Teacher’s Guide

Lesson Title

BSCS Biology: Understanding for Life
Viruses

Learning Objectives

By the end of the lesson, students will be able to:

1. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functionsDistinguish between bacterial and viral infections and explain bacterial structure and function
2. Understand Interactions among organisms and their environment
3. Evolution is driven by genetic variation and environmental pressures
4. Integrate biology, public health, and ethics.

Alignment with NGSS

- **Disciplinary Core Ideas (DCIs)** in LS1, LS2, LS3, and LS4
- **Science & Engineering Practices (SEPs)** focused on explanation, data interpretation, and societal decision-making
- **Crosscutting Concepts (CCCs)** like cause and effect,

Disciplinary Core Ideas (DCIs)

LS1: Structure and Function

- viral structure (DNA/RNA, capsid, envelope)
- attachment to host receptors
- viral life cycle stages
- host-cell hijacking

MS-LS1-2

“Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.”

HS-LS1-2

“Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions.”

Why it aligns well:

- Viruses are used as a contrast case to cellular life
  Structure–function is explicit (envelope → entry; genome → replication)
- Host–virus interaction reinforces systems thinking

LS2: Interactions and Systems

- MS-LS2–1 / MS-LS2–2
  Interactions among organisms and their environment
- HS-LS2–8
  Human activity affects ecosystems and population dynamics

Why it works:

- Viral spread is framed as a system (virus–host–environment)
- Zoonotic transmission explicitly connects human and animal systems
- COVID-19, SARS, MERS provide real-world phenomena

LS3: Inheritance and Variation of Traits

Primarily HS alignment

- viral genomes (DNA vs RNA)
- mutation rates
- antigenic variation
- vaccine design challenges

HS-LS3–1

HS-LS3–2

- Viral mutation is explicitly tied to vaccine effectiveness
- Students see how genetic variation → population outcomes
- This is developmentally above MS expectations, but exactly right for HS biology

LS4: Natural Selection and Evolution

- MS-LS4–4
  Natural selection leads to population-level change
- HS-LS4–2 / HS-LS4–4
  Evolution is driven by genetic variation and environmental pressures
- Viral evolution is fast, observable, and concrete
  COVID-19 and influenza provide compelling evidence
  Students can explain evolution without abstraction

Science & Engineering Practices (SEPs)

Asking Questions & Defining Problems

- Why don't some viruses have vaccines?
- Why are some viruses more deadly?
- Why do vaccines take time to develop?

Constructing Explanations

- Explaining viral replication
- Explaining vaccine mechanisms
- Explaining mutation-driven challenges

Analyzing &Interpreting Data

- Mortality rates
- Outbreak comparisons
- Timelines of virus discovery

Engaging in Argument from Evidence

- Vaccine development tradeoffs
- Accelerated approval during COVID-19
- Prioritization of research funding

Obtaining, Evaluating, and Communicating Information

- Clinical trial phases
- Regulatory approval
- Global health data

Crosscutting Concepts (CCCs)

- Cause and Effect
  - mutation → vaccine difficulty
  - transmission → outbreaks
- Structure and Function
  - capsid, envelope, receptors
- Systems and System Models
  - host–virus–population–global health
- Stability and Change
  - endemic vs emerging viruses
  - immune memory vs viral evolution

Middle School vs High School Fit

Middle School (NGSS MS)

Best-aligned content:

what viruses are (non-living, host-dependent)

- basic structure
- transmission
- vaccines as prevention
- societal impacts of outbreaks

Recommendation – For MS, minimize:

- detailed clinical trial timelines
- molecular vaccine design
- mortality statistics nuance

High School (NGSS HS)

- HS biology
- BSCS *Biology: Understanding for Life*
- Health, evolution, and biotechnology units

Especially strong for:

- evolution through real-world evidence
- genetics in context
- science–society decision-making

BSCS Biology: Understanding for Life

Viruses

What is a Virus?

A virus is a tiny infectious agent that infects living organisms, including humans, animals, plants, and even bacteria. Unlike other microorganisms, viruses are not considered truly alive because they cannot reproduce on their own - they require a host cell to replicate.

Vocabulary

Antigen – A molecule, often a protein on the surface of a virus, that is recognized by the immune system and triggers an immune response.

Attenuated Virus – A weakened form of a virus used in some vaccines that stimulates immunity without causing serious disease.

Capsid – The protein shell that surrounds and protects a virus's genetic material. The shape of the capsid helps determine how the virus attaches to host cells.

Case Fatality Rate – The percentage of people diagnosed with a disease who die from it. Used to compare the severity of different viral outbreaks.

