Unit 1: Lesson 4 – Defending Our DNA: How Cells Protect Against Foreign Genetic Material

LESSON QUESTIONS

- What are the different layers of protection that prevent foreign DNA from sources like bacteria, food and vaccines from damaging our own DNA?
- How do the innate and adaptive immune systems work together with cellular level defenses to protect against foreign DNA?
- Why is the ability to defend against foreign DNA important at the cellular, individual, generational, and evolutionary levels?

LESSON OBJECTIVES

- Identify and evaluate common misconceptions about foreign DNA and vaccines using scientific evidence and reasoning
- Identify and describe at least four cellular defense mechanisms that protect against foreign DNA
- Connect the cellular defense mechanisms shown in the animation to the broader innate and adaptive immune responses studied in Lessons 2 and 3
- Construct an evidence-based argument explaining why cellular defenses against foreign DNA are important across multiple levels of biological organization (e.g., cellular, individual, generational, and evolutionary)

OVERVIEW

In this lesson, students apply their understanding of the immune system - its organs and tissues (Lesson 1), innate defenses (Lesson 2), and adaptive responses (Lesson 3) - to investigate a specific threat: exposure to DNA from external sources. Using the animation *How Do Cells Defend Against Foreign DNA?* as a resource, students discover that our bodies possess multiple built-in safety mechanisms, including extracellular enzymes that degrade DNA fragments before they reach cells, the physical barrier of the cell membrane, nucleases within the cytoplasm, and the protective compartmentalization of our own DNA inside the nucleus. Students then apply critical thinking skills to construct an evidence-based argument explaining why protection against foreign DNA is important at one or more levels: cellular (preventing disruption of gene expression), individual (maintaining health and preventing disease), generational (protecting heritable genetic information), and/or evolutionary (preserving species survival over time).

LENGTH

Approximately two 45-minute sessions

STANDARDS

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-LS1-2 Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
- 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.
- HS-LS3-2 Make and defend a claim based on evidence that inheritable genetic variations may result from new genetic combinations through meiosis, viable errors occurring during replication, and/or mutations caused by environmental factors.
- HS-LS4-4 Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

- Disciplinary Core Ideas
  - LS1.A Structure and Function
    - Systems of specialized cells within organisms help them perform the essential functions of life.
    - All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.
  - LS3.A Inheritance of Traits
    - Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA

codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function.

- LS3.B
  - In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited.

- Science and Engineering Practices
  - Practice 2 Developing and Using Models
    - Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
  - Practice 6 Constructing Explanations and Designing Solutions
    - Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.
  - Practice 7 Engaging in Argument from Evidence
    - Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
  - Practice 8 Obtaining, Evaluating, and Communicating Information
    - Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

- Crosscutting Concepts
  - Structure and Function: The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
    - The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

- Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
    - Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

- Systems and System Models: Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
    - Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

- Stability and Change: For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.
    - Much of science deals with constructing explanations of how things change and how they remain stable.

Common Core State Standards

- RST.11-12.1 Cite specific textual evidence to support analysis of science and technical subjects, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- RST.11-12.2 Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

- RST.11-12.7: Integrate and evaluate multiple sources of information presented in diverse formats and media in order to address a question or solve a problem.

- SL.11-12.1: Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

- WHST.11-12.1: Write arguments focused on discipline-specific content.

- WHST.11-12.9: Draw evidence from informational texts to support analysis, reflection, and research.

