American Society for Virology
Undergraduate Virology Curriculum Guidelines: Examples of Learning Objectives
2024

ASV Undergraduate Virology Learning Objectives Committee - Contributing Authors

David B. Kushner, Chair
Co-chair, ASV Education & Career Development Committee
Department of Biology
Dickinson College, PA

Mya Breitbart
College of Marine Science
University of South Florida, FL

Kari M. Debbink
Department of Molecular Microbiology & Immunology
Johns Hopkins Bloomberg School of Public Health, MD

Maureen C. Ferran
Thomas H. Gosnell School of Life Sciences
Rochester Institute of Technology, NY

Dylan M. Johnson
Department of Biotechnology & Bioengineering
Sandia National Laboratories, CA

Laura L. Newcomb
Department of Biology
California State University - San Bernadino, CA

Lauren A. O'Donnell
School of Pharmacy
Duquesne University, PA

John S. L. Parker
Baker Institute for Animal Health
Cornell University, NY

Background and context. In 2012, the American Society for Microbiology (ASM) posted a set of curriculum guidelines for undergraduate microbiology courses to their website (https://asm.org/guideline/asm-curriculum-guidelines-for-undergraduate-microb)[1]. A companion paper was published that explained the rationale for their development (Merkel S. *et al.*, 2012. The Development of Curricular Guidelines for Introductory Microbiology that Focus on Understanding. J. Microbiol. Biol. Educ. 13:32-38).

During the late 2010s, it became apparent that a similar set of guidelines would be useful for instructors of undergraduate courses in virology. The COVID-19 pandemic further illustrated the need for such guidance, as helping undergraduates learn virology became even more important. Using the ASM's general microbiology guidelines as a model, during 2021-2022, curriculum guidelines for undergraduate virology courses were developed. In 2022, the guidelines were posted to the American Society for Virology (ASV) website (https://asv.org/curriculum-guidelines/) and an overview of the guidelines was published in *Journal of Virology* (Kushner D.B. *et al.*, 2022. Curriculum Guidelines for Graduate and Undergraduate Virology Courses. J. Virol. 96:e01305-22). The guidelines were organized into sections on Learning Outcomes for a stand-alone virology course, Content Recommendations for a stand-alone virology course, and Content Recommendations for a virology unit within a larger course (*e.g.*, semester-long microbiology course or an introductory level cell/molecular, human biology, or infectious disease course). The content recommendations for a stand-alone virology course were catalogued into five sections: (a) Virus Evolution and Ecology; (B) Virus Structure and Function; (C) Virus Replication Cycle; (D) Host-Virus Interactions; (E) Impact of Viruses; each of these five sections features four or five fundamental statements.

Subsequently, a committee (see previous page for composition) was formed to build example learning objectives for the virology fundamental statements. A learning objective is a brief statement that describes what a student should be able to demonstrate (in a measurable fashion using some form of assessment) upon completion of a learning unit (for more information, see Orr R.B. *et al.*, 2022. Writing and Using Learning Objectives. CBE Life Sci. Educ. 21:fe3). Learning objectives often are linked to Bloom's Taxonomy (Bloom B.S., 1956. *Taxonomy of Educational Objectives: The Classification of Educational Goals.* New York: Longmans, Green), which is a six-level pyramid with lower-order skills (knowledge, comprehension, application) at the foundation, or base, of the pyramid, and higher-order skills (analysis, synthesis, evaluation) that illustrate critical thinking at the top of the pyramid. The learning objectives in this document are catalogued into lower-order and higher-order examples, but minor adjustments to the assessment could move many of the examples from one level to the other.

The learning objectives shown below are examples, and as such the list is not intended to be comprehensive. The list below also is not meant to be prescriptive. Our goal is to illustrate ways in which an instructor can address the fundamental content statements. While we recommend that instructors cover as many fundamental statements as possible in their undergraduate virology course, learning objectives should be integrated as warranted based on the needs of their student cohort. Instructors can and should design their own objectives based on the specific ways they are helping their students learn the content described by the fundamental statements.

[1] The ASM microbiology curriculum guidelines found at this website were updated in March, 2024.