Clinical Trials – Research studies conducted in humans to evaluate the safety, effectiveness, and side effects of medical treatments such as vaccines.

- Phase 1: Tests safety and dosage
- Phase 2: Tests effectiveness and side effects
- Phase 3: Confirms effectiveness in large populations

DNA Virus – A virus that uses DNA as its genetic material. DNA viruses generally mutate more slowly than RNA viruses.

Emerging Virus – Methicillin-resistant Staphylococcus aureus (MRSA) infection is caused by a type of staph bacteria that's become resistant to many of the antibiotics used to treat ordinary staph infections.

Envelop – A lipid (fatty) outer layer found in some viruses, taken from the host cell membrane. Enveloped viruses often enter host cells through membrane fusion.

Host Cell - A living cell that a virus infects and uses to replicate. Viruses cannot reproduce without a host cell.

Immune Response – The body's defense reaction against foreign invaders, such as viruses, involving immune cells and antibodies.

mRNA Vaccine - A type of vaccine that uses messenger RNA to instruct cells to make a viral protein, triggering an immune response without using a live virus.

Mutation – A change in genetic material. In viruses, mutations can alter surface proteins, affecting how easily the immune system recognizes them.

Non-Living - A classification for viruses because they cannot reproduce, metabolize, or carry out life processes without a host cell.

Pandemic – An outbreak of a disease that spreads across multiple countries or continents and affects a large number of people.

Protein Coat - See Capsid.

Receptor – A specific molecule on the surface of a host cell that a virus binds to in order to enter the cell.

Replication - The process by which a virus produces new copies of itself inside a host cell using the host's cellular machinery.

RNA Virus – A virus that uses RNA as its genetic material. RNA viruses tend to mutate quickly, making vaccine development more challenging.

Viral Lifecycle - The series of steps a virus follows to infect a host cell, reproduce, and spread, including attachment, entry, replication, assembly, and release.

Viral Vector – A virus modified to deliver genetic material into cells. Some vaccines use harmless viral vectors to stimulate immunity.

Vaccine - A medical treatment that stimulates the immune system to recognize and fight a specific pathogen without causing disease.

Vector (Disease Transmission) – A living organism, such as a mosquito or tick, that transmits a virus from one host to another.

Virion - A complete, infectious virus particle outside a host cell, consisting of genetic material and a protein coat (and sometimes an envelope).

Virus - A microscopic infectious agent made of genetic material (DNA or RNA) enclosed in a protein coat that can only reproduce inside a living host cell..

Zoonotic Virus - A virus that can be transmitted from animals to humans, often through direct contact or animal vectors.

How is a Virus Composed?

Viruses are composed mainly of genetic material—either DNA or RNA—encased within a protein coat called a capsid. Some viruses also have an outer lipid envelope derived from the host cell membrane, which helps them infect host cells more effectively.

The lifecycle of a virus typically involves several stages. First, the virus attaches to a susceptible host cell via specific receptors. Next, it enters the cell through several different methods (i.e. fusion or endocytosis). Once inside, the virus releases its genetic material, hijacking the host's machinery to produce new viral components. Alternatively, viruses like bacteriophages can also inject their genomic material directly into the cells. These components are assembled into new virions, which then exit the host cell, often destroying it, to infect adjacent cells and propagate the infection.

Discovery of Viruses

Viruses were discovered in the late 19th century when scientists observed that certain diseases caused by filterable agents—agents small enough to pass through filters that trapped bacteria—could not be explained by bacteria alone. The first virus identified was the tobacco mosaic virus in 1892. Later, the first human virus, yellow fever, was discovered in the early 20th century.

Examples of viruses include influenza virus, Human Immunodeficiency Virus (HIV -which causes AIDS)), herpesviruses (like herpes simplex), hepatitis B and C viruses, and the recent coronavirus Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2 responsible for COVID-19).

While some viruses can infect humans directly, many viruses do have animal vectors which transmit the virus from animals to humans. For example, the Zika virus, dengue virus, and West Nile virus are transmitted through mosquitoes. In contrast, viruses like HIV are primarily transmitted through sexual contact or blood.

How are Vaccines Developed?