MATERIALS

- Computer with internet access or projector/screen
- Anticipation Guide (Activity 1)
  https://vaccinemakers.org/sites/default/files/lessons/HS.student%20worksheet.unit1_.lesson4.Activity1_Anticipation%20Guide_Final.pdf
- Student Worksheet: Guided Observation Sheet
  https://vaccinemakers.org/sites/default/files/lessons/HS.student%20worksheet.unit1_.lesson4.Guided%20Observation_Final.pdf
- Student Worksheet: Vocabulary and Guided Notes
  https://vaccinemakers.org/sites/default/files/lessons/HS.student%20worksheet.unit1_.lesson4.Vocabulary%26Guided%20Notes_Final.pdf
- Defense Map (Activity 2)
  https://vaccinemakers.org/sites/default/files/lessons/HS.student%20worksheet.unit1_.lesson4.Activity2_Defense%20Map_Final.pdf
- Jigsaw Expert Group Instruction Cards (Activity 3)
  https://vaccinemakers.org/sites/default/files/lessons/HS.Jigsaw%20cards.unit1_.lesson4.Activity3_Final.pdf
- Poster paper and markers or a digital collaboration tool for Jigsaw synthesis activity (Activity 3)
- Summative Constructed Response - CER Prompt (Activity 4)
  https://vaccinemakers.org/sites/default/files/lessons/HS.student%20worksheet.unit1_.lesson4.Activity4_Summative.Constructed.Response_Final.pdf

BACKGROUND FOR TEACHER

The animation, *How Do Cells Defend Against Foreign DNA?* serves as the cornerstone resource for this lesson. The animation was created by and for the Annenberg Public Policy Center at the University of Pennsylvania in collaboration with the Vaccine Makers Project (VMP) and XVIVO Scientific Animation. The animation illustrates that cells are not defended by a single mechanism but by a series of overlapping barriers. Foreign DNA fragments, whether introduced by bacteria, food, or vaccines, encounter extracellular enzymes (DNases) in the blood and tissues that break them down before they can even reach a cell. If fragments survive, the cell membrane itself acts as a selective barrier. Any fragments that do enter the cytoplasm face additional nucleases. Finally, the host's own DNA is sequestered inside the

nucleus, physically separated from the cytoplasm. This layered defense theme connects directly to the "castle" metaphor used in Lesson 2 (innate immunity) and is revisited in the Engage, Explore, and Explain phases. The animation emphasizes how the structural organization of cells, compartmentalization of DNA within the nuclear envelope, the lipid bilayer of the cell membrane, and the shape and active sites of nuclease enzymes directly enable the protective functions that keep foreign DNA from causing harm. This theme is central to the Explain phase and connects to NGSS Disciplinary Core Idea LS1.A (Structure and Function). A key message of the animation is that it is virtually impossible for fragments of foreign DNA to integrate into or damage our own genetic material. For foreign DNA to alter a host cell's genome, a fragment would need to survive all extracellular and intracellular defenses, cross the nuclear membrane, and then possess the specific molecular machinery (such as integrase enzymes or transposase activity) needed to insert itself into a chromosome. Random DNA fragments from food, bacteria, or vaccines lack this machinery. This theme is explored in the Elaborate phase, where students analyze the question across cellular, individual, generational, and evolutionary scales. The animation normalizes the concept that humans are constantly exposed to foreign DNA: eating, breathing and in other ways - interacting with microorganisms introduces DNA fragments into the body. The fact that humans have survived and thrived despite these constant exposures is itself evidence that our defense mechanisms are robust and effective. This theme grounds the Engage phase's opening discussion and the Evaluate phase's culminating argument.

TEACHER NOTES

The lesson will activate prior knowledge from Unit 1, Lessons 1–3. If you did not recently cover the innate and adaptive immune system in class, you may want to show the animation, *The Innate and Adaptive Immune System* (https://vimeo.com/304418567).

LESSON RESOURCES

- Lesson animation: *How Do Cells Defend Against Foreign DNA?* https://vimeo.com/1045119029

- Additional resources that may be useful:
  - Comprehensive human immune system overview, VEC, https://www.chop.edu/vaccine-education-center/human-immune-system
  - Unit 1: Lesson 2 Activity "Castle of the Body," VMP, https://vaccinemakers.org/sites/default/files/lessons/HS.activity1.%20Castle%20of%20the%20Body.unit1_.lesson2.FINAL_.pdf
  - Vaccine Ingredients: DNA, VEC, https://www.chop.edu/vaccine-education-center/vaccine-safety/vaccine-ingredients/dna
  - Basic information on immune system function, How Stuff Works.com, https://health.howstuffworks.com/human-body/systems/immune/immune-system.htm#pt2

