

Teacher Notes for “Covid-19 Vaccines – How do they work?”¹

Students learn that vaccination or a previous coronavirus infection reduces the risk of severe Covid-19. They learn how the immune system responds to a coronavirus infection and analyze how this response differs after a first vs. second exposure to the coronavirus. Then, students analyze the biological effects of an mRNA vaccine and develop an evidence-based explanation of how vaccination protects against severe Covid-19.

Before beginning this activity, your students should understand the basic biology of the coronavirus. For this purpose, I recommend that your students complete either version of the Student Handout for, “Coronaviruses – What They Are and How They Can Make You Sick” (<https://serendipstudio.org/exchange/bioactivities/coronavirusintro>).

NGSS Learning Goals

In accord with the Next Generation Science Standards (NGSS)²:

- This activity helps students to understand the Disciplinary Core Idea LS1.A. “Systems of specialized cells within organisms help them perform the essential functions of life.”
- Students engage in the Scientific Practice, “Constructing Explanations. Apply scientific ideas, principles and/or evidence to provide an explanation of phenomena...”
- This activity helps students to understand the Crosscutting Concept, “Cause and Effect: Mechanism and Prediction. Cause and effect relationships can be suggested and predicted for complex natural... systems by examining what is known about smaller scale mechanisms within the system.”
- This activity helps students to prepare for Performance Expectation 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.”

Instructional Suggestions and Biology Background

To maximize student participation and learning, I suggest that you have your students work in pairs or individually to complete each group of related questions and then have a class discussion after each group of questions. In each discussion, you can probe student thinking and help them develop a sound understanding of the concepts and information covered before moving on to the next group of related questions.

If your students are learning online, we recommend that they use the Google Doc version of the Student Handout, which is available at <https://serendipstudio.org/exchange/bioactivities/coronavirusvaccine>. To answer questions 1, 7 and 8, students can either print the relevant pages, draw on those and send you pictures, or they will need to know how to modify a drawing online. They can double-click on the relevant drawing in the Google Doc, which will open a drawing window. Then, they can use the editing tools to add lines and other shapes.³ If you want to revise the GoogleDoc or Word document to prepare a version of the Student Handout that will be more suitable for your students, please check the format by viewing the PDF.

¹ By Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, 2022. These Teacher Notes and the related Student Handout are available at <https://serendipstudio.org/exchange/bioactivities/coronavirusvaccine>.

² Quotations are from NGSS "High School Life Sciences" at <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>

³ To draw a shape, at the top of the page, find and click Shape; choose the shape you want to use; click and drag on the canvas to draw your shape. When you are done, click Save and Close.

A key is available upon request to Ingrid Waldron (iwaldron@upenn.edu). The following paragraphs provide additional instructional suggestions and background information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

The novel coronavirus that is causing the current global pandemic is called SARS-Cov-2 because of its similarity to SARS-Cov, a coronavirus that caused an epidemic of Severe Acute Respiratory Syndrome in 2002-2004, mainly in Asia. This earlier coronavirus disease was Covid, which had different characteristics than Covid-19, the current pandemic disease. (“Co” stands for corona, “vi” stands for virus, and “d” stands for disease. 19 stands for 2019, the year when Covid-19 was first identified.)

The anchoring phenomenon is presented in the bulleted sentence near the top of page 1 of the Student Handout. Supporting evidence for the efficacy of vaccines includes the following.

- The clinical trials for the Moderna and Pfizer/BioNTech vaccines showed ~95% efficacy. This means that the rate of Covid-19 was ~95% lower among the vaccinated group than among the placebo group in their phase 3 clinical trials.⁴
- More recent data show that unvaccinated people have had at least 10 times higher risk of hospitalization and death due to Covid-19, both during the time when the Delta variant was prevalent and more recently when the Omicron variant was prevalent. (Appendix 1 gives some of the supporting data.)^{5 6}
- For teens, an observational study estimated that the Pfizer/BioNTech vaccine was 94% effective at preventing hospitalizations and 98% effective at keeping patients out of intensive care.
- An observational study of pregnant women found that vaccination substantially reduced the risk of coronavirus infection; this protected their babies, since maternal coronavirus infection was associated with increased preterm birth and perinatal mortality.

Immune Defenses against Coronavirus Infection

Students are expected to answer question 1c by pointing out that, if antibodies are bound to the spike proteins, then the spike proteins cannot bind to the receptor molecules on body cells, so the coronavirus RNA can't enter the cells and the coronavirus can't be reproduced. (This is the effect of “neutralizing” antibodies.) Additional effects of antibodies bound to viral antigens include increased phagocytosis of the virus (see figure on the bottom of page 1 of the Student Handout).

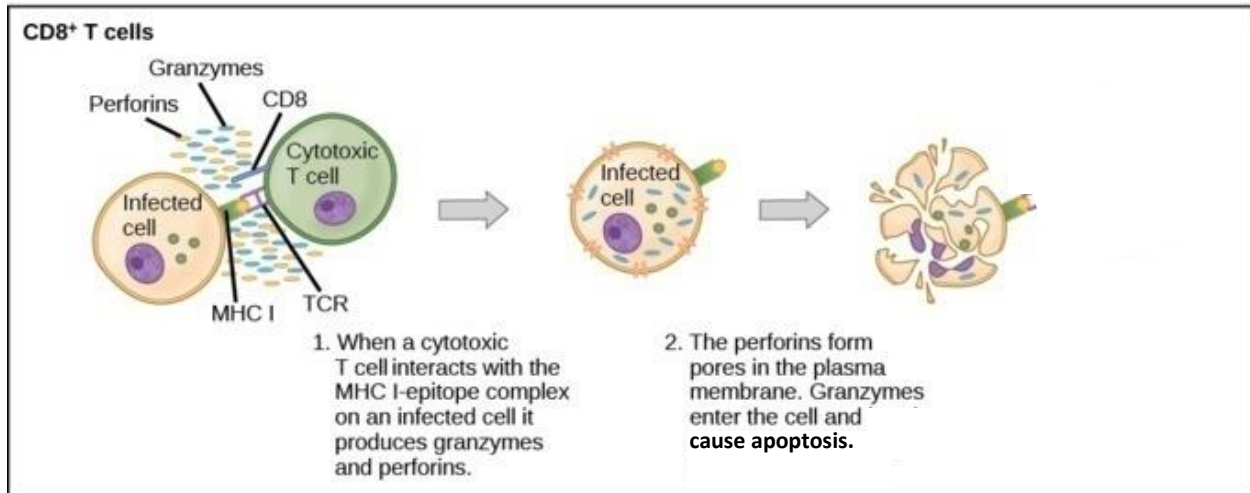
⁴ For an explanation of the clinical trials used to test the efficacy and safety of vaccines, see <https://www.cdc.gov/vaccines/hcp/conversations/ensuring-safe-vaccines.html>.

