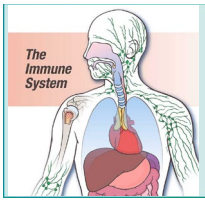


The Immune System

hhmi | BioInteractive

Click & Learn
Educator Materials

OVERVIEW

The Immune System Click & Learn illustrates the main organs, tissues, cells, and molecules that make up the human immune system. It presents the approximate timeline of the innate and adaptive responses that occur during the course of an infection. The timeline includes the differences between the first time a pathogen is encountered versus subsequent infections and how vaccines work.

The accompanying "Student Worksheets" incorporate concepts and information from the Click & Learn. The "General Immunology" worksheet is a guided exploration of the Click & Learn. The "Immunotherapy" worksheet applies the content in the Click & Learn to cancer immunotherapy. The "Vaccine Research Extension" worksheet guides students through an optional research project on vaccines. The worksheets can be modified based on your learning goals.

This document contains multiple resources for using the Click & Learn with students, including the following (click links to go directly to each section):

- general teaching tips for this resource
- suggested procedures for engaging students, using the Click & Learn, and using the student worksheets
- answer keys for the "General Immunology" and "Immunotherapy" worksheets

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

KEY CONCEPTS

- The human immune system is made up of many cells, organs, and tissues. Some prevent pathogens from entering the body, and some attack pathogens already inside the body.
- Most immune cells develop from stem cells in the bone marrow.
- The immune system responds to pathogens in two main ways: innate and adaptive immune responses. These types of responses communicate with and complement each other.
- The innate immune response is the body's first line of defense. It includes barriers to infection, phagocytes, mast cells, and inflammation.
- The adaptive immune response takes longer to mount but provides more specific protection against pathogens. It includes T cells, B cells, and antibodies.
- The immune system reacts to antigens, small molecules recognized by immune cells.
- After the first infection by a specific pathogen, the adaptive immune response can mount a greater and faster response (the secondary immune response) to subsequent infections.
- Vaccines stimulate an immune response to a weakened or partial pathogen so that the secondary immune response can occur when the real pathogen is encountered.

STUDENT LEARNING TARGETS

FOR THE "GENERAL IMMUNOLOGY" WORKSHEET:

- **PART 1**
  - Identify the main organs and cells of the immune system, and explain how they work together.
  - Describe the origin of the immune cells that might appear in a medical report.
- **PART 2**
  - Compare and contrast the innate and adaptive immune responses, and explain how they interact.

- Provide examples of how cells communicate with each other using cytokines.
- Explain the role of T cells, B cells, and antibodies during repeated infections with the same pathogen.

- **PART 3**
  - Explain the role of memory cells in responding to a previously encountered pathogen, and apply this knowledge to the function of vaccines.
  - Interpret graphs to support scientific explanations.

FOR THE "IMMUNOTHERAPY" WORKSHEET:

- **PART 1**
  - Explain how the body produces, selects, and replaces various types of immune cells.
- **PART 2**
  - Compare the innate and adaptive immune responses.
  - Explain how the innate and adaptive immune responses interact (e.g., how information is transmitted from one to the other).
- **PART 3**
  - Apply knowledge about the role of T cells and B cells in a secondary immune response to the function of vaccines.
- **PART 4**
  - Apply knowledge of the immune response and vaccines to a novel scenario: cancer immunotherapy.

FOR THE "VACCINE RESEARCH EXTENSION" WORKSHEET:

- Communicate current information about vaccines and disease.

PRIOR KNOWLEDGE

Students should know that:

- human bodies contain organs, tissues, and cells
- there are many different types of cells in the body
- cells differentiate to produce different cell types
- microbes include bacteria, viruses, and fungi

TEACHING TIPS

IMPLEMENTING THE ACTIVITY

- Provide students with a clear transparency statement about the purpose of the activity and what they will get out of doing it.
- Students can work individually or in small groups.
- The vocabulary associated with immunology can be overwhelming. Provide support for students learning new terms, which could include the following strategies:
  - Let students know they should **focus more on the main concepts than on specific terms.**
  - Show students the vocabulary support features in the Click & Learn. They can click on bold underlined terms throughout the Click & Learn to view their definitions. They can also refer to the "Glossary" (top-right tab) for the meaning of unfamiliar terms. However, stress to students that they are *not* expected to know all those terms.
  - Provide students with a short list of terms they *will* be expected to know.
  - Ask students to generate their own vocabulary cards, lists, posters, or other graphic organizers.