ENGAGE

1. Present students the question: "Estimates suggest that the average person consumes between 0.1 and 1 gram of DNA from other organisms every day through food. If foreign DNA were dangerous, what would you expect to see?"
2. Students think individually for 1-2 minutes, then discuss with a partner. Select pairs to share their responses with the class and record student ideas on the board without correcting them, creating a reference point to revisit at the end of the lesson.
3. Instruct students to complete the Anticipation Guide (see "Rubric - Activity 1: Anticipation Guide") with true/false/unsure statements such as:
    a "DNA from the food I eat can change my own DNA."
    b "My cells have no way to destroy foreign DNA."
    c "The only defense against foreign DNA is the immune system cells I learned about in Lesson 3."
    d "Foreign DNA fragments have the tools needed for insertion into my chromosomes."
    e "Humans would not have survived as a species without defenses against foreign DNA."
4. Students will revisit this guide in Evaluate to see how their thinking has changed.

EXPLORE

1. Students watch the animation *How Do Cells Defend Against Foreign DNA?* one time through without pausing, focusing on the big picture.
        a Before viewing, distribute the Guided Observation Sheet (See Rubric – Student Worksheet: Guided Observation Sheet) and instruct students to watch for:
            i The different barriers or defenses shown
            ii Where each defense is located
            iii What happens to the foreign DNA at each stage
2. Replay the animation, pausing at key moments for students to complete their observation sheet. Below are suggested pause points:
    a [00:07] After the introduction of foreign DNA sources (bacteria, food, vaccines), students note that exposure is constant and comes from multiple sources.
    b [00:40] After the depiction of extracellular enzymes (DNases in blood/tissues), students describe how DNA fragments are broken down before reaching cells.
    c [01:08] After the depiction of the cell membrane barrier, students note that DNA cannot freely pass through the lipid bilayer.
    d [01:17] After the depiction of cytoplasmic nucleases, students describe intracellular degradation of any DNA that enters the cell.

e [01:31] After the depiction of the nuclear envelope, students note that host DNA is compartmentalized and protected within the nucleus, with nuclear pores that regulate what enters.

f At the conclusion students summarize why it is virtually impossible for foreign DNA fragments to alter host DNA.

3. In groups of 3–4, students use their observation sheets to create a "Defense Map" (See "Rubric – Activity 2: Defense Map) - a visual diagram showing the journey of a foreign DNA fragment from outside the body to (attempted) entry into a cell. They label each defense layer and describe what happens to the DNA fragment at each step. Groups should use the terms DNase/nuclease, cell membrane, cytoplasm, nuclear envelope, and nuclear pore.

EXPLAIN

1. Pass out the Vocabulary and Guided Notes Student Worksheet (see Rubric – Student Worksheet: Vocabulary and Guided Notes: Defenses Against Foreign DNA.
2. Facilitate a whole-class discussion using student Defense Maps from Activity 2 as a starting point, introducing and reinforcing key vocabulary (nuclease, DNase, lipid bilayer, nuclear envelope, nuclear pore complex, integrase). The discussion should explicitly connect the animation content to prior lessons:
    a. Connection to Lesson 1 (Organs and Tissues): Where in the body do the extracellular defenses (DNases) operate? How do organs like the spleen and lymph nodes contribute to clearing foreign material from the body?
    b. Connection to Lesson 2 (Innate Immune System): The extracellular nucleases and the cell's structural barriers (membrane, nuclear envelope) are part of the innate, non-specific defense system. How does this compare to the "castle" model from Lesson 2? What are the "walls" against foreign DNA?
    c. Connection to Lesson 3 (Adaptive Immune System): If a pathogen containing foreign DNA (such as a virus) infects a cell, how does the adaptive immune system respond? How do T cells and B cells target cells that have been compromised by a pathogen?
3. Explain a critical distinction - foreign DNA fragments from food, bacteria, or vaccines are fundamentally different from the DNA of an actively infecting virus. A virus carries specialized molecular machinery, such as integrase enzymes in retroviruses like HIV, studied in Unit 2 Lesson 2 specifically designed to insert its genetic material into the host genome. Random DNA fragments lack this machinery entirely. Even retroviruses must overcome many cellular defenses to succeed. This distinction is central to the animation's message.
4. Students create a summary table identifying each defense mechanism, its location, how it works, and how it connects to what they learned about the immune system in prior lessons. (See "Rubric – Summary Table" for a sample structure.)