Core concept 1: Virus Evolution and Ecology

***Fundamental Statement 1*: Viruses evolve because of variation within their genomes introduced by a variety of processes including random mutation, recombination, and reassortment. These variants are then subjected to selection pressures exerted by their hosts and the environment or by random sampling *via* genetic drift.**

Example lower-order thinking learning objectives include:

- Define (viral) evolution
- Define random mutation, recombination, reassortment, selection pressure, and genetic drift
- Compare the rate of random mutation of mammalian hosts, double-stranded DNA viruses, and single-stranded RNA viruses
- For a specific virus, describe the mechanism of mutation that can lead to virus evolution
- For a specific virus, describe how recombination can lead to virus evolution
- For a specific virus, describe how reassortment can lead to virus evolution
- Explain what is a transmission bottleneck and how it can impact viral evolution
- Explain the difference between synonymous and nonsynonymous mutations, and how the ratio of these may be used to describe evolutionary pressure vs. random mutation
- Describe a specific example of viral co-evolution with its host

Example higher-order thinking learning objectives include:

- Design an experiment to examine the relationship between the fidelity of viral polymerases and the accumulation of mutations during viral genome replication
- Compare and contrast the selective pressure on a virus exerted by a host, the environment, and/or though transmission bottlenecks
- Create a visual representation showing how selection pressure in a mixed population of virus variants leads to changes in the make-up of the population
- Hypothesize how use of antiviral medication might direct or influence viral evolution
- Argue whether any viruses evolved before cell-based life forms
- Propose why some viruses have open reading frames with no homology to known cellular genes

***Fundamental Statement 2*: Virus emergence and spread can be impacted by a variety of environmental, viral, and social factors.**

Example lower-order thinking learning objectives include:

- Define the One Health concept
- Define viral zoonosis
- Define virus surveillance
- List at least one environmental factor, viral factor, and social factor that can impact virus emergence and spread
- Relate a historical example of the emergence of a virus
- Provide an example of a virus with a beneficial effect on its host or on society
- Describe an example of virus-virus interaction

Example higher-order thinking learning objectives include:

- Assess how public health policy can change social factors related to the emergence and spread of viruses
- Argue why virus surveillance can help identify likely origins of virus emergence/spread
- Propose how human activity (*e.g.*, travel; climate change) may impact viral emergence and spread in the future
- Given a specific scenario, develop and defend a strategy that could reduce the spread of a viral pathogen

- Predict the next emerging virus/pandemic and analyze factors (viral, social, environmental, etc.) that will lead to its emergence

***Fundamental Statement 3*: Although viruses are ubiquitous in nature and infect all forms of life, much of the global virosphere remains unstudied.**

Example lower-order thinking learning objectives include:

- Define virosphere
- Define "virome"; define viral metagenomics/viromics
- List two examples of challenges in the characterization of the global virosphere
- Provide a specific example of a virus infecting each of the following host types: mammal, plant, bacterium, archaeon, insect, fungus
- For a given environment, compare the relative number of viruses to bacteria
- Discuss how the number of viruses that cause human disease compares to the number of viruses that exist in the global virosphere
- Viruses infecting photosynthetic bacteria often encode key proteins involved in photosynthesis; describe how this helps facilitate infection
- Explain how the development of new technologies (*e.g.*, sequencing) has expanded knowledge of the global virosphere
- Explain why viruses cannot be identified using 16S/18S rRNA gene sequence

Example higher-order thinking learning objectives include:

- Evaluate why most of the global virosphere is unknown/unidentified; indicate at least one recent advance that has allowed for a dramatic improvement in determination of the extent of virus diversity
- Propose how would you determine if a virus is the causative agent of an ongoing mortality event in a species of wildlife
- Write an essay that argues for or against the importance of investing resources into discovering and characterizing a wide variety of currently unknown viruses
- Outline how you can enumerate the number of viruses (*e.g.*, infectious viruses/defective virion/virus-like particle) in any environment

***Fundamental Statement 4*: Taxonomic classification and naming of viral species, overseen by the International Committee on the Taxonomy of Viruses (ICTV), resembles the taxonomical binomial nomenclature system used with cellular organisms.**

Example lower-order thinking learning objectives include:

- Define taxonomy
- Give an example of the taxonomic structure of two related viruses identifying the similarities and differences in their naming scheme
- State that viruses are taxonomically classified by realm, kingdom, phylum, class, order, family, (subfamily), genus, and species
- Explain why the species demarcation criteria are different for different viral families
- Explain the role of percent sequence identity for distinguishing viruses at the level of genus, species, etc.
- State that taxonomic classification is distinct from the Baltimore classification system (used for grouping viruses based on genome structure and replication method)

Example higher-order thinking learning objectives include:

- Examine the criteria used to differentiate between viral species, viral strains, and viral variants
- Assess the challenges with applying a classical taxonomic system to viruses
- In 2016, the ICTV pivoted to allow classification of viruses based on sequence data alone, without requiring information on host range or visualization of the virus capsids; outline the advantages and disadvantages of this approach

- Argue why the number of named viral species is increasing at a rapid rate
- If you isolated and sequenced a new virus, formulate a plan as to how you would approach its naming and classification

***Core concept 2*: Virus Structure and Function**

***Fundamental Statement 1*: Viruses come in a variety of shapes and sizes, from giant mimiviruses to tiny circoviruses.**

Example lower-order thinking learning objectives include:

- Recall the approximate size range of viruses (diameter or length) in nanometers or microns
- Describe the size range of different viruses in relation to other microbial life forms
- List the types of shapes that plant, animal, insect, and bacterial viruses can have
- Describe differences between icosahedral virions and helical virions
- List methods used to study the structure of viruses

Example higher-order thinking learning objectives include:

- Analyze if there is a relationship between virus size and genome size/protein-coding capacity/presence of multifunctional proteins
- Analyze if there is a relationship between virus size, genome size, and presence of overlapping reading frames
- Compare how/why X-ray crystallography and cryo-EM are important for the study of viruses
- Calculate the number of viral subunits within an icosahedral viral particle from the capsid triangulation number
- Assess how the concept of quasi-equivalence relates to icosahedral viral structure
- Evaluate why certain viruses have evolved specialized substructures such as fiber proteins of Adenovirus, or tails on bacteriophage

***Fundamental Statement 2:* Viruses are composed of viral nucleic acids surrounded by a protective protein shell, and in some cases a lipid envelope.**

Example lower-order thinking learning objectives include:

- Describe the types of nucleic acid that viruses can have
- Explain the basic structural components of a virion, and their roles
- List the components of a simple nonenveloped virus and a simple enveloped virus
- Define the location of the matrix protein within an enveloped virus
- For a given enveloped virus, describe how it obtains its lipid envelope

Example higher-order thinking learning objectives include:

- Compare and contrast the functional significance of DNA vs RNA as viral genetic material
- Formulate a simple experiment to determine if a virus' genome is composed of DNA or RNA
- Formulate a simple experiment to distinguish between an enveloped and nonenveloped virus
- Compare and contrast the consequences of a virus being enveloped vs non-enveloped
- Compare and contrast the shared and unique viral structural components necessary for infection of different life forms (*e.g.*, bacteria, plants, and animals)
- Differentiate between structural components all viruses have versus those found only in some viruses

Fundamental Statement 3: **The Baltimore classification system groups viruses based on whether the genome is composed of DNA or RNA, is single- or double-stranded, and according to the mechanism by which viral messenger RNA (mRNA) is synthesized.**

Example lower-order thinking learning objectives include:

- List the seven groups of viruses in the Baltimore classification system
- Draw a simple decision-tree to classify viruses according to the Baltimore system
- Recall the order of viral biomolecule synthesis upon entry of a single-stranded RNA virus into a host cell if given the RNA polarity (positive-sense vs. negative-sense RNA)
- Explain how replication proceeds for each of the seven Baltimore classification groups
- Explain why different polymerases are required depending on genome type and/or replication strategy
- For a given Baltimore virus genome class, describe if a virus uses host enzymes and/or needs to bring/encode their own to complete the process of viral transcription
- For a given Baltimore virus genome class, describe if a virus uses host enzymes and/or needs to bring/encode their own to complete the process of viral genome replication

Example higher-order thinking learning objectives include:

- Differentiate modes of mRNA synthesis between different groups in the Baltimore classification system
- Evaluate why some viruses must carry their polymerase within the capsid
- Formulate a hypothesis to explain how a viral positive-sense, single-stranded RNA is sometimes translated, and other times used as a replication template
- Pararetroviruses were discovered after Baltimore's seminal 1971 publication – based on knowledge of the seven main groups of viruses and differences in pararetroviruses, can you construct a novel way for a virus to express and replicate its genome to add an 8th classification?