CLARIFICATIONS AND CAVEATS

- Vaccination is an example of a cultural controversy in which an idea that is not contested within the scientific community has become contentious because of different cultural perspectives or worldviews. It can be helpful to acknowledge students' concerns on this topic and highlight the scientific evidence and areas of scientific consensus.
- Talking about immune responses and infectious diseases may be difficult for students who may know people who, or who may themselves, have been affected by autoimmune diseases or infectious diseases.
  - Check in with students for their reactions and feedback, and offer support as needed.
  - Also be intentional about which analogies you use to describe the immune system. For example, depending on context, comparing the immune system to border patrol, immigration police, or a military force can have negative connotations and alienate some students.

EXTENSIONS AND SUPPLEMENTS

- You can use the "Vaccine Research Extension" worksheet, which can be downloaded from this resource's webpage, to have students research vaccines. More information is provided in the "Using the 'Vaccine Research Extension'" section below.
- To extend knowledge of the immune system to lab techniques, consider using the *Immunology Virtual Lab*, in which students perform a simulated enzyme-linked immunosorbent assay (ELISA).

PROCEDURE

Usage of the Click & Learn and its materials is flexible and can be adapted based on your classroom context. As a starting point, some suggestions are provided for the following (click links to go directly to each section):

STRATEGIES TO ENGAGE STUDENTS

Before starting the Click & Learn, you may want to engage your students' curiosity with one of the following strategies.

Strategy 1: Have students list the parts of the immune system (cells, organs, organ systems, etc.) they are familiar with.

- Ask students to volunteer what they have included on their lists. Then, have students discuss the role of each part in responding to infection.
- Keep this list for discussion after students have completed the Click & Learn. Students can also refer to this list when answering Question 7 in Part 1 of the "Student Worksheet (General Immunology)."

Strategy 2: Ask students to write a description of or discuss in small groups one time they were sick and had a fever. Ask them to include:

- How did it feel? What caused these feelings? When did they feel better? How long did it take for them to feel better?
- Have students revisit these descriptions after completing the Click & Learn. Ask them to add what they have learned about the immune system and immune response to what they recorded before.

Strategy 3: Have students discuss in small groups if each of the following statements is true or false. (*Note:* All these statements are false. After working through the Click & Learn, these statements should be revisited and discussed.)

- Having an autoimmune disease means you don't have an immune system.
- If you look okay after being sick, you must be better.
- Your immune system is concentrated in your upper body.
- The immune system functions independently of other systems throughout your body.
- If you get vaccinated against the measles, you will be protected from other viruses, like the virus that causes the flu.

USING THE CLICK & LEARN

The goal of the Click & Learn is to provide a thorough introduction to how the human body responds to pathogens. Videos, images, and a detailed glossary of terms allow this Click & Learn to be explored at varying levels of depth. Since the human immune system is amazingly complex, many aspects that are more advanced are simplified or not covered.

Due to the length and breadth of the Click & Learn, it is recommended to tailor which sections you use to your course learning objectives and students' needs. Some general recommendations are as follows:

- For **general high school biology and college introductory biology classes**, use the "Introduction" and "Barriers to Infection" sections under the "Immune System Anatomy" tab and the "Introduction" and "Timeline" sections under the "Immune Response" tab.
- For **anatomy and physiology classes**, focus on the "Immune System Anatomy" tab.
- For **microbiology classes**, focus on the "Immune Response" tab. You will probably want to supplement this content with additional readings and videos.

Some sections of the Click & Learn can be used to learn about specific concepts, such as the following:

- For **T cell selection and autoimmune disease**, use the "Thymus" section under the "Immune System Anatomy" tab.
- For **immune cell development from stem cells**, use the "Bone Marrow" section under the "Immune System Anatomy" tab.
- For a **comparison of the innate and adaptive immune responses**, use the "Innate Immune Response," "Adaptive Immune Response," and "Summary" sections under the "Immune Response" tab.
- For **inflammation, including fever and cytokines**, use the "Inflammation" section under the "Immune Response" tab.
- For **secondary immune responses and vaccines**, use the "Repeated Infections" section under the "Immune Response" tab.