⁵ For an introduction to the coronavirus variants, see "Coronavirus Evolution and the Covid-19 Pandemic" (<https://serendipstudio.org/exchange/bioactivities/coronavirusOrigin>). Data collected before the Omicron variant spread widely show that, after an initial coronavirus infection, the risk of a subsequent infection was reduced by approximately 80-93% (<https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/vaccine-induced-immunity.html#print>; <https://pubmed.ncbi.nlm.nih.gov/34592838/>). The recent Omicron variant and subvariants are particularly good at evading immune defenses, so reinfections have become more common, but previous infection still provides strong protection against severe Covid-19 (<https://www.nejm.org/doi/full/10.1056/NEJMoa2203965>; <https://www.theatlantic.com/health/archive/2022/07/ba5-omicron-variant-covid-surge-immunity-reinfection/670485/>).

⁶ Students may argue that breakthrough infections show that the vaccines are not working. To counteract this opinion, you may want to show the ~1-minute video, “What are vaccine breakthrough cases?” (available, about halfway down at <https://www.health.state.mn.us/diseases/coronavirus/stats/vbt.html>); this video explains how to correctly interpret statistics about breakthrough cases.

An antigen is a foreign protein, carbohydrate or glycoprotein that stimulates a response of the adaptive immune system.⁷ You may want to help your students understand and remember the term antigen by pointing out that an antigen stimulates or generates an antibody response.

Much of the research and popular coverage of immune system resistance to Covid-19 has focused on antibodies, but cytotoxic T cells play an important role in limiting and ending an infection. The figure below shows how a cytotoxic T cell kills a virally infected cell. The death of infected cells prevents coronavirus replication and releases the coronaviruses from the cell so they can be taken up and digested by phagocytic cells. You may want to explain to your students that “cyto-” stands for cell and ask them to explain why these T cells are called cytotoxic.



(An antibody binds to a specific part of an antigen molecule, often called an epitope.

<https://thebiologyblogs.wordpress.com/2018/11/10/helper-t-cells-and-cytotoxic-t-cells/>)

The descriptions of cytotoxic T cells and phagocytic cells will introduce or reinforce the Disciplinary Core Idea that “systems of specialized cells within organisms help them perform the essential functions of life”.

The driving question for this activity is presented in question 3, which is intended to stimulate a class discussion. If students respond that the immune system “learns” how to defend against the coronavirus, you may want to ask probe questions. You may also want to display a consensus hypothesis or several hypotheses to be evaluated as students learn more during this activity. Then, you can revisit the hypotheses when you discuss questions 10-11.

In the figure at the top of page 2 of the Student Handout, the first graph shows that the production of antibodies against the coronavirus is very low during the first week after a first exposure to the coronavirus. The cartoon figure on the same page shows what happens during this time. Antigen-presenting cells take up coronaviruses and present antigen to helper T cells that stimulate the B cells that can mature into cells that produce antibodies that can bind to the

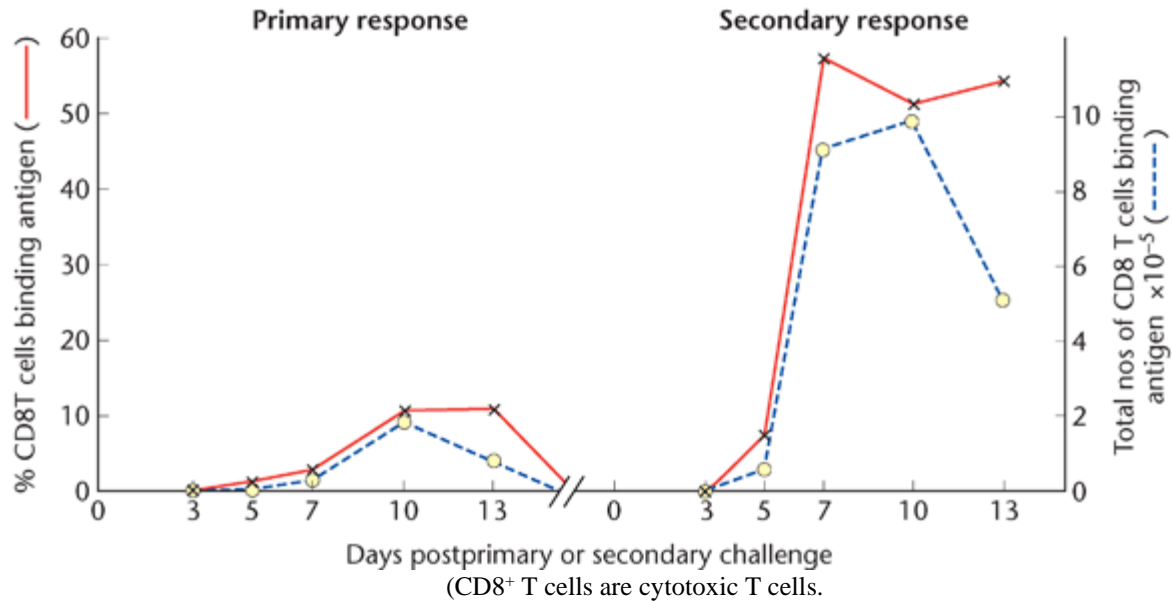
⁷ The adaptive immune system includes the B cells, antibodies, helper T cells, and cytotoxic T cells. The adaptive immune system responds slowly the first time a person is infected with a virus. The response of the adaptive immune system is much faster and stronger if the person is exposed to the same virus again.

The innate immune system includes the phagocytic cells and a variety of molecules that help to fight infections. The innate immune system has a fast response each time a person is infected, but it often needs help from the adaptive immune system to clear an infection.

A crucial property of the immune system is that it responds to foreign antigens (e.g., molecules in invading viruses or bacteria). When it is functioning properly, the immune system does not respond to molecules that are part of the person's own body.

coronavirus antigens.⁸ These B cells multiply; some of the resulting B cells mature to produce antibodies, while others become memory B cells. After a second exposure to the same virus, memory B cells result in a faster and stronger antibody response.

