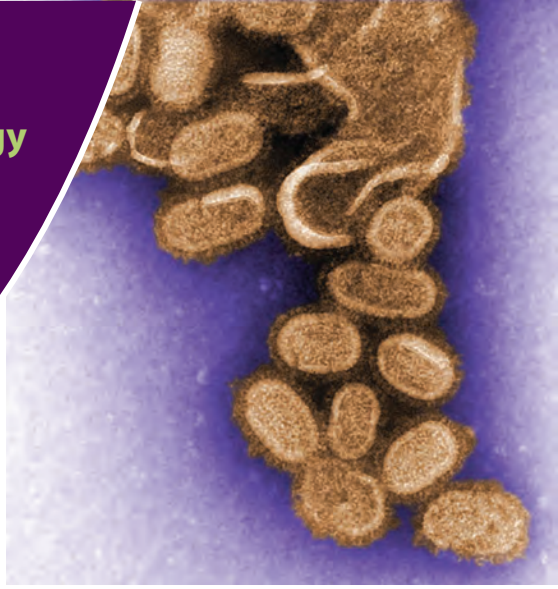
FEATURE ARTICLE

The Role of Virology in the Biology Curriculum



ADAM STEFANILE

Abstract

In the 21st century, post coronavirus disease 2019 (COVID-19) pandemic, virology has been, and continues to be, in the public eye. The impact of the COVID-19 pandemic globally has affected political, economic, social, policy, and health aspects. Transformative breakthroughs in the field of virology such as disease prevention, vaccines, drug therapy, and cancer research have continued to improve all aspects of human health. Yet, with all these breakthroughs, high school curriculum and pedagogy have not adequately kept up with the majority of basic virology principles. In today's modern world, post COVID-19 pandemic, it is essential to consider introducing basic and modern principles of virology to high school students. In this paper, a systematic literature review was performed to identify, assess, and evaluate high school biology and health curricula to see whether modern principles of virology were included in the curriculum, as reported by the selected scientific publications. This study also highlights several challenges for implementing modern principles of virology to pave the way for further research.

Key Words: *biology; Coronavirus disease 2019; curriculum; education; high school; virology.*

○ Introduction

A virus is a microscopic infectious pathogen composed of proteins and nucleic acids, and in some cases lipids in a surrounding envelope. Lipid-coated viruses are viruses that have a lipid bilayer coat that protects their genome (Motsa & Stahelin, 2021). Some examples of Lipid-coated viruses include: coronaviruses, such as SARS; filoviruses, such as Ebola virus and Marburg virus; paramyxoviruses, such as measles virus and Nipah virus; flaviviruses, such as dengue and Zika viruses (Stahelin, 2023).

Viruses are *not living* and not able to replicate without invading a host cell (living organism) and use the host cell's metabolism to reproduce its genome and its surrounding coat (Taylor, 2014). Once a virus replicates itself, it leaves the host cell to infect other cells (Strumillo et al., 2021). How we define life, however, is important because too frequently we (the general public) make assumptions that a living entity composed of genetic/genomic material is considered to be alive, when in fact, a virus is not alive because it lacks the essential characteristics of living organisms including reproducing and growing independently and maintaining homeostasis (Koonin & Starokadomskyy, 2016). At a rudimentary level, viruses are composed of proteins and genomic material that survive and replicate only within the environment inside another life form (Harris & Hill, 2021; Louten, 2016). Furthermore, the characteristics associated with living cells and life properties include reproduction, growth, responsiveness, and the ability to metabolize. Viruses lack the capability to perform all of these independently.

Viruses are known to infect all living organisms; "We live in what many now describe as the *virosphere*, since almost all living multicellular and unicellular organisms are susceptible to virus infection" (Burrell, Howard, & Murphy, 2017, p. 9). Viral hosts include bacteria, protozoa, fungi, plants, and animals (including humans) (Dolja & Koonin, 2011). There are, however, multiple factors associated with how a virus can infect a host. This includes environmental factors, viral factors, and host factors. Environmental factors include human-to-human contact, temperature, and human hygiene (Babuna et al., 2021). Viral factors include virulence, viral infectivity, and viral tropism (Louten, 2016). Host factors include receptor compatibility, age, gender, health, and genetics/genomics (Rouse & Sehrawat, 2010).

The primary aim of introducing principles of virology in high school teaching of biology, whether it be in the established curriculum or as an elective course, is to introduce modern, relevant, and pragmatic principles of virology and their applications.

