suggested time: Two to three 50-minute class periods
Suggested units: Genetic technology, DNA, protein synthesis

Overview

This lesson examines gene-editing technology and asks students to consider both the potential benefits and the potential dangers of its application. On the one hand, gene editing is already being used to treat previously irreversible genetic diseases. On the other hand, gene editing is also being used to allow parents to choose the traits of their future children, and, used in this way, this technology has the potential to deepen systemic inequalities and fortify white supremacy. In addition, attempts to "democratize" gene-editing technology have generated intense debates about who should be allowed access to such powerful technology and how such technology should be used. In this lesson, students will discuss these and related questions, using the Netflix docuseries "Unnatural Selection" to help inform these discussions.

Objectives

- Students will apply their knowledge of DNA and genetics to understand how gene-editing technologies make changes to the human genome.
- Students will discuss and debate the moral implications of gene-editing technology, as well as how such technologies should be used and regulated.

Key Understandings

- Science can be used to dismantle systemic racism and other forms of injustice. At the same time, science and technology can be – and have been – used to fortify racism, white supremacy, and other forms of injustice.

  Possible misunderstanding: Science is morally neutral and therefore has no role in relation to social justice.

- Seemingly neutral scientific concepts and technologies can be used in ways that are harmful to particular groups of people based on their race, immigration status, ability, the community they live in, and other aspects of their identity.

  Possible misunderstanding: the intentions of those developing, profiting from, and/or using technologies justify their use, even if these technologies are negatively impacting other people's lives.

- Eugenics is an inherently racist and oppressive belief system that labels certain people as "good" and certain traits as "desirable," while excluding other people and traits from its vision of the future of humanity. While perhaps no longer as popular or as public as they were during and before World War II, eugenic philosophies still exist today and remain just as dangerous.

  Possible misunderstanding: Eugenic ideologies disappeared with the defeat of Nazi Germany.

Materials

- Kaufman, L., & Egender, J. (Directors). (2019). *Unnatural Selection* [film]. Radley Studios, Reel Peak Films, & Twist and Turn Films. Distributed by Netflix. Accessed October 1, 2021, at: www.netflix.com.
- Internet connection, a projector, and speakers to show a film in class

- Ayeh, D. (2015). Bioethical silence & Black lives. *Voices in Bioethics*, 1. Accessed February 1, 2022 at: https://journals.library.columbia.edu/index.php/bioethics/article/view/6605.
- Hubbard, R., & Newman, S. (2002). Yuppie eugenics: Creating a world with genetic haves and have-nots. *Z Magazine*. Accessed February 1, 2022 at: https://www.researchgate.net/publication/325674750_Yuppie_eugenics.

Vocabulary

bioethics
CRISPR
designer babies
eugenics
gene editing
white supremacy

National Standards

This lesson aligns with the following Next Generation Science Standards:

- **HS-LS1-1** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

This lesson also aligns with the following Social Justice Standards learning outcomes:

- **ID.9-12.1** I have a positive view of myself, including an awareness of and comfort with my membership in multiple groups in society.
- **ID.9-12.2** I know my family history and cultural background and can describe how my own identity is informed and shaped by my membership in multiple identity groups.
- **ID.9-12.3** I know that all my group identities and the intersection of those identities create unique aspects of who I am and that this is true for other people too.
- **ID.9-12.4** I express pride and confidence in my identity without perceiving or treating anyone else as inferior.
- **DI.9-12.10** I understand that diversity includes the impact of unequal power relations on the development of group identities and cultures.
- **DI.9-12.8** I respectfully express curiosity about the history and lived experiences of others and exchange ideas and beliefs in an open-minded way.
- **JU.9-12.12** I can recognize, describe and distinguish unfairness and injustice at different levels of society.
- **JU.9-12.13** I can explain the short and long-term impact of biased words and behaviors and unjust practices, laws and institutions that limit the rights and freedoms of people based on their identity groups.
- **JU.9-12.14** I am aware of the advantages and disadvantages I have in society because of my membership in different identity groups, and I know how this has affected my life.