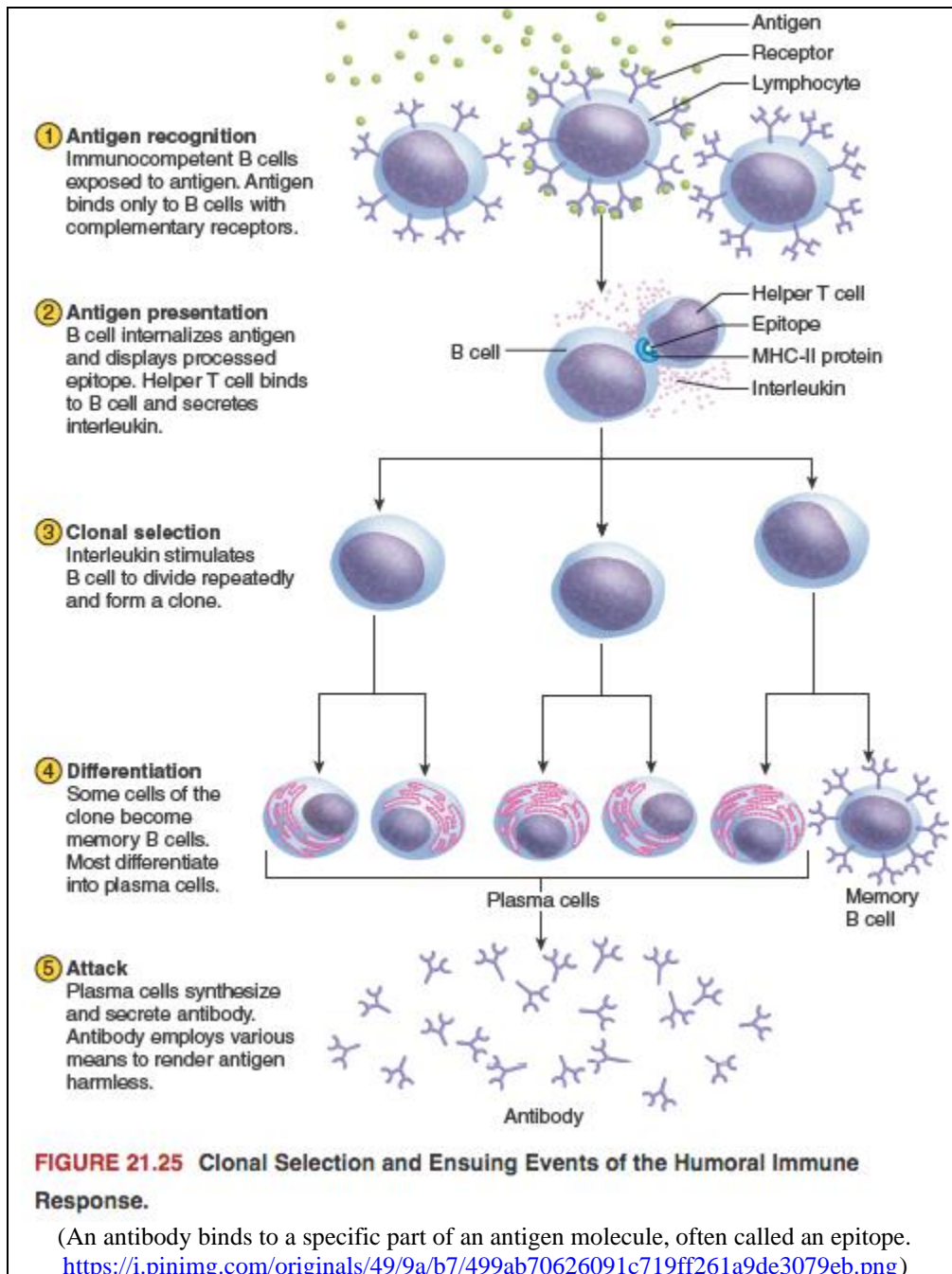
The figure below shows that, after a second exposure to the same virus, there is also a faster and bigger increase in cytotoxic T cells that respond to cells infected with that virus. This faster, bigger secondary response is due to the production of memory cytotoxic T cells during the primary response.



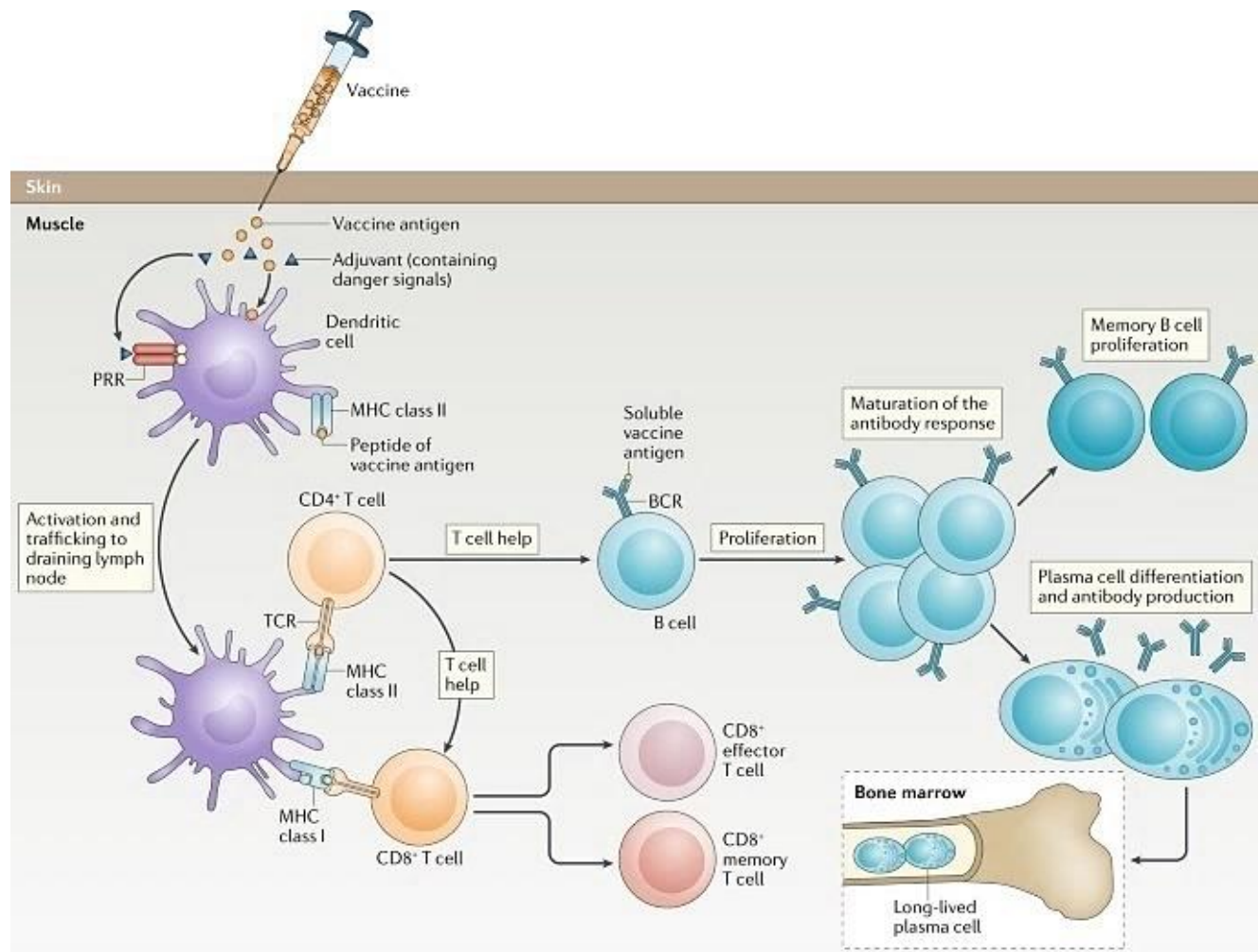
<https://novel-coronavirus.onlinelibrary.wiley.com/cms/asset/182143ad-a94b-4315-acc1-2a352003c1e7/nfgz002.gif>

The cartoon figure in the middle of page 2 of the Student Handout illustrates the NGSS Disciplinary Core Idea, “Systems of specialized cells within organisms help them perform the essential functions of life.” To avoid undue complexity, this cartoon figure omits cytotoxic T cells, memory cytotoxic T cells, and memory helper T cells; these are discussed on the top of page 3 of the Student Handout and shown in the figure on the same page. Although the cartoon figure shows a single antigen-presenting cell, a single helper T cell, and a single initial B cell, there are multiple cells of each type. The same caution applies to the figure on page 3 of the Student Handout. You may want to clarify that an immune response to an antigen activates only the B cells and T cells that can respond specifically to that antigen (see 1-2 in the figure below).