Multiple "What Do You Think?" questions are strategically embedded throughout the Click & Learn. You may want to use these questions to encourage review and discussion, and as a means of formative assessment.

At the conclusion of the "Immune System Anatomy" section of the Click & Learn, and again after the "Immune Response" section, consider having students write responses to one or two of the following prompts (by filling in the "…" parts):

- Three things I learned today are… One thing I'm curious about is… One thing I don't understand is…
- I used to think... Now I think…
- This topic is hard because… I don't understand…
- Learning about…made today's work on the Click & Learn interesting. This helps me to better understand…

Use students' responses to formatively assess their understanding of the information presented in the Click & Learn. Trends in responses can show you where to plan differentiated instruction strategies to revisit or review certain concepts.

Using the "General Immunology" Worksheet

The "General Immunology" worksheet provides questions and scenarios that guide students in their exploration of the Click & Learn. This worksheet is divided in three parts: immune system anatomy, immune response, and vaccines.

You may want to provide students with one part of the worksheet at a time. **You may also choose to have students work on some parts but not others.** If you are using the entire worksheet, consider dividing students' work into several sessions.

Using the "Immunotherapy" Worksheet

The "Immunotherapy" worksheet is also divided into sections that correspond to those in the Click & Learn. Overall, it is much shorter than the "General Immunology" worksheet and focuses on the interactions between the innate and adaptive immune response. It ends by applying the concepts to cancer immunotherapy.

Consider using Parts 1 and 2 as questions during a lecture on the immune system, in which you explore the Click & Learn as a class; students can answer the questions in a discussion or using polling software. You can then use Parts 3 and 4 as a homework assignment.

For an extension activity, students can research other types of cancer immunotherapies that have been approved by the FDA or are currently in clinical trials, such as:

- Pembrolizumab (Keytruda), which targets a protein (PD-1) that keeps T cells from attacking cells in the body (including cancer cells).
- Chimeric antigen receptor (CAR) T-cell therapy, which involves taking a patient's T cells and attaching receptors for cancer-specific antigens.
- Antibodies linked to chemotherapy drugs. These antibodies bind to proteins produced in large amounts by cancer cells.
- Oncolytic virus therapy, in which an adenovirus carrying a prostate-specific antigen (PSA) infects cells, triggering the immune system to target PSA throughout the body (including in prostate cancer cells).

Using the "Vaccine Research Extension"

The "Vaccine Research Extension" worksheet guides students through researching a disease and an associated vaccine. The worksheet provides specific questions and a rubric that can be used to evaluate students' work. It can be used on its own or paired with another worksheet.

Make sure to provide students with guidance about what you expect in terms of presentation, any preferred format for references, and how to work together as a group (if applicable).

If students are not familiar with how to identify reliable sources of scientific information, you may want to spend some time going over the criteria used. The BioInteractive activity "Evaluating Science in the News" discusses some example criteria.

In addition, you may choose to provide students with some specific references they can use. Examples in the United States include these websites:

- Main CDC website
  - Epidemiology and Prevention of Vaccine-Preventable Diseases
  - Summary of Notifiable Infectious Diseases
- National Network for Immunization Information

ANSWER KEY (GENERAL IMMUNOLOGY)

The answers below may include more detail than would be provided by most students. They are meant to give additional information that you may want to discuss with students.

PART 1: INTRODUCTION TO IMMUNE SYSTEM ANATOMY

1. The body has physical and chemical barriers to prevent pathogens from entering and infecting tissues.
   a. Having a runny nose (and blowing your nose) protects your body from pathogens. How do you think that works?
   Cells that line the inside of the nose are covered in sticky mucus, which traps pathogens. When you have a runny nose, these cells are making more mucus. Blowing your nose helps to eliminate the mucus and the pathogens trapped in it.
   b. Why do cells that line the respiratory tract (including the nose and lungs) have hairs?
   The hairs sweep mucus and pathogens out of the body.
2. The table below is an example "report" from a blood test. It shows the numbers of five different cell types in a person's blood. It also shows the expected ranges of numbers if the person is currently healthy. (These values are just examples — other people's might be different.)