ELABORATE

1. This is the core critical thinking activity, the *"Why Does This Matter?"* (See Rubric – Activity 3: Jigsaw Cooperative Learning Activity). Students are divided into four expert groups, each assigned one level of analysis. Each group develops an evidence-based explanation of why protection against foreign DNA is important at their assigned level:
    a. **Group 1 - Cellular Level.** If foreign DNA could integrate into a cell's genome, what could happen to gene expression and cell function?
    b. **Group 2 - Individual Level.** What would it mean for a person's health if cells could not defend against foreign DNA?
    c. **Group 3 - Generational Level.** What if foreign DNA could alter the DNA in reproductive cells (eggs and sperm)?
    d. **Group 4 - Evolutionary Level.** How has the evolution of these defense mechanisms contributed to species survival?
2. Students regroup into mixed teams (one representative from each expert group) and share their analyses. Each mixed team creates a poster or collaborative document that synthesizes all four levels of analysis into a unified argument about why defense against foreign DNA is essential. Teams present key findings to the class in a brief gallery walk or round-robin sharing session.

EVALUATE

1. Students return to their Engage phase anticipation guide and revise their answers using evidence from the animation and class activities. For each statement they now answer differently, they write 1–2 sentences explaining what changed their thinking. The teacher collects these to gauge conceptual growth.
2. Students respond to the following prompt using Claim-Evidence-Reasoning format (see "Rubric: Activity 4: Summative Constructed Response"). This assessment requires students to synthesize content from the animation with their understanding from Lessons 1–3, apply critical thinking, and communicate scientific reasoning. This may be designated as a take home assignment.

    A friend tells you they are worried that DNA fragments in their food or in a vaccine could change their own DNA. Using evidence from the animation and what you have learned in this unit about the immune system, explain why their concern is not supported by science. Your response must address at least two cellular defense mechanisms and explain why protection against foreign DNA is important at one or more of the following levels: cellular, individual, generational, or evolutionary.

RUBRIC - ACTIVITY 1: Anticipation Guide

#	Statement	
1	DNA from the food I eat can change my own DNA.	FALSE
2	My cells have no way to destroy foreign DNA.	FALSE
3	The only defense against foreign DNA is the immune system cells I learned about in Lesson 3.	FALSE
4	Foreign DNA fragments have the tools needed for insertion into my chromosomes.	FALSE
5	Humans would not have survived as a species without defenses against foreign DNA.	TRUE

RUBRIC - STUDENT WORKSHEET: Guided Observation Sheet

First viewing

1. The different barriers/defenses shown - there are multiple, successive layers, not just one.

2. Where each defense is located - defenses exist outside the cell, at the cell membrane, in the cytoplasm, and at the nucleus.

3. What happens to the foreign DNA - it is broken down / blocked at stage after stage, so it never reaches the host DNA.

Second Viewing (pause and record)

#	Stage in the animation	Expected observation (sample answer)
1	**Sources of foreign DNA**	Foreign DNA enters constantly and from many sources, bacteria, the food we eat, and vaccines. The key idea is that exposure to foreign DNA is normal, continuous, and unavoidable, yet it does not alter our DNA.
2	**Extracellular enzymes (DNases in blood & tissues)**	Enzymes called DNases in the blood and tissues break foreign DNA into small fragments before it ever reaches a cell. Much of the DNA is destroyed in this extracellular space (and, for food, in the digestive tract).