⁸ The cartoon figure on the middle of page 2 of the Student Handout refers to the spike protein as the antigen that stimulates the immune response. This is accurate for the mRNA vaccines, but incomplete for a coronavirus infection, which introduces multiple viral proteins that act as antigens and stimulate production of antibodies that can bind to these varied viral proteins.



Many aspects of the complex immune system are omitted from the Student Handout. The figure on the next page shows additional aspects of the immune response in the context of the immune response to a vaccine that contains the coronavirus spike protein (e.g., the Novavax vaccine). For example, some B cells mature into long-lived plasma cells which travel to the bone marrow and continue to produce antibodies over relatively long periods of time; thus, the long-lived plasma cells contribute to immunity after a vaccination or an initial infection. For simplicity, long-lived plasma cells are not mentioned in the Student Handout.



The Immune Response Following Vaccination with a Protein Antigen

The vaccine is injected into muscle, and the protein antigen is taken up by dendritic cells (a type of antigen-presenting cell), which travel to lymph nodes. In the lymph nodes, the dendritic cells present antigen to activate CD4⁺ helper T cells. The activated CD4⁺ helper T cells stimulate B cells to multiply and develop into plasma cells. Short-lived plasma cells secrete antibodies specific for the vaccine protein, resulting in increased serum antibody levels over the next few weeks. Long-lived plasma cells travel from the lymph nodes to the bone marrow where they can continue to produce antibodies for decades. CD8⁺ effector T cells (*cytotoxic T cells*) kill infected body cells. When a person is exposed to the same antigen again, memory B cells and CD8⁺ memory T cells proliferate rapidly to produce a fast and effective immune response. (<https://www.nature.com/articles/s41577-020-00479-7>)

If you want to learn more about immune responses, I recommend the following resources.

- Understanding the Immune System in One Video (15 minutes; <https://www.youtube.com/watch?v=jBpv9fYSU4>)
- Coronavirus: How It Infects Us and How We Might Stop It (minutes 26-52 of <https://www.scientificamerican.com/video/coronavirus-how-it-infects-us-and-how-we-might-stop-it/>).
- How the Body Reacts to Viruses (<https://onlinelearning.hms.harvard.edu/hmx/immunity/>)

Understanding the immune system response to a coronavirus infection can help students to understand two of the tests for coronavirus infection. A sample of blood can be tested for antibodies against the novel coronavirus. If these antibodies are found, this indicates that the person has had a coronavirus infection. However, a failure to detect these antibodies does not

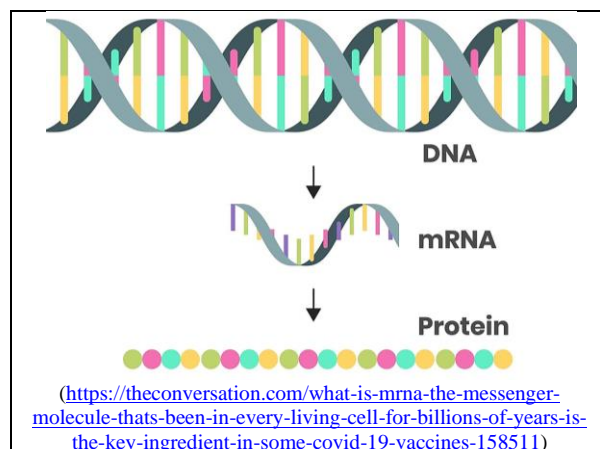
establish that the person never had Covid-19; e.g., the infection may have occurred so long ago that the antibody levels are too low to be detected (<https://www.the-scientist.com/news-opinion/can-taking-a-test-now-tell-you-if-you-ve-already-had-covid-19-70332>). The rapid antigen test (home test) evaluates whether a person has a current infection by testing whether a nasal sample contains coronavirus proteins that react with test antibodies; this test is less sensitive and more prone to false negatives than the PCR test which tests for coronavirus RNA. Good explanations of the different types of tests are available at <https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/testing.html> and <https://www.fredhutch.org/en/research/diseases/coronavirus/serology-testing.html>.

How Covid-19 Vaccines Work

The figure on page 3 of the Student Handout presents an overview of how the mRNA vaccines prevent Covid-19.

If your students are not familiar with mRNA, you can introduce mRNA, using this figure, together with the 5-minute video, “What Is DNA and How Does It Work?”

(<https://www.statedclearly.com/videos/what-is-dna/>; explain that the RNA shown in the video is mRNA, which stands for messenger RNA.)

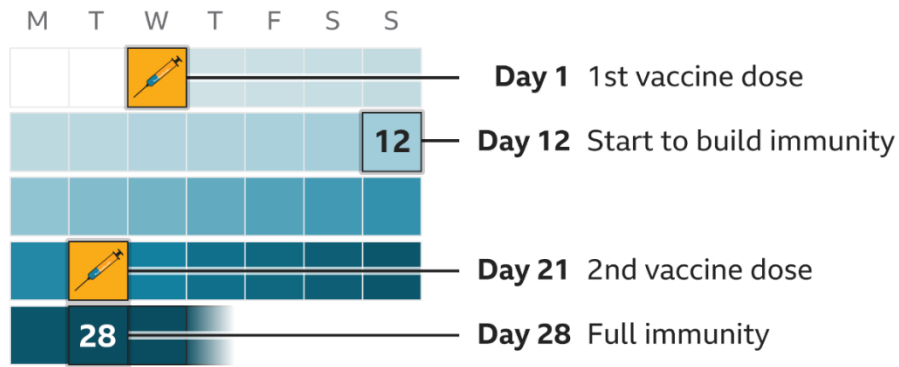


After an mRNA vaccine is injected, the mRNA is taken up by muscle cells and/or white blood cells, which are represented by the large cell near the top of the figure on page 3 of the Student Handout. To prevent misunderstanding, I suggest that you ask your students to identify distortions of relative size in this figure (the cells, coronavirus, and molecules are too big relative to the hypodermic needle; also, the top cell, coronavirus, and molecules are too big relative to the immune system cells shown in the bottom half of the figure).

You may want to supplement the explanation of mRNA vaccines with the 2-minute video, “How Covid-19 mRNA vaccines work” (<https://xvivo.com/blog/how-covid-19-mrna-vaccines-work-vaccine-makers-project/>). This video prominently mentions dendritic cells, which are one type of antigen-presenting cell (described in the cartoon figure on page 2 of the Student Handout).