Type of cell	**Number of cells** (per microliter of blood)	**Expected number of cells** (per microliter of blood)
Neutrophils	4,165	1,560–6,450
Lymphocytes (T cells, B cells, NK cells)	1,050	950–3,070
Eosinophils	142	30–480
Monocytes	519	260–810
Basophils	24	10–80

   a. Where in the body are these types of cells produced?
   They are produced in the bone marrow.
   b. Are this person's numbers of immune cells within their expected ranges? If not, which cell types are *not* within their expected ranges?
   All the numbers of cells (per microliter of blood) are within their expected ranges.
3. Below is a similar report for an adult with **leukemia**, a cancer of immune cells. Cancer is caused by uncontrolled cell division.

Type of cell	**Number of cells** (per microliter of blood)	**Expected number of cells** (per microliter of blood)
Neutrophils	2,580	1,560–6,450
Lymphocytes (T cells, B cells, NK cells)	124	950–3,070
Eosinophils	30	30–480
Monocytes	2,280	260–810
Basophils	60	10–80

a. Which parts of this report might show that this person has leukemia? Be specific.
The number of monocytes (2,280 cells/microliter) is much higher than expected (260–810 cells/microliter). These results could indicate uncontrolled division of immune cells, which is indicative of leukemia.

Students may wonder why the number of lymphocytes is lower than expected. This can happen if the monocytes crowd out other blood cells. Different types of leukemias have different symptoms and numbers of cells.

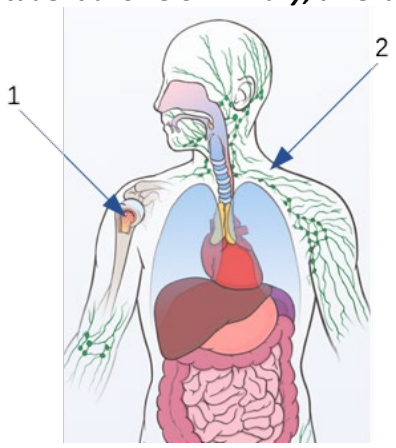
b. One treatment for leukemia is a **bone marrow transplant**. First, doctors use various methods to kill the cancer cells in the person's body. They can then replace these cells with stem cells from the bone marrow of a person without leukemia. Why might a bone marrow transplant help a person with leukemia?
Immune cells develop from blood stem cells in the bone marrow. When a person has leukemia, it could be because their blood stem cells or the resulting immune cells are dividing uncontrollably. A bone marrow transplant replaces these stem cells with new stem cells, which should divide at more controlled rates and produce the appropriate numbers of immune cells.

4. In very rare cases, a baby may be born without a thymus. How might this affect their immune system?
T cells develop in the thymus, so a baby without a thymus might not be able to produce fully developed T cells. Without T cells, the baby could be more likely to get infections. (Students may also suggest that other parts of the baby's immune system could help compensate for their lack of T cells.)

5. When a person is sick, a doctor may check the lymph nodes under their jaw and on each side of their neck. Swollen lymph nodes can be a sign that the body is responding to an infection. Why do you think this is?
Lymph nodes are organs with a variety of immune cells. When you are infected by a pathogen, the lymph nodes may swell due to increased immune cell activity. (Students will learn more about inflammation in the "Immune Response" tab.)

6. An athlete injured their spleen during a game. At the hospital, doctors removed the spleen and then recommended that the athlete get all their vaccines, including the flu vaccine. **Vaccines** are medicines that help protect the body from infections. Explain why getting vaccines would be particularly important for someone without a spleen.
The spleen is an organ that contains many immune cells (such as phagocytes, B cells, and T cells) that are important for destroying pathogens. If a person's spleen is removed, they might not have as many immune cells to respond to infections. Getting vaccines can help protect the person from some of these infections. (Students will learn more about vaccination in the "Immune Response" tab.)

7. Label **two** organs of the immune system on the figure below, and explain how they work together.
Student answers will vary; an example is shown below.



The two organs I chose are the bone marrow (1) and lymph nodes (2). The bone marrow produces immune cells, which include phagocytes, B cells, and T cells. Once these cells leave the bone marrow, they can eventually enter the lymph nodes, where they help destroy pathogens.