#	Stage in the animation	Expected observation (sample answer)
3	**The cell membrane barrier**	The cell membrane is a lipid bilayer. DNA is a large, charged molecule, so it cannot freely pass through this fatty barrier. The membrane blocks foreign DNA from simply drifting into the cell.
4	**Cytoplasmic nucleases**	Any DNA that does manage to get inside the cell meets nucleases in the cytoplasm, which chop it up. This intracellular degradation destroys foreign DNA before it can reach the nucleus.
5	**The nuclear envelope & nuclear pores**	The host's own DNA is sealed inside the nucleus by the nuclear envelope (a double membrane). Nuclear pores regulate what is allowed in and out, so foreign DNA cannot freely enter the nucleus where the host genome is kept.
6	**Conclusion**	Foreign DNA must survive extracellular DNases, cross the cell membrane, escape cytoplasmic nucleases, and then pass the nuclear envelope and pores, all without any machinery of its own to do so. Because it faces this series of independent defenses and has no tools to insert itself, it is virtually impossible for a foreign DNA fragment to alter host DNA.

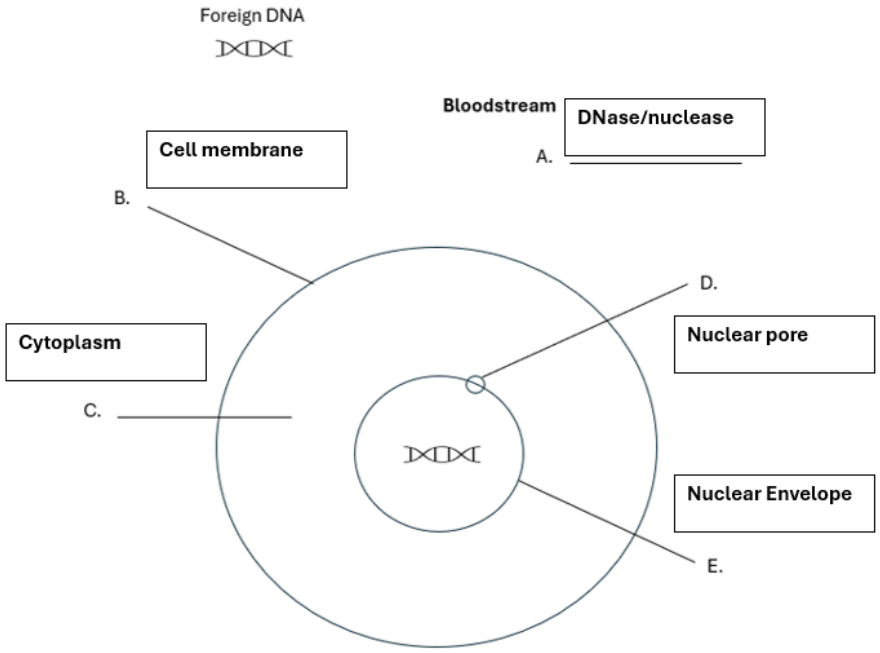
Putting it together — defense sequence

Students list the defenses in the order foreign DNA encounters them, outside the body to the nucleus:

Outside the body → **extracellular DNases** → **cell membrane (lipid bilayer)** → **cytoplasmic nucleases** → **nuclear envelope** → **nuclear pore** → Nucleus (host DNA protected)

RUBRIC - ACTIVITY 2: Defense Map

Labeled diagram - cell components that defend against foreign DNA.



Description of what happens to foreign DNA fragments at each cellular defense layer:

Layer 1 – DNase/nuclease: Before the DNA fragment ever reaches a cell, it encounters nucleases (DNases) present in blood, serum, and other extracellular fluids. These enzymes cut DNA into smaller pieces, so most foreign DNA is degraded here. Any fragment that survives is likely to be shortened or damaged.

Layer 2 - Cell membrane: The plasma membrane is a selectively permeable lipid bilayer. Because DNA is large and negatively charged, it cannot simply diffuse across. A fragment only gets in through processes like endocytosis, and much of what is taken up this way ends up in vesicles/lysosomes where it can be broken down further. This is a major physical barrier.