The two mRNA vaccines approved for use in the US by the beginning of 2022 were developed by Moderna and by Pfizer and BioNTech. Both the Moderna and Pfizer/BioNTech vaccines require two injections, separated by three or four weeks. Immunity develops gradually during the weeks after the first and second doses, as shown in the graphic below for the Pfizer vaccine.⁹ Notice that the development of immunity after the first vaccine dose follows a time course that is similar to the time course for the development of immunity after an infection. Question 8a calls students’ attention to other similarities between the immune response to vaccination and the immune response to natural infection; the biggest advantage of vaccination is that it is much safer.

⁹ The vaccine efficacy data summarized on page 2 of these Teacher Notes begin about two weeks after the second vaccine dose.

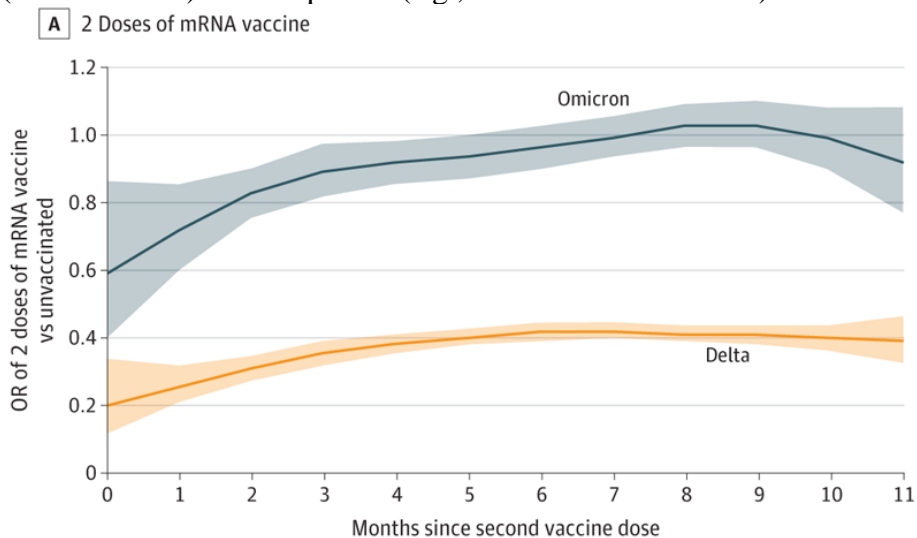


(<https://www.bbc.com/news/health-55244122>)

In response to question 8b, students may suggest that the second vaccine injection stimulates the production of more memory cells. In addition, the second vaccine injection stimulates B cells to produce antibodies that have increased affinity for the spike protein of the coronavirus (through mutations followed by selection of appropriate B cells).

Question 8c asks students about possible reasons why a vaccinated person might benefit from an additional booster shot. Over time, memory cells may become less functional or even die. Also, new variants of the coronavirus have altered spike proteins that are less well recognized by the immune defenses. The effectiveness of the mRNA vaccines in preventing Covid-19 has decreased over time, due to changes in the immune system of vaccinated people and changes in the coronavirus antigens. This is illustrated in the figure below. An odds ratio of 1 indicates that, by six months after vaccination, two doses of mRNA vaccine did not protect against infection by Omicron (although two doses of vaccine did protect against severe Covid-19). The lower odds ratios for the Delta variant indicate that vaccination resulted in relatively strong and persistent protection against infection by the Delta variant. Two doses plus a booster provided better protection than two doses alone

(https://jamanetwork.com/journals/jama/fullarticle/2788487?utm_campaign=articlePDF&utm_medium=articlePDFlink&utm_source=articlePDF&utm_content=jama.2022.0470). Notice that the effectiveness of immune defenses against SARS-CoV-2 depends on characteristics of the coronavirus (which variant) and the person (e.g., time since vaccination).



(OR = odds ratio; for an explanation of odds ratio, see <https://psychscenhub.com/psychpedia/odds-ratio-2/>; figure from https://jamanetwork.com/journals/jama/fullarticle/2788485?guestAccessKey=ccd57888-8fd5-4d31-9a19-82ee2b987521&utm_source=silverchair&utm_campaign=jama_network&utm_content=covid_weekly_highlights&utm_medium=email)

Question 9 introduces the important topic of the safety of these vaccines. For more information about vaccine safety and the rapid development of the mRNA vaccines, see Appendix 2 at the end of these Teacher Notes.

The top part of page 4 of the Student Handout helps students understand why coronavirus infections vary in severity, ranging from asymptomatic infections in some people to fatal illness in some others. If a person's immune system responds quickly and effectively to prevent the coronavirus from replicating, she or he may have an asymptomatic infection.¹⁰ People with symptomatic infections can have relatively mild and self-limiting infections or severe Covid-19, which in the US is defined as Covid-19 that results in hospitalization and/or death. A delayed and excessive immune response appears to contribute to severe Covid-19 (<https://serendipstudio.org/exchange/bioactivities/coronavirusintro>).

Question 10 returns to the driving question introduced in question 1. I recommend that you expand your discussion of student answers to questions 10 and 11 to include the reasons why prior Covid-19 protects against future severe Covid-19. During your class discussion of student answers to these questions, you may want to refer back to the hypotheses from your discussion of question 1.

Question 11 further develops the important point that immunity is variable, not absolute. The data provided in the table immediately preceding question 11 indicate very good protection against mild or moderate Covid-19 and even stronger protection against the risk of severe Covid-19. The data shown are from the clinical trial for the vaccine made by Moderna (<https://www.nejm.org/doi/full/10.1056/NEJMoa2035389>). The results of the clinical trial for the Pfizer/BioNTech vaccine were similar. I recommend that you emphasize the excellent protection against severe Covid-19 (defined as Covid-19 that requires hospitalization or results in death). To help your students meet the challenge of answering question 11, you may want to mention that the number and effectiveness of memory cells formed after vaccination varies between individuals. For some people, the memory cells produce an immune response that is not fast and strong enough to prevent mild or moderate Covid-19, but is sufficient to prevent a severe case of Covid-19 (<https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/vaccine-induced-immunity.html#print>).

Previous infection produces immune responses that are even more variable than the responses to vaccination. This is one reason why Covid-19 vaccinations are recommended even for people who have already had COVID-19. For previously infected people, vaccination increases immune defenses and decreases the risk of reinfection (<https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/vaccine-induced-immunity.html#print>).