LESSON PROCEDURE

Day 1: Introduction to CRISPR and Gene Editing

1. Ask students to reflect on and discuss the questions below. Start by having students spend 10 minutes writing down their responses in a notebook. Next, have students share and discuss their responses with a partner for another 10 minutes. Finally, have each student share out one or two points that their partner made during their discussion with the rest of the class.
   - If you could genetically alter any of your natural traits, such as your appearance, your innate talents, and/or your genetically encoded health risks, would you do it? Why or why not? Would you do it for certain traits but not others? If so, how would you select which traits you would alter?
   - Think about the trait you would most like to change. Now imagine a fellow student, known for being excellent at science, came to you and said she had developed a gene-editing tool in her basement to change exactly that trait. She tried it on herself, and she claims it is working. However, she also acknowledges that she has not tried her genetic editing tool on anyone else yet, and that this tool has not gone through any of the rigorous testing required of federally approved drugs or medical technologies. Would you try it anyway? Why or why not?
   - Think again about the trait you would most like to change. Now imagine a panel of doctors, scientists, and politicians came to you to get your opinion on whether a gene-editing tool to change this trait should be approved for use in fertility clinics so that parents could alter this trait in their unborn children. How would you advise this panel, and what reasoning would you give them to justify your response?
2. Show students Episode 1 of the Netflix limited series entitled *Unnatural Selection*. While students watch, they should take notes on the questions below. Afterward, have students discuss their responses to these questions in small groups or as a whole class.
   - What is selective breeding? What advantages and disadvantages does gene editing have compared to selective breeding?
   - What is CRISPR and how does it work?
   - One student expresses concern that gene editing could become a tool of Nazism. How is gene editing potentially related to racism and white supremacy? How might gene editing be related to other forms of inequality and systemic oppression?
   - What impact might gene editing have on the planet and the environment? How might these impacts be prevented or mitigated, if at all?
   - Do you think it is possible to democratize something like gene-editing technology? Why or why not?
   - What arguments did you hear during this episode in favor of gene editing in humans? What arguments against, or concerns about, gene editing in humans did you hear? Based on what you have heard and seen so far, what do you think the right path forward is regarding gene editing in humans?

Asynchronous work: Have students write short essays responding to the following prompt:

> How might gene-editing technology interact with structural racism and individual prejudices? How might such technology be used in the hands of racists and/or antiracists? Do you expect gene-editing technologies to make racism worse, better, or some combination? Explain your reasoning.

Day 2: The Moral Implications of Gene-Editing Technologies

1. Show students Episode 4 of the Netflix limited series entitled *Unnatural Selection*. While students watch, they should take notes on the questions below. Afterward, have students discuss their responses to these questions in small groups or as a whole class.
   - Why did Tristan Roberts inject himself with N6? Why were many in the medical community outraged by his actions?

- Zaynor argues that even if there are rules against using gene editing for non-medical enhancements, some people will inevitably break these rules, and that therefore the better approach is to spread the technology as widely as possible so that *everyone* can use it to make personal enhancements. Is there merit in trying to democratize gene editing? Is there merit in making rules against non-medical enhancements even if some people will break these rules? Could there be any additional consequences to making gene-editing technology accessible to individuals?
- What are the arguments for and against parents being able to create "designer babies" by choosing traits such as their eye color and sex? For each argument, do you agree or disagree? Why?
- What is a three-parent baby? Explain how a person can have three biological parents.
- Unlike in the first episode, Zaynor expresses some guilt and concern about gene editing and his own involvement in attempting to democratize the technology around it. What inspires this change of heart?
- What is eugenics? How is eugenics related to racism and white supremacy? How is eugenics related to ableism? Are you familiar with connections between eugenics and any other forms of systemic oppression and, if so, which ones? How could gene editing be used as a tool for eugenics?
- Based on both episodes, what do you notice about who is and is not part of the discussions about whether gene editing should be widely available and how gene-editing technology should be used? How might the people who do not have a say in these discussions be impacted by the decisions of those deciding the future of gene editing?
- What is bioethics and why are bioethical discussions important? In what ways are scientific discoveries and technologies susceptible to being misused? How can science contribute to both perpetuating and also dismantling white supremacy and other forms of systemic injustice?
- If genetic engineering could eliminate different races by having everyone look the same, would that be a solution to racism? Why or why not?
- In Episode 4 of *Unnatural Selection*, a student moderator for a panel of genetic scientists poses the following question: "Who should draw these lines about what we're allowed to edit and what people should be allowed to pursue [using gene-editing technology]?" If you were asked to answer this question for society, what would your answer be?

Asynchronous work: Have students write short essays responding to the following prompt:

Which genes, if any, should humans be allowed to edit? Why?

In making their arguments, students should use three or more examples from the docuseries, or from additional sources, as supportive evidence. In addition, students should address at least one counterargument to their own thesis. Remind students that there is no right answer, and that they will be evaluated not based on their beliefs, but on their use of evidence and reasoning, and their ability to form an argument and address at least one counterargument.

In addition, have students read the articles Bioethical Silence and Black Lives by Derek Ayeh and Yuppie Eugenics by Ruth Hubbard and Stuart Newman.

Day 3: The Big Picture: Our Obsession With the "Cutting Edge"

1. Using the chalk talk method, post the questions below on chart paper around the classroom. Then allow students to walk around the room with pens or markers, adding their responses to the chart paper and reading and responding to others' comments.
   - What causes inequality? What causes suffering in society?
   - Can cutting-edge science solve society's problems? Can cutting-edge science solve inequality?
   - Is perfection possible? Is perfection good?

- If we allowed gene editing, who would benefit from it? Who would be hurt by it?
- Who decides the standards for which genes are "good" and which genes are "bad"? Where do these standards come from?