Vaccine development is a complex, multi-stage process aimed at creating safe and effective immunizations to prevent infectious diseases. *5 It involves several critical steps:

1. **Antigen Identification:**
    - Researchers identify the parts of the virus (antigens) that can trigger a protective immune response. These are often surface proteins like the spike protein in coronaviruses.
2. **Vaccine Design:**
    - Based on the antigen, scientists develop different types of vaccines, such as

Smallpox: Brief Summary

Smallpox was a highly contagious viral disease caused by the variola virus. It caused fever, rash, and often characteristic fluid-filled lesions covering the body. The more severe form (variola major) killed about 30% of people who were infected. Smallpox appears to have affected humanity for at least 3,000 years, with evidence from ancient Egyptian mummies and early historical descriptions in China, India, and the Mediterranean world. The smallpox virus evolved into distinct lineages over centuries. It is believed to have diversified from related viruses in animals and ultimately adapted to humans, spreading widely as civilizations expanded trade and travel. After the development of the first successful vaccine by Edward Jenner in 1796, vaccination gradually reduced disease in parts of the world.

The World Health Organization (WHO) launched an intensified global eradication campaign in 1967, based on mass and "ring" vaccination. The last naturally occurring case was reported in 1977 in Somalia, and global eradication was officially certified in 1980.

Estimating deaths across all of human history is more uncertain, but researchers suggest smallpox likely killed hundreds of millions more over centuries, especially before widespread vaccination. Figures often cited range from 500 million to more than a billion total deaths over millennia, though precise numbers are difficult to confirm. Historians estimate that smallpox killed roughly 300 million people in the 20th century alone, making it one of the deadliest diseases of that era.

Why Smallpox Still Matters

- It was one of humanity's deadliest diseases for thousands of years.
- It was the first disease ever eradicated through coordinated global vaccination.
- Its elimination remains a landmark achievement in public health.

inactivated (killed virus), live attenuated (weakened virus), subunit (pieces of the virus), mRNA, or vector-based vaccines.

3. **Preclinical Testing (can take 3–6 years):**
   - Laboratory and animal studies assess the vaccine's safety and ability to induce immunity. This stage helps determine appropriate doses and delivery methods.
4. **Clinical Trials:*6**
   - Human testing occurs in three phases:
     - **Phase 1:** Small group of volunteers to evaluate safety and immune response.
     - **Phase 2 (can take 1–2 years):** Larger group to assess efficacy, dosage, and side effects.
     - **Phase 3 (can take 2–5 years):** Thousands of participants to confirm efficacy and monitor adverse effects.
5. **Regulatory Approval (can take 6–10 months):**
   - Data from clinical trials are submitted to regulatory agencies, like the Federal Drug Administration (FDA) or World Health Organization (WHO), for review and approval before widespread use.
6. **Manufacturing and Distribution:**
   - Once approved, vaccines are produced at a large scale, ensuring safety, quality, and consistency. Efficient distribution networks are crucial to reach populations worldwide.

The Discovery of of the First Vaccine

The discovery of vaccines has been a significant milestone in controlling viral diseases. Vaccines actually go back as far as the 1700s when Edward Jenner discovered the process of *vaccination*. Strictly speaking, Jenner did not "discover" vaccination, but was the first person to pursue its scientific investigation. For many years, he had heard the inherited knowledge among milkmaids that they were protected from the deadly disease, smallpox, if they had caught and recovered from cowpox (carried by the cows they milked). Jenner *hypothesized* that cowpox not only protected against smallpox, but that it could be taken from a cow and transmitted to a person, and to another, to provide protection against future exposure to smallpox without these individuals having to work or associate closely with cows (as the milkmaids did).

He tested his hypothesis in May 1796, with the help of the milkmaid, Sarah Nelms, who had a fresh case of cowpox. Jenner used pus from her sores [*lesions*] to *inoculate* [introduce the pus into a cut] a young boy, James Phipps. The boy developed a mild fever but recovered quickly. In July, Jenner inoculated the boy again, this time with pus from a fresh *smallpox* lesion. He did not get smallpox, and Jenner concluded that he was protected. Jenner called this new procedure *vaccination* – [from the Latin word for cow – *vacca*, and cowpox – *vaccinia*].

This represents the first scientific attempt to control and prevent an infectious disease by the deliberate use of vaccination and established the groundwork for all future study in virology, vaccination, and disease prevention.

Vaccines work by stimulating the immune system to recognize and combat the virus without causing the disease itself.

The process of vaccine development involves identifying viral antigens that elicit immune responses, testing for safety and efficacy, and then manufacturing the vaccine under strict regulations.

Challenges in Vaccine Development

- Viral Mutation: Rapidly mutating viruses, like influenza or HIV, require frequent updates for vaccines to remain effective.
- Laboratory Cultivation: some viruses are difficult to grow and maintain in the lab, hindering initial research.
- Complex Structures: Some viruses have complicated structures that are difficult to replicate or target with a vaccine.
- Safety Concerns: Ensuring the vaccine does not cause adverse effects is paramount, which can extend development times.
- Production Scalability: Manufacturing vaccines at scale without compromising quality is challenging.