The bulleted paragraph at the bottom of page 4 of the Student Handout continues the theme that the protection provided by a vaccine is not absolute, but varies by the characteristics of the person and the coronavirus exposure. For example, elderly people and cancer or transplant patients who are immunosuppressed have weaker immune systems, so they are more vulnerable to severe Covid-19, even if they have been vaccinated. Also, recent variants of the coronavirus have evolved the ability to evade our immune defenses, so reinfections have become more common (see “Coronavirus Evolution and the Covid-19 Pandemic”,

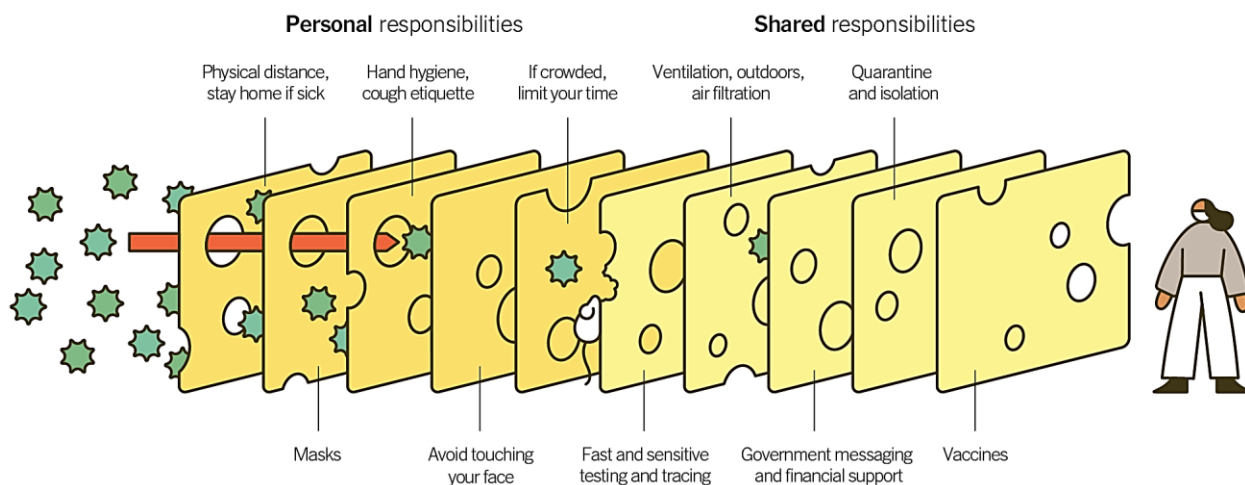
¹⁰ The Student Handout does not mention that many initial coronavirus infections are asymptomatic, especially in children. Asymptomatic and pre-symptomatic infections play a major role in spreading coronavirus infections (see “How to Reduce the Spread of COVID-19; <https://serendipstudio.org/exchange/bioactivities/coronavirusprev>).

<https://serendipstudio.org/exchange/bioactivities/coronavirusOrigin>). Both Moderna and Pfizer/BioNTech have developed updated vaccines that stimulate immune protection against the current Omicron subvariants, as well as the original coronavirus (<https://www.verywellhealth.com/what-is-a-bivalent-vaccine-6385845>); these bivalent vaccines are available as boosters, beginning in September 2022.

Question 12 will remind students that some people will continue to be vulnerable to severe Covid-19 and students can protect these people by getting vaccinated (to reduce the risk that they will become infected and transmit the coronavirus), getting tested before interacting with a vulnerable person, and wearing effective masks. You can also show your students the figure below, which conveys the basic point that **no single type of prevention is foolproof**, so multiple preventive actions have the best chance to stop the Covid-19 pandemic. Thus, we need a combination of vaccination, public health measures, and individual responsibility to minimize the risks due to the spread of the coronavirus.

Multiple Layers Improve Success

The Swiss Cheese Respiratory Pandemic Defense recognizes that no single intervention is perfect at preventing the spread of the coronavirus. Each intervention (layer) has holes.



(<https://www.nytimes.com/2020/12/05/health/coronavirus-swiss-cheese-infection-mackay.html>)

For a supplementary illustrated guide to how mRNA vaccines work, see <https://www.inquirer.com/health/coronavirus/a/covid-19-coronavirus-vaccine-rna-science-20210122.html>. For a more detailed explanation of how mRNA vaccines work, you may want to view:

- the ~3-minute video available at <https://www.cas.org/blog/covid-mrna-vaccine#:~:text=mRNA%20vaccines%20trigger%20the%20body's,antibody-mediated%20immunity%2C%20respectively>
- the 16-minute video, “How does an mRNA vaccine work?”, available at (https://www.youtube.com/watch?v=elz2-vwBhlY&fbclid=IwAR0e65NplkyXt1oe-wBYeI1T7zGQx92b5oGz_K2-8ioDHOWe2jiZZ8selected and zS68); one error in this informative video is the speaker’s failure to recognize that the vaccine is thawed before it is injected)

An informative (although somewhat quirky) explanation of the molecular biology of the RNA in the Pfizer vaccine is available at <https://berthub.eu/articles/posts/reverse-engineering-source-code-of-the-biontech-pfizer-vaccine/>.

As of September 2022, two other vaccines have been approved for use in the US. The vaccine that is made by Novavax contains a spike protein (see figure on page 6 of these Teacher Notes; <https://www.washingtonpost.com/health/2022/07/13/covid-vaccine-tech-novavax/>). The other vaccine, made by Johnson & Johnson, uses an inactivated adenovirus to carry DNA with the spike protein gene into the nucleus of cells, where mRNA for the spike protein is produced. One advantage of both of these vaccines is that they do not require freezer storage. The FDA generally recommends against use of the Johnson & Johnson vaccine because of the risk of a rare blood clotting syndrome (0.5 deaths per million doses of vaccine; <https://www.washingtonpost.com/health/2022/05/05/fda-johnson-and-johnson-vaccine/>).

Other types of vaccines have been approved for use in other countries. All of these vaccines work by stimulating the production of memory cells (and long-lived plasma cells; see pages 5-6). If you would like to learn more about how vaccines are developed, how they work, and different types of Covid-19 vaccines, the following sources provide reliable information.

- Vaccine Testing and the Approval Process (<https://www.cdc.gov/vaccines/basics/test-approve.html>)
- Ensuring the Safety of Vaccines in the United States (<https://www.cdc.gov/vaccines/hcp/conversations/ensuring-safe-vaccines.html>)
- A guide to vaccinology: from basic principles to new developments (<https://www.nature.com/articles/s41577-020-00479-7>)
- A gamble pays off in “spectacular success”: How the leading coronavirus vaccines made it to the finish line (<https://www.washingtonpost.com/health/2020/12/06/covid-vaccine-messenger-rna/>)
- Coronavirus Vaccines – An Introduction (https://www.youtube.com/watch?v=KMc3vL_MIeo)
- What Do Vaccine Efficacy Numbers Actually Mean? (<https://www.nytimes.com/interactive/2021/03/03/science/vaccine-efficacy-coronavirus.html>)
- COVID-19 Vaccine FAQ: Safety, Side Effects, Efficacy (<https://www.webmd.com/lung/news/20201217/covid-19-vaccine-faq-safety-side-effects-efficacy>)
- What do we know about Covid vaccines and preventing transmission? (<https://www.bmj.com/content/376/bmj.o298>)
- How nine Covid-19 vaccines work (<https://www.nytimes.com/interactive/2021/health/how-covid-19-vaccines-work.html>)
- Coronavirus Vaccine Tracker (<https://www.nytimes.com/interactive/2020/science/coronavirus-vaccine-tracker.html>)
- Omicron thwarts some of the world’s most-used COVID vaccines (<https://www.nature.com/articles/d41586-022-00079-6>)
- Innovators target vaccines for variants and shortages in global South (<https://www.nature.com/articles/d41587-021-00001-x>)
- How to Redesign Covid Vaccines so They Protect Against Variants (<https://www.nature.com/articles/d41586-021-00241-6>)

The development and testing of COVID-19 vaccines are producing new results every week. For regularly updated information, you and your students can consult the following sources of reliable information.