2. Facilitate a class discussion in which students are asked to critically examine the purpose of gene editing. Many proponents of gene editing claim that its purpose is to reduce suffering, but what causes suffering? Do genes themselves cause suffering, or is suffering caused by society's accommodations (or lack thereof) for the emergent phenotypes of individuals with those genes? Help students iteratively discuss and reflect on the readings by extending the class discussion with the following questions:
   - Can cutting-edge science solve suffering and inequality? Can cutting-edge science solve structural racism? How might cutting-edge science make racism worse?
   - Where do our preferences for different genetic traits come from?
   - How do racist ideologies such as white supremacy tell us what to value and what "perfect" looks like? In a eugenicist society, what would we measure that would show the discrimination inherent to eugenics?
   - How can policies give power to interpersonal prejudices? How would gene editing allow prejudices to be given power? If gene editing were allowed, how might such technology interact with each of the Four I's of racism (e.g., individual, interpersonal, institutional, and ideological; see Appendix: Defining Racism from Biology Lesson 1)?
3. At this point in the discussion, you may want to introduce students to the social model of disability. Gene editing has enormous implications not only for racism but also for ableism. Furthermore, racism and ableism have operated intersectionally throughout history. For suggestions and resources on how to bring disability into the conversation, see the Extension Opportunities section.
4. Help students reflect on and name the assumptions we have in society about what causes suffering and about why we think technology will reduce suffering. Write down these assumptions for students to see and discuss.
5. Close by having students complete an exit ticket exercise summarizing how their thinking has changed over the course of this lesson. Consider having students use the format I used to think… Now I think… from Project Zero.

Demonstration of Learning

Provide students with the following prompt:

> The year is 2045. Gene editing has been democratized since 2025. What are the outcomes for society? Your task is to write a short creative piece from the future, in the style of science fiction, that imagines and describes the impact twenty years of gene editing has had on society. Your piece can be a short vignette, a sample newspaper article or clipping, a social media post, a video, a press release of a new research study on behalf of scientists, or another style approved by your teacher. In this piece, be sure to include quantitative, measurable impacts gene editing has had on society, and explain the cause-and-effect relationships behind these impacts.

Extension Opportunities

- Introduce students to epigenetics and the flexibility of gene expression, and contrast this reality with the simplistic view that a given genotype can only produce a single phenotype. To explore these themes, you might have students read the essay Die Selfish Gene, Die as well as expert responses to the essay. (For more information on these resources, see the Additional Resources section.)
- Introduce students to the concept of biological determinism, and the overwhelming science disproving this concept. Biological determinism has often a core pillar of eugenicist endeavors. Have students consider: How do some of the ideas shared by the proponents of gene-editing technologies rely on a reductionistic, deterministic view of biology?
- Discuss the relationship between epigenetics and intergenerational trauma. This topic may be particularly relevant for the descendants of enslaved and colonized peoples, and could serve as the basis for a research project. Students might investigate the primary literature establishing epigenetics as a pattern of inheritance and the demonstrated outcomes of changes to physiology across multiple generations. You might challenge students to consider how long-lasting epigenetic effects challenge the American belief in the meritocracy and the fallacy that people can "pull themselves up by their bootstraps."
- Help students understand the dangerous implications gene-editing technologies – and eugenics broadly – have for ableism. Begin by introducing students to the social model of disability; this video (2:43 minutes) can serve as an introduction. Have students consider: How does our society distinguish between "normal" variation (e.g., being tall, being nearsighted) and "disability" (e.g., being one-handed, using a wheelchair)? To what extent are these distinctions arbitrary? And, if these decisions are arbitrary, what is there to stop us from deciding that any trait is a disability? What are the implications of the social construction of disability on the ethical use of gene-editing technologies?

  This activity uses the following resource:

  Shape Arts. (2017). Social Model of Disability [video]. YouTube. Accessed April 1, 2022 at: https://www.youtube.com/watch?v=24KE__OCKMw.
- You can help students develop an intersectional analysis of gene editing by introducing them to some of the ways in which ableism has been used to uphold racism (and vice versa) through the pathologizing of race. These examples include drapetomania, the pseudoscientific idea the desire among enslaves people to run away was a mental illness.

  This activity uses the following resource:

  Kres-Nash, I. (2016). Racism and ableism. American Association of People With Disabilities. Accessed April 1, 2022 at: https://www.aapd.com/racism-and-ableism/.

Additional Resources

Dobbs, D. (2013). Die, selfish gene, die. *Aeon Magazine*. Accessed February 1, 2022 at: https://aeon.co/essays/the-selfish-gene-is-a-great-meme-too-bad-it-s-so-wrong

In this essay, David Dobbs outlines the shifting paradigm of biology which is moving away from the supremacy of the gene as determining everything about an organism, to instead a systems-based view in which the expression of genes is an outcome determined by the interaction of an organism with the internal and external environment. In the simplistic Central Dogma, the flow of information moves in one direction, but modern biology challenges this view and instead sees a phenotype as an outcome of many inputs and feedback loops within a system.

Hains, B. (Ed.). (2014). Dead or alive? An expert roundtable on the selfish gene. *Aeon Magazine*. Accessed February 1, 2022 at: https://aeon.co/essays/dead-or-alive-an-expert-roundtable-on-the-selfish-gene.

This article is a follow-up to David Dobbs' essay "Die, selfish gene, die" and incorporates expert analysis of the paradigm shift presented in the original essay. As the experts outline, the inherent variation present among organisms is key to understanding the dynamic nature of gene expression and the emergent phenotype.