Fundamental Statement 4: **All viruses are obligate intracellular parasites that must utilize a host cell's molecular machinery (*e.g.*, ribosomes) to complete a productive replication cycle.**

Example lower-order thinking learning objectives include:

- Define intracellular parasite
- Define the difference between a virion, an infectious virus, and a virocell
- Define host factor, and then give examples of how viruses use host factors to their advantage
- List one host molecule and one host molecular machine that are required for viral replication
- Explain why viruses need host cells for viral protein synthesis to occur
- Besides ribosomes, identify another host factor or host machinery and describe how a specific virus uses it to reproduce the virus
- Explain why some viruses enter the nucleus as part of the replication cycle and some do not; extend this to describe how this influences what host functions the virus can hijack

Example higher-order thinking learning objectives include:

- Propose an experiment that can distinguish viruses that require the host DNA-dependent RNA polymerase Pol II from those that do not
- Evaluate the pros and cons of a particular antiviral drug strategy based on its viral or cellular target
- Present an argument for or against viruses being defined as "alive"

Fundamental Statement 5**: Subviral agents (viroids, satellites, prions, etc.) can have important environmental and disease impacts.**

Example lower-order thinking learning objectives include:

- Define viroid, satellite virus, satellite RNA, and prion
- List one difference between a viroid and satellites
- For each of plants and animals, name a disease that is caused by a subviral agent

- State impacts that viroids, satellite viruses, satellite RNAs, and prions each can have on respective hosts

Example higher-order thinking learning objectives include:

- Distinguish viruses from viroids, satellite viruses, satellite RNAs, and prions, especially in regard to their structural composition, how they reproduce, and how they cause disease
- Design an experiment (or experiments) that could be used to identify whether an unknown agent is either a virus or a subviral agent

***Core concept 3*: Virus Replication Cycle**

Fundamental Statement 1: **Viruses are obligate intracellular pathogens and require living host cells in which to replicate.**

Example lower-order thinking learning objectives include:

- Define obligate intracellular pathogen
- Define host cell
- List properties of living host cells that distinguish them from dead cells
- Explain why a host cell must be living for a virus to replicate

Example higher-order thinking learning objectives include:

- Evaluate and list the properties, products, or factors within living cells that are needed for viral replication
- Virologists debate whether viruses are alive or dead; take a position and justify whether a virus is alive or not
- For at least two host factors or host machineries, compare how a specific virus uses each to reproduce itself

Fundamental Statement 2: **Virus life cycles consist of sequential processes beginning with entry into a host cell and ending with release of new virions from the infected cell.**

Example lower-order thinking learning objectives include:

- List the five main steps of the animal virus life cycle
- Illustrate and label the different steps of a virus life cycle in a model host cell
- Compare how animal vs plant viruses enter host cells
- State two different ways that viruses assemble
- Compare how enveloped viruses vs. non-enveloped viruses exit an infected cell

Example higher-order thinking learning objectives include:

- Assess why attachment of a virus to a host cell does not always result in the virus entering the host cell
- Appraise why entry into a host cell does not always result in the virus reproducing itself, and/or causing any negative impact in the host cell
- Compare and contrast how a virus life cycle differs from that of an intracellular bacterial pathogen
- Analyze how different classes of antivirals inhibit stages of the viral life cycle
- Outline how some host factors determine virus-host cell specificity

Fundamental Statement 3: **Virus replication cycles vary, impacted by their unique structures, genome organization, and host-cell specificity.**

Example lower-order thinking learning objectives include:

- Define DNA-dependent DNA polymerase (DdDp), DNA-dependent RNA polymerase (DdRp), RNA-dependent DNA polymerase (RdDp), and RNA-dependent RNA polymerase (RdRp)
- List which viral genomes require viral polymerase to be present within the viral particle