- Coronavirus (COVID-19) (<https://www.cdc.gov/coronavirus/2019-ncov/index.html> and <https://www.cdc.gov/coronavirus/2019-ncov/vaccines/stay-up-to-date.html#about-vaccines>)
- Science (<https://www.sciencenews.org/editors-picks/2019-novel-coronavirus-outbreak>)
- New York Times (<https://www.nytimes.com/news-event/coronavirus>)

There are several ways your students could pursue any questions that have not been answered yet.

- You could have students work in pairs or small groups to prepare a report using sources in these Teacher Notes and then present their results to their classmates, who should be encouraged to ask thoughtful questions. Class reports with discussion are useful for (1) sharing information, reinforcing learning, and clarifying important points, and (2) motivating students to develop a good understanding of the topic they are researching since they will need to be prepared to answer questions from their classmates and teacher.
- You could use the following steps to carry out a jigsaw activity using several related articles.¹¹
 1. Tell your class that they will read one article in their small group, summarize the main conclusions and evidence, and then share this information with a group of students who have read other articles.
 2. As students complete the reading individually, each of them should prepare a summary and possibly annotate the article.
 3. Have students who read the same article briefly share their findings with one another and discuss the article. This will help students prepare to briefly summarize their article in the mixed group.
 4. Regroup students so that one representative from each source is in each group. Ask students to briefly summarize their articles in their new groups. When sharing the summaries, students should make connections to what they have heard in the other students' summaries. They should talk through anything that is unclear or seems inconsistent from one source to the next. Students should take notes during this sharing, listening, and discussion process.
 5. Have a whole class discussion of the main takeaways from the jigsaw readings. Ask students what questions they are still wondering about and try to follow up.

Sources for Student Handout Figures

- Figure of coronavirus with antibodies, adapted from <https://www.nature.com/articles/d41586-020-01816-5>
- Figure of immune response to coronavirus infection, adapted from <https://www.thevaccinemom.com/2019/10/the-immune-system-in-a-nutshell/>
- Figure with antibody graphs, adapted from <http://www.as.wvu.edu/~rbrundage/chapter12b/sld016.htm>
- Figure of cytotoxic T cell, adapted from <https://i.pinimg.com/originals/d8/33/a1/d833a1b64f4500860fc804d8ea153b0b.jpg>
- Figure of mRNA vaccine effects, adapted from <https://www.washingtonpost.com/health/2020/11/17/covid-vaccines-what-you-need-to-know/?arc404=true>

¹¹ These instructions are adapted from <https://www.nsta.org/science-teacher/science-teacher-march-2020/novel-coronavirus>.

- Figure of exponential growth of coronavirus population, adapted from https://s.wsj.net/public/resources/images/B3-GL119_CHENG0_D_20200402114558.jpg

Related Activities

Coronavirus Evolution and the Covid-19 Pandemic

<https://serendipstudio.org/exchange/bioactivities/coronavirusOrigin>

In this analysis and discussion activity, students learn that the coronavirus responsible for the current pandemic very probably originated in bats. Students analyze how mutations and natural selection can produce a spillover infection. Next, students learn how natural selection increased the frequency of a mutation that made the coronavirus more contagious. Finally, students analyze how mutations contributed to the spread of the Omicron variant and its subvariants.

How to Reduce the Spread of COVID-19

<https://serendipstudio.org/exchange/bioactivities/coronavirusprev>

In this activity, students analyze information about how the coronavirus is transmitted and how to reduce the risk of coronavirus infection. Several questions engage students in thinking about how their behavior influences the risk of COVID-19 for more vulnerable individuals.

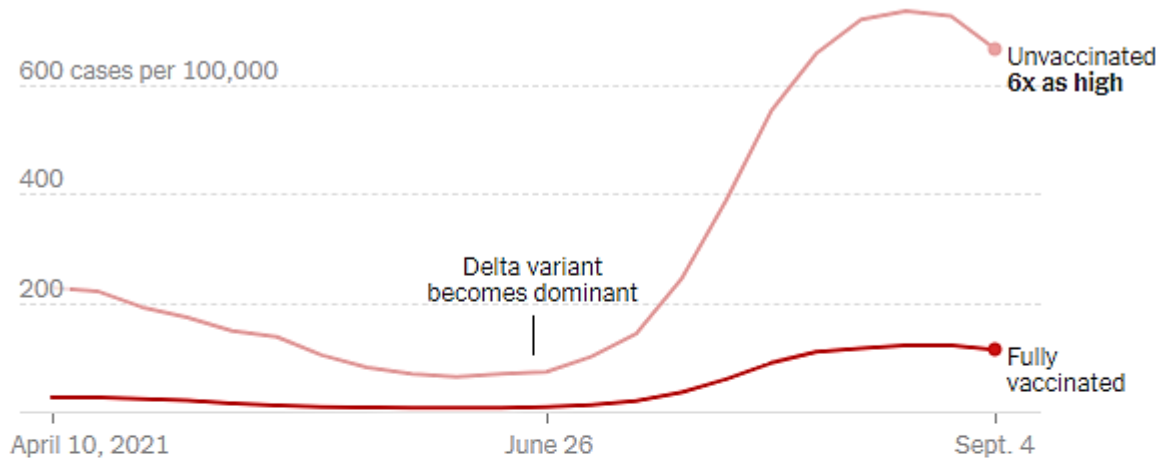
Resources for Teaching about Coronavirus

<https://serendipstudio.org/exchange/bioactivities/coronavirus>

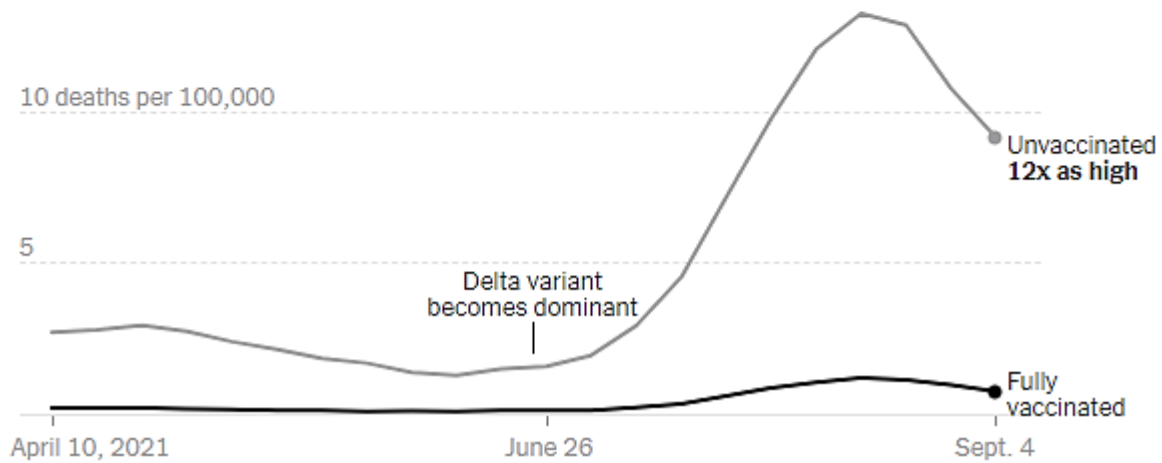
This webpage has compiled information about learning activities and other resources for teaching high school biology students about the coronavirus and Covid-19.