Layer 3 – Cytoplasm: If a fragment makes it into the cytoplasm, it faces cytoplasmic nucleases and must physically travel through a crowded, gel-like environment to reach the nucleus. Additional degradation happens here, so only a fraction of fragments cross the cytoplasm intact.

Layer 4 - Nuclear envelope: The nucleus is enclosed by the nuclear envelope, a double membrane that separates the nuclear contents from the cytoplasm. It blocks free passage of large molecules like DNA, acting as the final wall around the genetic material.

Layer 5 - Nuclear pore: The only route through the nuclear envelope is the nuclear pore complex, which regulates what enters the nucleus. Small molecules pass freely, but large molecules like DNA generally requires transport signals/proteins to get through.

RUBRIC - STUDENT WORKSHEET: Vocabulary and Guided Notes: Defenses Against Foreign DNA

Part 1 — Key Vocabulary

Answers shown in **bold underline**. Accept reasonable equivalents.

Term	Definition
Nuclease	An enzyme that cuts up (breaks down) **nucleic acids / DNA**, destroying it into harmless fragments.
DNase	A specific type of nuclease that breaks down **DNA**. These operate **outside** the cell (in blood and tissues).
Lipid bilayer	The structure of the **cell membrane**. Because DNA cannot freely cross it, it acts as a physical barrier.
Nuclear envelope	The double membrane that surrounds the **nucleus**, keeping the host's own DNA compartmentalized and protected.
Nuclear pore complex	Gateways in the nuclear envelope that **regulate / control** what is allowed to enter and exit the nucleus.
Integrase	Specialized viral machinery (found in retroviruses like **HIV**) designed to **insert** viral genetic material into the host genome. Random DNA fragments do NOT have this.

Part 2 — Connecting to Prior Lessons

Connection to Lesson 1 — Organs and Tissues

Where in the body do the extracellular defenses (DNases) operate?

Sample answer: In the extracellular spaces - in the bloodstream, in tissues, and in bodily fluids such as saliva and digestive secretions, before foreign DNA ever reaches a cell. DNA in food is largely broken down in the digestive tract.

How do organs like the spleen and lymph nodes help clear foreign material from the body?

Sample answer: The spleen and lymph nodes filter blood and lymph, trapping foreign particles and pathogens. Immune cells housed there, such as macrophages, engulf and degrade foreign material, removing it from circulation. This ties tissue/organ structure (Lesson 1) to the body's defense role.

Connection to Lesson 2 — Innate Immune System

How does this compare to the "castle" model from Lesson 2? What are the "walls" against foreign DNA?

Sample answer: These defenses are innate and non-specific - always present and not tailored to one invader, like a castle's fixed fortifications. The "walls" against foreign DNA are layered; extracellular DNases (like a moat that destroys invaders before they arrive), the cell membrane / lipid bilayer (the outer wall DNA cannot freely cross), the cytoplasm's nucleases (guards inside the walls), and the nuclear envelope with its pore complexes (the inner keep protecting the host DNA).

Connection to Lesson 3 — Adaptive Immune System

Our immune systems are designed to respond to anything foreign. When pathogens that contain foreign DNA infect our cells, the infection also introduces foreign proteins, including enzymes. How does the adaptive immune system respond to these proteins? How do T cells and B cells target compromised cells?

Sample answer: Infected cells display fragments of pathogen proteins on their surface (antigen presentation). Cytotoxic T cells recognize these markers and destroy the infected cell. Helper T cells coordinate the response, and B cells produce antibodies that tag free pathogens for destruction and block reinfection. Unlike the innate barriers, this response is specific and builds immune memory.

The critical distinction related to DNA from pathogens compared with other sources:

Foreign DNA fragments from food, bacteria, or vaccines are fundamentally **different** from the DNA of an actively infecting virus.

- Some viruses contain specialized molecular machinery, such as **integrase** enzymes in retroviruses like HIV (Unit 2, Lesson 2), designed to insert its genetic material into the host genome. Not all viruses integrate into the host genome; their DNA is copied into mRNA in the nucleus, but not as part of the host genome.
- Random DNA fragments lack this machinery **entirely**.
- Even retroviruses must overcome **many** cellular defenses to succeed.