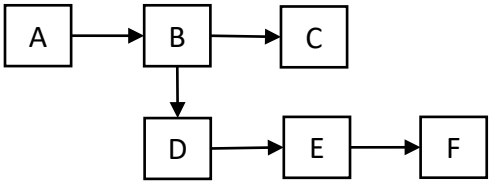
PART 2: IMMUNE RESPONSE

8. Determine whether each statement in the table below is true or false. Write your decision in the "True or False?" column.

Statement	True or False?
Innate immune cells can distinguish between specific types of viruses and bacteria.	***False***
Innate immune cells can activate other types of immune cells.	***True***
The innate immune response provides longer-lasting protection than the adaptive response.	***False***
The innate immune response includes phagocytes and proteins.	***True***

9. Cytokines are often referred to as "messengers." Provide **two** examples of "messages" that cytokines can deliver, and describe how cells or the body respond to each message.
Student answers will vary. Examples include the following:
   - ***Some cytokines signal the brain to raise the body's temperature, causing a fever.***
   - ***Some cytokines attract immune cells to the site of an infection.***
   - ***Some cytokines activate other cells to destroy pathogens, remove dead cells, or repair damaged tissues.***

10. Examine the diagram below. It represents some of the steps (A to F) that can occur when a person is infected.



Assign each letter in the diagram to a step in the table below. Some of the letters have already been filled in as examples.

Steps	Letter
Phagocytes with antigens on their surface activate T cells to start the adaptive immune response.	***E***
Pathogens get through the body's physical and chemical barriers.	***A***
Innate immune cells, which include phagocytes, respond to the pathogens.	***B***
Pieces of pathogens (antigens) attach to proteins on the surface of phagocytes.	D
The adaptive immune response destroys the pathogens, and the infection ends.	***F***
The innate immune response destroys the pathogens, and the infection ends.	C

11. In two or three sentences, describe how the innate and adaptive immune responses interact.
Student answers will vary. An example response is as follows:
Some cells from the innate immune response — such as dendritic cells and macrophages — engulf and destroy pathogens, then "display" antigens from these pathogens on their surfaces using MHC proteins. These antigen-MHC complexes bind to and activate T cells, which activate other cells in the adaptive immune response. The adaptive immune response can also strengthen the innate response by producing cytokines and antibodies, which promote inflammation, phagocytosis, etc.

12. Fill in the table below…

Immune response	
Innate immune response	**Adaptive** immune response
skin and mucous membranes	***cell-mediated immune response***
inflammation	***humoral immune response***
fever	

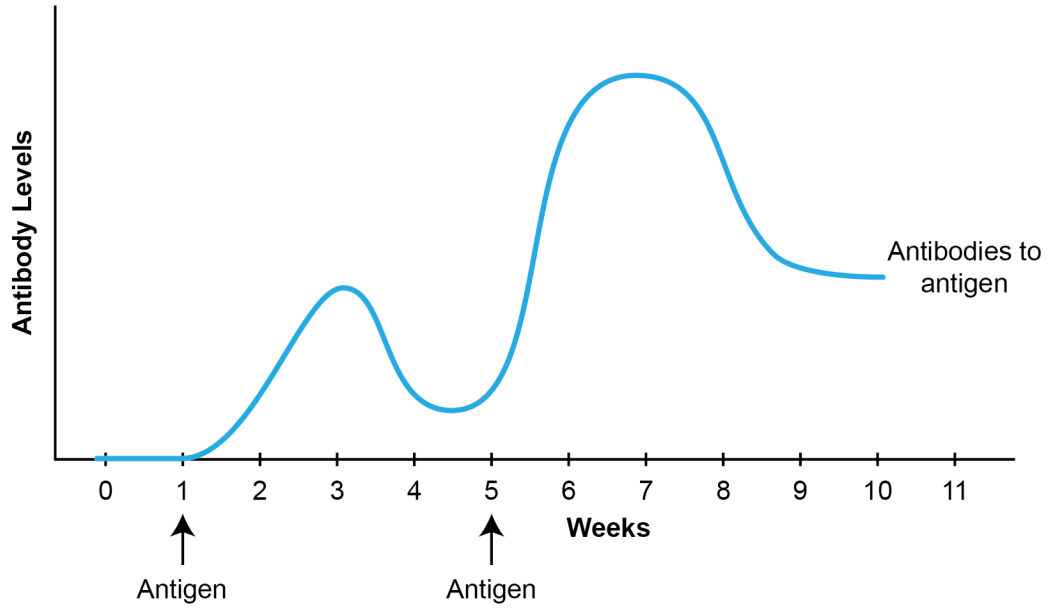
13. Hypogammaglobulinemia is a medical condition in which you have low levels of antibodies. People with hypogammaglobulinemia tend to get a lot of infections. Why do you think this is?
Antibodies can neutralize pathogens and mark them for destruction. If your body does not produce enough antibodies, the body might not be able to neutralize or destroy pathogens as effectively, resulting in more infections.