Appendix 1 – Recent Covid-19 Trends for Vaccinated vs. Unvaccinated People in the US

Average weekly cases by vaccination status



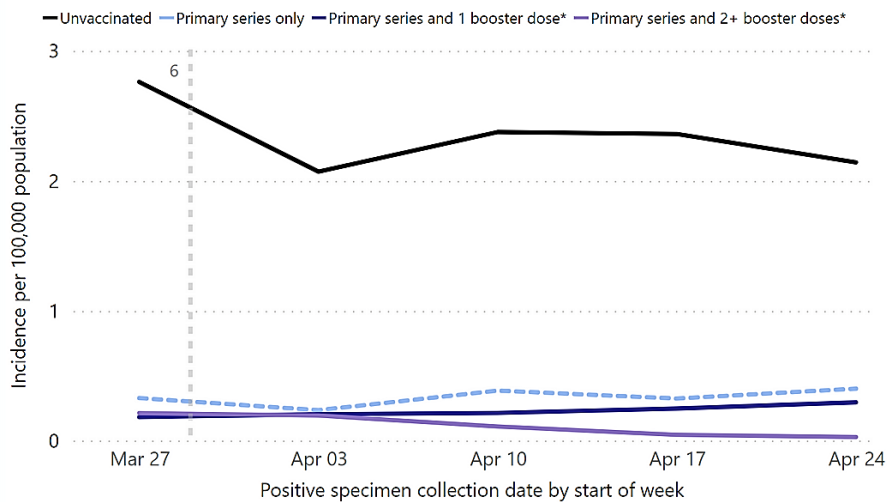
Average weekly deaths by vaccination status



(A fully vaccinated person has received two doses of vaccine separated by several weeks. The data are for 14 states and two cities in the US. As of October 2021, approximately 92% of vaccinated people in the US had received either of the mRNA vaccines and 8% had received the Johnson & Johnson vaccine; <https://www.nytimes.com/interactive/2021/10/28/us/covid-breakthrough-cases.html>).

Rates of COVID-19 Deaths by Vaccination Status and 2+ Booster Doses** in Ages 50+ Years

March 27, 2022–April 30, 2022 (18 U.S. jurisdictions)



In April 2022, among people ages 50 years and older, unvaccinated people had:

42X

Risk of Dying from COVID-19

compared to people vaccinated with a primary series and two or more booster doses.**

(During this time, almost all cases of Covid-19 in the US were due to the Omicron variant. Primary series refers to the first two doses of the vaccine. <https://yourlocalepidemiologist.substack.com/p/ba5-is-here-time-to-ride-the-wave>)

Appendix 2 – Rapid Development and Safety of the mRNA Vaccines

There are several reasons why the development, testing and initial production were much faster for the mRNA vaccines than for previous vaccines

(<https://www.washingtonpost.com/health/2020/12/06/covid-vaccine-messenger-rna/>).

- Researchers had been working for decades to develop the scientific understanding and technology needed to produce mRNA vaccines. (To help your students understand this point you may want to show them the 5-minute video, “The Miracle Workers: The Scientists Behind the Covid-19 Vaccines” (<https://time.com/6138566/pandemic-of-unvaccinated/>).
- mRNA vaccines are easier and faster to produce than conventional vaccines, which require cell cultures to produce proteins or inactivated or weakened virus.
- In response to the pandemic, governments and businesses invested a great deal of money to develop and test vaccines quickly and simultaneously ramp up production of these vaccines.

Some people worry that the rapid development of the vaccines means that they may not be safe. However, the clinical trials have confirmed the safety of these mRNA vaccines during the time period when most vaccine side effects usually occur. Fatigue and fever are common side effects, especially after the second shot. One reason for these side effects is that a vaccine activates phagocytes which release chemical signals that stimulate fatigue and fever, both of which help to fight an infection. Another reason is the expectation of these side effects, which were frequently reported, even by participants in clinical trials who received placebo injections.

Side effects that are rarer are being investigated by following up the millions of people who have been vaccinated. Because large numbers of people have been and will be vaccinated, there are bound to be unrelated health problems that emerge after vaccination just due to coincidence, similar to the health problems that emerged after injection of the placebo in the clinical trials. This is the reason why scientists distinguish between adverse events, which are any health

problems that happen after vaccination, and side effects, which are adverse events that are caused by the vaccination.

Systematic follow-up of vaccinated people has generally confirmed the safety of these vaccines. However, there are some very rare side effects.

- The estimated risk of anaphylaxis is less than or equal to approximately one case per 100,000 people vaccinated. Anaphylaxis is usually effectively treated with prompt injection of epinephrine; this is why vaccinated people should wait at the vaccination location for up to half an hour after being vaccinated (https://www.washingtonpost.com/health/covid-vaccine-allergic-reactions-study/2020/12/21/e01001d2-431a-11eb-b0e4-0f182923a025_story.html; <https://www.medscape.com/viewarticle/945313>).
- The estimated risk of heart inflammation (myocarditis and pericarditis) is roughly one case per 100,000 people vaccinated. Myocarditis and pericarditis have usually been mild and treatable (<https://www.medscape.com/viewarticle/960537#:~:text=%22The%20incidence%20of%20vaccine%2Drelated,first%20and%20second%20injections%2C%20respectively>).

The favorable safety profile fits with expectations that mRNA vaccines will be safe because:

- RNA is rapidly broken down. (The fragility of RNA molecules is the reason why the vaccines must be stored at very cold temperatures.)
- The mRNA provides the instructions to make only one of the proteins needed for the coronavirus, so there is no risk of producing a coronavirus that could cause an infection.
- mRNA does not affect the DNA.

For students who are concerned about the safety of these vaccines, you may want to suggest the following resources.

- Five things you need to know about mRNA vaccine safety (<https://horizon-magazine.eu/article/five-things-you-need-know-about-mrna-vaccine-safety.html>)
- What are the ingredients of Pfizer's Covid-19 vaccine? (<https://www.technologyreview.com/2020/12/09/1013538/what-are-the-ingredients-of-pfizers-covid-19-vaccine/>)
- Fact check: RFID microchips will not be injected with the Covid-19 vaccine, altered video features Bill and Melinda Gates and Jack Ma (<https://www.reuters.com/article/uk-factcheck-vaccine-microchip-gates-ma/fact-check-rfid-microchips-will-not-be-injected-with-the-covid-19-vaccine-altered-video-features-bill-and-melinda-gates-and-jack-ma-idUSKBN28E286>)