Big idea — sample response:

Sample answer: A random foreign DNA fragment is just a broken piece of genetic material with no tools of its own. It cannot cross the cell membrane, survives poorly against nucleases, and has no way to enter the nucleus or splice itself into host DNA. An actively infecting virus, by contrast, carries specialized machinery (like integrase) built to breach these defenses, and even then it must overcome many layers to succeed. Because the DNA in food has none of this machinery and faces every one of the body's defenses, it is effectively impossible for the food you eat to change your own DNA.

DNA can be introduced by vaccines in two ways, as an antigen (active ingredient to which the immune system responds) or as a manufacturing byproduct. Adenovirus vector vaccines are an example of the first; adenoviruses do not contain the tools to integrate their DNA into the person's genome. As a manufacturing byproduct, purification techniques ensure very small and fragmented quantities of DNA that do not have the necessary tools to access the nucleus or integrate into the genome.

Rubric -Summary Table

Table identifying each defense mechanism, its location, how it works, and connection to prior lessons.

Defense Mechanism	Location	How It Works	Connection to Lessons 1–3
Extracellular nucleases (DNases)	Blood, tissue fluids	Enzymes degrade foreign DNA fragments before they reach cells	Part of innate defense (Lesson 2); operate in tissues (Lesson 1)
Cell membrane	Cell surface	Lipid bilayer blocks entry of charged DNA molecules	Physical barrier; analogous to castle walls (Lesson 2)
Cytoplasmic nucleases	Inside the cell (cytoplasm)	Intracellular enzymes degrade any foreign DNA that enters the cell	Intracellular innate defense (Lesson 2)
Nuclear envelope and pore complex	Around the nucleus	Separates and protects host DNA; nuclear pores regulate entry with selective transport signals	Structure enables function (LS1.A); protects heritable information (Lesson 1)
Lack of integration machinery	N/A (property of the foreign DNA)	Random DNA fragments lackintegrase/transposase enzymes needed to insert into chromosomes	Contrast with retroviruses like HIV (Unit 2 Lesson 2 preview)

RUBRIC - ACTIVITY 3: Jigsaw Cooperative Learning Activity

Group 1 - Cellular Level. *If foreign DNA could integrate into a cell's genome, what could happen to gene expression and cell function?*

Students should note insertional mutagenesis (disrupting a gene's coding region), potential disruption of regulatory sequences, and the consequences for protein production. They should connect to the NGSS concept that DNA structure determines protein structure and function (HS-LS1-1).

Group 2 - Individual Level. *What would it mean for a person's health if cells could not defend against foreign DNA?*

Students should consider the consequences of uncontrolled DNA damage: mutations that could lead to cancer, disrupted immune cell function, or organ dysfunction. They connect this to the concept that the body is a system of interacting subsystems (HS-LS1-2).

Group 3 - Generational Level. *What if foreign DNA could alter the DNA in reproductive cells (eggs and sperm)?*

Students should consider the implications for offspring, heritable mutations, genetic disorders, and the importance of protecting germline DNA. They connect to NGSS concepts about inheritance of traits (HS-LS3-1) and variation of traits (HS-LS3-2).

Group 4 - Evolutionary Level. *How has the evolution of these defense mechanisms contributed to species survival?*

Students should note that organisms without effective defenses against foreign DNA would have been at a significant disadvantage and consider how these defense systems have been conserved across species as evidence of their importance, connecting to natural selection (HS-LS4-4) and the fact that the human immune system has been shaped by millions of years of exposure to foreign genetic material.

RUBRIC - ACTIVITY 4: Summative Constructed Response

CER writing format: Student responses to the prompt should state a clear, concise answer to the given question (Claim), use relevant and credible data or facts to support their answer (Evidence), and explain, logically, how the data proves their point (Reasoning). Student responses should use evidence from the animation and lesson, must address at least two cellular defense mechanisms, and explain why protection against foreign DNA is important at one or more of the following levels: cellular, individual, generational, or evolutionary."