14. Explain the difference between an antibody and an antigen.
An antigen is a piece of biological material (protein, nucleic acid, carbohydrate, or lipid) that can trigger an immune response. An antibody is a specific protein produced by immune cells in response to a specific antigen. Antibodies bind to antigens.

15. What does it mean to say that the adaptive immune response has "memory"?
Some of the T and B cells that responded to a pathogen stay in the body. These cells, called memory cells, can respond quickly to a new infection with the same type of pathogen. The presence of these cells represents a "memory" of that specific pathogen.

PART 3: VACCINES

16. The figure below shows the antibody levels of an individual who was injected with a specific antigen. The individual was injected with this antigen twice: once in Week 1 and again in Week 5.



a. Which cells produce antibodies?
Either B cells or plasma cells are acceptable answers. B cells develop (differentiate) into plasma cells, which produce antibodies.

b. Between the first and second antigen injections, when are antibody levels the highest?
Around Week 3

c. Describe **two** differences between the antibody levels after the first and second injections.
Student answers will vary. They may indicate that the antibody levels were higher, and rose more rapidly, after the second injection compared to the first.

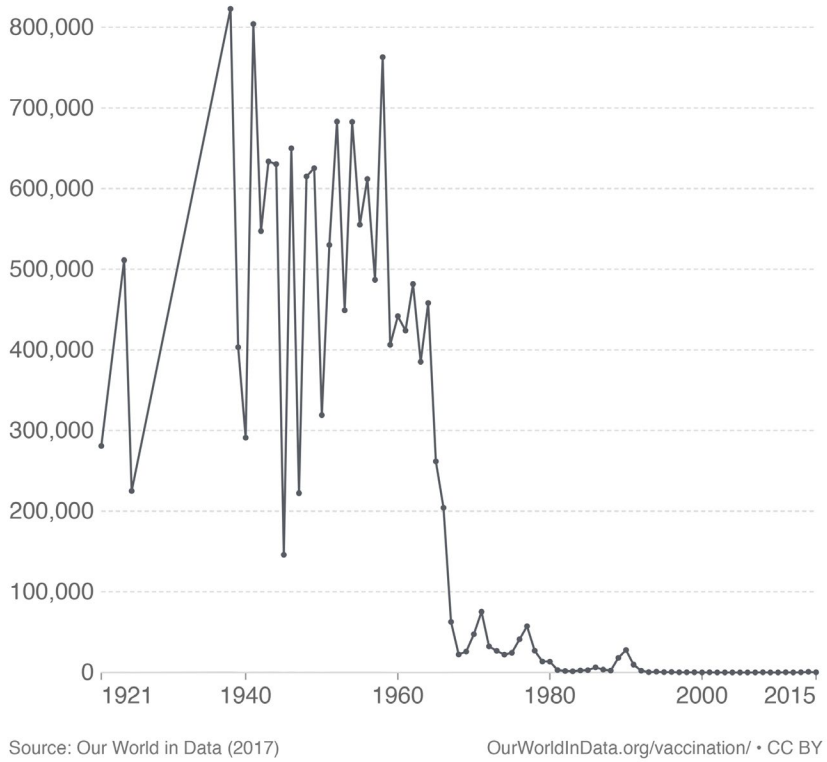
d. What might explain the differences you described?
It takes longer to activate B cells and produce antibodies after the first injection. After the second injection, memory B cells can start producing antibodies right away. As a result, we see more antibodies being produced more quickly after the second injection.