Why Do Some Viruses Have No Vaccine?

Some viruses lack vaccines due to various factors:

- High mutation rates make vaccine design difficult.
- Limited understanding of the immune response they elicit hampers development.
- Lack of financial incentives or market size can reduce research investments.

Additionally, developing vaccines for certain viruses, like HIV, has proven difficult due to their ability to swiftly evade immune responses.

In the last 25 years, scientists have discovered over 200 new viruses, many of which have the potential to cause outbreaks in humans.

These include:

- Severe acute respiratory syndrome coronavirus (SARS-CoV)
- Middle East respiratory syndrome coronavirus (MERS-CoV)
- Novel coronaviruses (like SARS-CoV-2)

Here are some notable viruses discovered during the above period, ordered roughly by their deadliness based on mortality rates and the severity of outbreaks:

1. **SARS-CoV (Severe Acute Respiratory Syndrome Coronavirus) (2002–2003)**
    - Deadliness: Approximately 9.6% case fatality rate
    - Cause of SARS, a highly contagious respiratory illness with significant fatalities during the outbreak.
2. **MERS-CoV (Middle East Respiratory Syndrome Coronavirus) (2012)**
    - Deadliness: About 34–35% case fatality rate
    - Causes severe respiratory illness mainly in the Middle East, with high mortality in confirmed cases.
3. **H5N1 Influenza Virus (Avian Influenza) (early 2000s identification, but ongoing detection)**
    - Deadliness: Around 60% case fatality rate among diagnosed cases
    - Though not continuously endemic, it causes severe disease with a high mortality rate when infecting humans.
4. **Nipah Virus (1998–1999, continue to emergence)**
    - Deadliness: Up to 40–75% case fatality rate
    - Causes encephalitis and respiratory illness, with outbreaks primarily in South and Southeast Asia.
5. **SARS-CoV-2 (COVID-19) (2019–present)**
    - Deadliness: Varies by region and age group, overall around 1–2% globally, but higher in vulnerable populations
    - Responsible for the COVID-19 pandemic with millions of deaths worldwide; less deadlier per individual but highly transmissible.
    - Vaccine creation within less than a year from virus identification to authorization This vaccine is developed differently than previous vaccines. It is an MRNA vaccine.
6. **Hepatitis C Virus (HCV) (discovered in 1989, but ongoing research and recognition continued into the 2000s)**
    - Deadliness: Chronic infection can lead to liver cirrhosis or cancer, causing over 290,000 deaths annually
    - Long-term health consequences but often asymptomatic initially.

This list reflects the relative deadliness based on case fatality rates and impact during outbreaks, but exact rankings can vary depending on regional health responses and other factors.

What is the Most Challenging Virus Today

Today, the most challenging viruses include HIV, which remains incurable; influenza viruses, which rapidly mutate, making yearly vaccines necessary; and emerging viruses like Ebola and novel coronaviruses, which can cause global health crises. Their ability to adapt and spread continues to pose significant threats to global health, emphasizing the need for ongoing research and preparedness.

Recent Advances

The COVID-19 pandemic accelerated vaccine development dramatically through novel technologies like mRNA vaccines, which can be developed quickly once the viral genetic sequence is known. This vaccine had an accelerated approval process and took less than a year from when the virus was identified to vaccine authorization, in comparison to what was previously needed (6–10 years). This innovation holds promise for rapid responses to future emerging viruses.

Vaccine development is an intricate balance of scientific research, clinical testing, regulatory oversight, and manufacturing logistics. While advancements continue, obstacles like viral mutation and complexity remain significant hurdles.

Some Questions for Discussion

- Why is it important to know about and apply this knowledge of viral infections?
- Why are antibiotic-resistant infections a 21st century societal challenge that we can no longer ignore?
- When do Infectious Diseases Become a Regional, National, or International Issue?
- What is society's role in addressing a disease?
- How does society decide which diseases to fully address regionally, nationally, and globally? Which diseases seem to attract the most attention?
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. For example, sometimes the process of scientific research touches on issues that society finds controversial and uncomfortable. Stem Cell research, Genetically Modified Organisms (GMOs), therapeutic cloning, human testing, and animal models in medical research are examples of such "science-based societal issues". Discuss this.
- What other issues can impact the distribution of medications to fight or prevent infectious diseases?
- What has happened to introduce societal skepticism of some vaccines?
- What is herd immunity and why is it important?
- How do public health officials help to maintain herd immunity?