- Explain why viruses only infect certain cells within a host
- Explain why plant viruses can infect many different plant hosts, but many bacteriophages only infect a single bacterial host

Example higher-order thinking learning objectives include:

- Describe which type of viral genome uses which of these polymerases (DdDp, DdRp, RdDp, RdRp), and analyze why this is the case
- Analyze why a viral particle would have to carry its own polymerase
- Compare and contrast how and why translation must occur before transcription in positive-sense, single-stranded RNA viruses, but transcription occurs before translation in negative-sense, single-stranded RNA viruses
- Assess how a specific drug that targets a specific viral factor is able to block the ability of a virus to replicate its genome
- Evaluate why gene order in non-segmented negative-sense single-stranded RNA viruses is important for efficient viral replication
- Compare and contrast the potential advantages and disadvantages of a segmented viral genome
- Compare and contrast the potential advantages and disadvantages of a virus being multipartite

Fundamental Statement 4: **Expression of virus genes and replication of virus genomes requires a combination of cellular and viral factors as determined by the viral genome and site of replication.**

Example lower-order thinking learning objectives include:

- Explain why most DNA viruses replicate in the nucleus, and most RNA viruses replicate in the cytoplasm
- Explain why most RNA viruses replicate in the cytoplasm, but a few RNA viruses (*e.g.*, influenza virus) replicate in the nucleus
- Explain why all RNA viruses must encode a polymerase
- List viral factors and cellular factors or organelles needed for viral genome replication
- List reasons why intracellular membranes are required for positive-sense, single-stranded RNA genome replication
- For a DNA virus, a positive-sense single-stranded RNA virus, a negative sense single-stranded RNA virus, and a retrovirus, state how one viral factor and one cellular factor allow the virus to replicate its genetic material
- For translation of protein for some viruses, define the importance of (i) polyprotein processing; (ii) an internal ribosome entry site (IRES); (iii) ribosomal frameshifting

Example higher-order thinking learning objectives include:

- Cells segregate biosynthetic functions to the nucleus or cytoplasm; list and distinguish nuclear and cytoplasmic biosynthetic functions required for viral genome replication
- Develop an experiment that can help you determine if a certain cellular factor is involved in viral genome replication
- State which genome category of virus requires intracellular membranes for genome replication and analyze why
- Compare how and why host cell and viral helicases impact viral genome replication in different ways
- Outline at least two ways that some RNA viruses manage the "monocistronic problem" to make the most out of their relatively small genome

Fundamental Statement 5: **Virus gene expression and replication are coordinated through dynamic spatiotemporal interactions with host cell factors.**

Example lower-order thinking learning objectives include:

- Describe the general features of early genes versus late genes
- List host factors that are dynamically regulated during the viral replication cycle

- Discuss how and why some viruses encode proteins to activate the cell cycle

Example higher-order thinking learning objectives include:

- The process of cell division influences replication of some viruses; analyze why the stage of cell cycle can influence the replication efficiency of viruses
- Design an experiment that shows how subgenomic RNAs can be used by some viruses to regulate temporal expression of one or more genes

***Core concept 4*: Host-Virus Interactions**

Fundamental Statement 1: **Not all viral exposures result in infection or disease.**

a. Some host-virus interactions can be beneficial for the host.

Example lower-order thinking learning objectives include:

- Define permissive host
- Discuss beneficial viruses
- Define cytopathic effect
- Discuss varied phenotypic cytopathic effects
- Explain how cytopathic effect can be used to confirm viral infection
- Explain why some viral infections do not result in cytopathic effects
- Explain how a host can gain novel genes from viral genome integration
- Describe how human endogenous retroviruses (HERVs) have modified the human genome

Example higher-order thinking learning objectives include:

- Compare ways that viruses confer positive aspects for a host
- Catalog what a specific host cell would require in order to be permissive to infection by a specific virus
- Evaluate what is needed for a host to be permissive to infection by different viruses
- Analyze how CRISPR can prevent some bacteriophages from successfully infecting some bacteria

Fundamental Statement 2: **Virus infections can be acute, latent, or persistent; some are oncogenic.**

Example lower-order thinking learning objectives include:

- Define latent, lytic, and persistent infections
- Explain mechanisms of latency and reactivation
- Explain the viral lytic life cycle
- Define oncogenesis
- Explain different oncogenic mechanisms involving viral protein(s)
- Define oncolytic virus

Example higher-order thinking learning objectives include:

- Distinguish between latent, lytic, and persistent infection in regard to outcomes for the infected cell or host
- For a virus that establishes latency, assess how the virus maintains its genome (*e.g.*, integration or episomal), evades the immune response (*e.g.*, internal sanctuaries; limited expression of viral proteins), and does not cause cytopathic effect (*e.g.*, arbovirus infecting an insect cell)
- Compare and contrast when integration of a viral genome does not, or might, lead to latency
- Compare and contrast when integration of a viral genome does not, or might, lead to oncogenesis
- Argue how a virus can cause cancer, yet the virus is not maintained in the cell/organism
- Compare different viral oncogenic mechanisms and propose features needed in an inhibitor (drug)

Fundamental Statement 3: **The processes by which viruses cause disease involve interactions of virus and host factors at the cellular and organismal level.**

Example lower-order thinking learning objectives include:

- Discuss diseases caused by different viruses
- Discuss viral tropism in relation to disease
- Define host pattern recognition receptors (PRRs) and virus pathogen-associated molecular patterns (PAMPs)
- Discuss host innate immunity and the antiviral interferon response
- Define passive immune evasion and active immune evasion

Example higher-order thinking learning objectives include:

- Investigate a specific virus and mechanism of disease
- Hypothesize how virus-receptor interactions can influence viral tropism
- Investigate the evolutionary race between infectious disease-causing viruses and host antiviral defenses
- Compare and contrast how some viruses "outrun" the host while others encode genes that evade/modulate the vertebrate immune response to potentially cause disease

Fundamental Statement 4: **After a non-lethal exposure to a virus, the host often develops a protective immune response against the virus (in some cases, also against related viruses).**

a. Vaccines also elicit a protective immune response.

Example lower-order thinking learning objectives include:

- Define the antiviral roles seen with T cells, B cells, and natural killer cells
- Define neutralizing antibodies
- Define antibody dependent enhancement

Example higher-order thinking learning objectives include:

- Judge the importance of different immune cells (*e.g.*, T cells; B cells; natural killer cells) in the antiviral response
- Investigate antibody dependent enhancement, and consider why it can be problematic

Fundamental Statement 5: **Virus infection and disease can be prevented and/or treated using a variety of biological, chemical, and physical approaches.**

a. Vaccination has led to reduced morbidity and mortality for a wide variety of human and animal diseases.

Example lower-order thinking learning objectives include:

- Discuss the history of vaccination
- Define the difference between antivirals and vaccines
- Define the different vaccine platforms in use today
- Discuss why some viruses require yearly vaccination
- Examine the degree to which vaccines have led to reduced morbidity and mortality
- Read a few secondary sources and briefly describe how bacteriophages can (i) treat antibiotic-resistant bacterial infections, and (ii) be potentially useful for burn victims

Example higher-order thinking learning objectives include:

- Compare and appraise different vaccine platforms, *e.g.*, live attenuated vaccines vs mRNA vaccines
- Investigate a vaccination program and judge its success
- Develop a plan to convince “anti-vaxxers” that vaccination is safe and effective
- Identify a common misconception about vaccines and provide scientific evidence to dispute it
- For one antiviral drug, analyze how it interferes with the virus replication cycle

- Create an antiviral therapy or vaccine for an important viral pathogen with no current antivirals or vaccine, respectively; defend why its mechanism of inhibition or protection will be successful
- Assess why scientists have struggled to create a vaccine against some viruses (*e.g.*, HIV)

***Core concept 5*: Impact of Viruses**

Fundamental Statement 1: **The study of viruses has been key to the understanding of cell and molecular biology, immunology, and infectious disease processes.**

Example lower-order thinking learning objectives include:

- Identify, and discuss, aspects of cell/molecular biology first observed studying viruses (*e.g.*, first genome sequenced, splicing, the discovery of p53, reverse transcription, etc.)
- State the properties of viruses employed to reveal information about cellular functions
- Discuss historic experiments that employed viruses
- Discuss current ways viruses are employed as molecular laboratory tools
- Discuss how viruses impact cellular evolution