17. The table below lists the four main types of vaccines.
a. Complete the table with a short description of what the vaccine consists of.

Type of vaccine	**Description**
Live-attenuated	***weakened, harmless form of a pathogen***
Inactivated	***killed or inactive version of a pathogen***
Subunit/recombinant	***specific pieces of a pathogen, like part of a protein***
Toxoid	***an inactivated toxic substance produced by a pathogen***

b. Explain why vaccines do *not* cause disease.
Vaccines do not contain a form of the pathogen that can cause disease. They either use a part of the pathogen that is harmless on its own or a form of the pathogen that is harmless (because it has been killed or weakened).

18. The graph below shows how many cases of measles were reported in the United States from 1921 to 2015. **Measles** is an infectious disease caused by a virus.



The measles vaccine has been available in the United States since 1963. What happened to the number of reported measles cases at that time?
The number of reported measles cases significantly decreased after 1963. After around 1990, the number of reported cases each year appears negligible. (To have students explore the case numbers in more depth, consider using the interactive version of this graph.)

ANSWER KEY (IMMUNOTHERAPY)

PART 1: ORGANS OF THE IMMUNE SYSTEM

1. The thymus is essential for preventing the immune system from attacking self-antigens.
   a. Define "antigen" and "self-antigen."
   Antigens are small pieces of biological material (protein, carbohydrate, lipid, or nucleic acid) that can be recognized by the immune system. Self-antigens are antigens that are part of a person's body.

   b. What happens to T cells that bind to self-antigens?
   They are destroyed (through apoptosis).

   c. What type of condition may be caused by T cells that bind to self-antigens?
   An autoimmune disease (such as rheumatoid arthritis)

2. How does the body replace immune cells and red blood cells that have died? Where does this process occur?
   Blood stem cells develop (differentiate) into new immune cells and red blood cells. This process occurs in the bone marrow.

PART 2: THE IMMUNE RESPONSE

3. The innate immune response includes both cells and proteins.
   a. Give one example of a **cell** in the innate immune system, and briefly describe its function.
   Answers will vary. Options include:
      - ***dendritic cell: engulfs and destroys pathogens, displays antigens to activate other cells***
      - ***macrophage: engulfs and destroys pathogens, can release cytokines***
      - ***neutrophil: usually the first cell type to respond to pathogens***
      - ***mast cell: releases histamine to cause inflammation, which helps get rid of infections***
      - ***natural killer (NK) cell: kills infected and abnormal cells***
      - ***monocyte: engulfs and destroys pathogens, differentiates into macrophages***

   b. Give one example of a **protein** in the innate immune system, and briefly describe its function.
   Answers will vary. Options include:
      - ***cytokines: help cells communicate with each other***
      - ***complement proteins: help destroy pathogens and infected cells, can be activated by antibodies***

   Some students may also mention antigens. If so, clarify that antigens are not part of the immune system but rather something that the immune system responds to.

4. Any cell in the body that accumulates DNA mutations can become a cancer cell. Cancer cells divide uncontrollably and cause disease. Which type of innate immune cell can destroy cancer cells by making them undergo apoptosis (cell death)?
   Natural killer (NK) cells

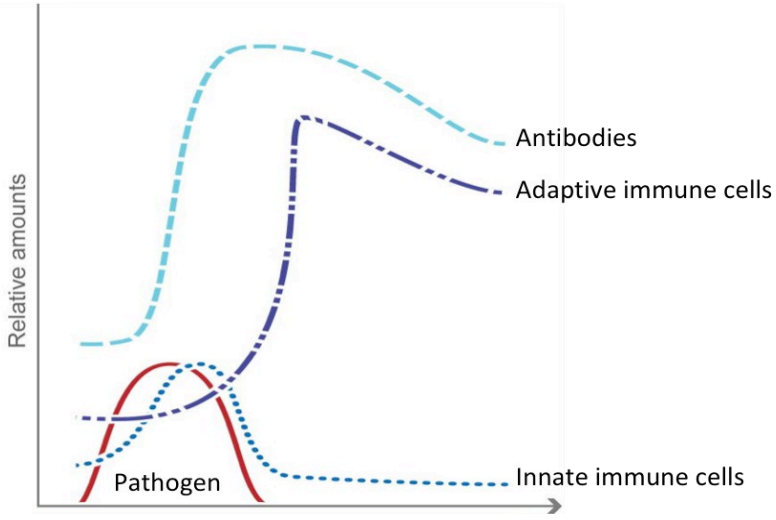
5. Both the innate immune response and the adaptive immune response involve dendritic cells.
   a. Briefly describe the function of dendritic cells in the **innate** immune response.
   Dendritic cells bind to and engulf pathogens, destroying them.

   b. Briefly describe their function in the **adaptive** immune response.
   Dendritic cells activate T cells to start the adaptive immune response. Students may mention that dendritic cells do this by displaying antigens on their surface (becoming antigen-presenting cells).

6. List **three** ways in which the innate immune response differs from the adaptive immune response.
   Answers should include some of the following points (summarized in the "Immune Response" section of the Click & Learn under the "Summary" tab):
   - ***The innate immune response involves phagocytes, NK cells, and inflammatory cells. The adaptive immune response involves T cells and B cells.***
   - ***The innate immune response is less specific than the adaptive immune response.***
   - ***The innate immune response generally acts more quickly than the adaptive response.***
   - ***The adaptive immune response is more powerful than the innate immune response.***
   - ***The innate immune response does not have memory cells like the adaptive immune response.***
7. What are antigen-presenting cells (APCs)? What do they do?
   APCs are cells (often dendritic cells or macrophages) displaying antigens on their surface using MHC proteins. APCs can activate T cells that bind to the antigen-MHC complex.
8. How does the function of helper T cells differ from the function of cytotoxic T cells?
   Helper T cells activate other immune cells, such as B cells. Cytotoxic T cells destroy infected cells.
9. What do B cells do?
   B cells help produce antibodies, which help the body fight a specific pathogen. (Specifically, activated B cells differentiate into plasma cells that produce antibodies.)
10. Do antibodies affect the function of the *innate* immune response in any way? If so, how?
    Students may indicate that phagocytes (which are part of the innate immune response) engulf pathogens bound to antibodies. Antibodies also activate complement proteins.

PART 3: VACCINES

11. Draw a graph showing what the primary immune response would look like if this person had been *vaccinated* against the pathogen. Include the relative amounts of pathogen, innate immune cells, adaptive immune cells, and antibodies.
    In general, students' graphs should resemble the graph of the secondary immune response in Figure 1. An example is shown below.



PART 4: USING THE IMMUNE SYSTEM IN A CANCER TREATMENT

12. Which type of T cell would you expect to attack the cancer cells after being activated by sipuleucel-T?
    Cytotoxic T cells

13. Which other types of immune cells would you expect to be activated and recognize the PAP antigen?
Helper T cells and B cells

14. For each type of cell you listed in Questions 12 and 13, briefly explain how it might help destroy the prostate cancer cells.
Cytotoxic T cells could recognize the PAP antigen and then kill the cancer cells producing it. Helper T cells could recognize the PAP antigen and activate B cells, which could help generate antibodies to the PAP antigen.

15. Some news articles refer to sipuleucel-T as a "cancer vaccine."
Students' answers will vary and may include some of the points below.

    a. How is sipuleucel-T *similar* to a typical vaccine against a pathogen?
    Both sipuleucel-T and a typical vaccine cause an immune response to a specific antigen.
    Both responses involve antigen-presenting cells, the activation of T cells and B cells, and the creation of memory cells.

    b. How does sipuleucel-T *differ* from a typical vaccine?
    Typical vaccines include only an antigen, not antigen-presenting cells like in sipuleucel-T. For typical vaccines, the antigen is also from a different organism (the pathogen) rather than from cells in the body like in sipuleucel-T.

16. The thymus removes all immune cells that recognize self-antigens. So why would a prostate cancer patient have immune cells that recognize the PAP antigen?
The PAP antigen is an abnormal protein produced only by prostate cancer cells. Since it is not produced by "normal" noncancer cells, it is not treated as a self-antigen.

    You may want students to know that T cell development and selection in the thymus occurs early in an individual's life, most likely before they have any prostate cancer cells. So, the PAP antigen would not be present among the antigens for which T cells are selected against in the thymus.

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"IMMUNOTHERAPY" WORKSHEET

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