Example higher-order thinking learning objectives include:

- Design an experiment which employs a virus to address a question about a cellular function
- Investigate a historic manuscript which employed a virus to reveal cellular functions
- Examine and appraise experiments which employ a virus to reveal cellular functions
- Investigate the co-option of viral sequences for cellular (mammalian) genes (*e.g.*, syncytins)

Fundamental Statement 2: **Viruses and their proteins can be used to develop research tools, products, and therapeutics.**

Example lower-order thinking learning objectives include:

- Give a specific example of how a virus (or viral product) has been used as part of a therapeutic
- Explain a property of a virus that allows scientists to manipulate it for a desired purpose
- Describe the use of viral elements in expression systems (*e.g.*, strong viral promoter in expression vectors)
- Discuss viral laboratory tools (*e.g.*, phage display; lentivirus integration of desired genes)
- Discuss viral therapies (*e.g.*, oncolytic viruses to treat cancer; phage therapies to treat antibiotic resistant bacterial infections and dysbiosis)

Example higher-order thinking learning objectives include:

- Compare and contrast the advantages and disadvantages of viral vectors in gene therapy experiments
- Design a novel virological tool or therapy and pitch your product to potential investors

Fundamental Statement 3: **The study of virology is rapidly evolving, and helps drive the development of novel techniques in fields such as genomics and computational biology, allowing scientists to better understand viruses and their roles in life.**

Example lower-order thinking learning objectives include:

- Describe a technology or technique used in biological research that was made possible by virology
- Discuss advances in microscopy which enabled the study of viruses in greater detail
- Explain why cell/molecular and computational technologies are needed to study viruses

Example higher-order thinking learning objectives include:

- Summarize how the study of virology led to CRISPR technology; hypothesize how this technology can be applied to a novel biological problem
- Develop a specific question in virology and design an experiment to address that question

- Obtain a recently-published piece of primary literature and interpret experimental virological data from it
- Reconstruct experiments from a historic virological manuscript, but using technologies available today

Fundamental Statement 4: **Human lives and economics are impacted by viral diseases in humans and other organisms.**

Example lower-order thinking learning objectives include:

- Provide specific examples of how pandemics (*e.g.*, 1918 influenza or COVID-19) have impacted individuals, communities, and the global economy
- Recognize that viruses infect all cellular life
- Define zoonosis, emerging viruses, epidemics, and pandemics
- Discuss how non-human viruses impact human life, such as in agriculture
- Discuss how modern life influences emerging viruses

Example higher-order thinking learning objectives include:

- Predict what emerging viruses may have the greatest impact on society based on their characteristics
- Predict the next human pandemic and defend your prediction
- Hypothesize how future changes in the environment or human activity (*e.g.*, climate change, space exploration, increased mobility) could impact viral emergence and spread
- Investigate the molecular details of a zoonotic virus
- Formulate a hypothesis as to why evolution of viruses can lead to impacts on human lives

Fundamental Statement 5: **Viruses have large-scale effects on ecosystems and the environment.**

Example lower-order thinking learning objectives include:

- Explain why viruses are known as the most abundant replicating entities on Earth
- Describe how viruses are involved in nutrient cycling (*e.g.*, carbon turnover in the oceans)
- Explain how bacteriophages regulate bacterial populations (*e.g.*, inside animals [microbiome], or in the environment)

Example higher-order thinking learning objectives include:

- Search for primary literature on the link between COVID-19, or dengue virus/mosquitoes, and global climate change; interpret the information that you find
- Given a description of the transmission characteristics and host range of a zoonotic virus, create a research question regarding the environmental impact of the appearance of this virus in a new ecosystem
- Design a screen to discover unknown environmental viruses with a specific desired activity
- Search for and read primary literature on plant viruses that confer drought tolerance and assess what is known about how this can occur
- Debate if viruses are living or non-living
- Debate if viruses belong on the tree of life

Acknowledgments

The contributing authors thank JJ Miranda (Barnard College) for clarifying suggestions regarding the phrasing of some of the learning objectives.