Viruses did not become widely recognized until the 20th century with the research on the tobacco mosaic virus (TMV) by Wendell Stanley in 1934 (Creager, 2022), and the development of the polio vaccine by Jonas Salk (Baicus, 2012). Currently in the 21st century, virologists have developed major technological advancements merged with principles of microbiology, biochemistry, genomics, and human health

The American Biology Teacher, Vol. 87, No. 9, pp. 500–504, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2025.87.9.500.

that have enabled virologists to make major advances in research and medical applications. These include genetically altered viruses for cancer research, the extraction and sequencing of viral DNA and RNA genomes for human health, (Capobianchi, Giombini, & Rozera, 2013), and development of vaccines (Brisse et al., 2020). Moreover, virologists have documented about 3,200 viral species (Hufsky et al., 2018). These discoveries have been augmented by major advances in virological research using astonishing modern technologies including next-generation sequencing (Capobianchi, Giombini, & Rozera, 2013), Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), CRISPR-associated (Cas) proteins, and gene therapy (Uddin, Rudin, & Sen, 2020).

With all of these advancements in technology-based tools and modern scientific and medical research that clearly have significant scientific and social importance, why are high school students not sufficiently learning principles of virology in their schools? Why aren't high school biology and health educators more consistently teaching their students basic principles of virology? Why hasn't the biology curriculum of many high schools across the nation included modern virology principles? Should virology be taught as an elective in high school?

○ Basic Principles of Virology

Ever since the inception of the Coronavirus disease 2019 (COVID-19) pandemic, the field of virology has become more relevant to, and a pragmatic topic for, society and human health than any other topic in human health over the last 100 years (Pitlik, 2020). Given the emphasis on virology in undergraduate biology education, greater attention to virology principles should be included in the high school curriculum for students to be properly prepared for college-level biology coursework. The basic principles of virology that are generally taught in an undergraduate biology course include, but are not limited to, the historical aspects, origins of viruses, types of viruses based on the family of viruses (DNA or RNA), size and shape (structure), naming and categorizing (taxonomy and nomenclature), viral transmission, viral replication, human immunity, and the myriad of viral genomes that have and continue to evolve (Berman, 2019; Fermin, 2018). Moreover, it is important for high school students who are planning to enter into the biological sciences and informed citizenry to understand the role of viruses as it relates to cancer and other diseases. This has been and continues to be a significant field of research because cancer research has shown that viruses are responsible for 15–20% of human cancers (McLaughlin-Drubin & Munger, 2008).

○ Practical Suggestions for Incorporating Virology in the High School Biology Curriculum: What Should be Taught?

Given that there are different pedagogical skills and strategies that are needed to communicate the principles of virology to high school students, one must ask: Which pedagogical approach is most likely needed to meet the educational needs of all high school students? This question should be addressed by biology educators in all educational settings, including private and public schools.

Virology education should be focused on providing access and exposure for high school students to learn about preventing and/or managing the spread of specific viral diseases by educating them about the behaviors that are conducive to promoting a safe and healthy lifestyle. Making virology education a priority for high school students can be a pivotal role in promoting public health and empowering high school students with relevant knowledge about viral diseases. Moreover, this provides them with a better understanding to prevent and mitigate the spread of viruses and also fosters healthier lifestyle choices (de Souza et al., 2020). Currently, there are no recommended curriculum guidelines for high school biology educators. Therefore, some specific viral topics that should be taught to high school students are listed in Table 1.

Table 1. Incorporating virology topics in the high school biology curriculum.

Viral topic	Duration	Content
Characteristics of Viruses	1 day (45–60 minutes)	Definition of a virus, components of viruses, genetic material
Size and Shapes of Viruses	1 day (45–60 minutes)	Compare size and shapes of DNA and RNA viruses, classification of viruses
Hosts of Viruses	1 day (45–60 minutes)	Definition and examples of a host, mechanism by which viruses are specific for their host cell
Viral Replication	1 day (45–60 minutes)	List and describe the five stages of viral replication and replication of animal viruses
Bacteriophages	1 day (45–60 minutes)	List and describe the lytic replication cycle in bacteriophages
Viral Diseases to the Human Body	1–3 days	List and describe the viruses and systems of the human body that the virus infects
Viral Emerging and Re-emerging diseases	1–2 days	Listing the viral emerging and re-emerging diseases and their impact and burden to human health

Additionally, biology educators should emphasize the topic and content of the online document "*Disease X*," which was introduced by the World Health Organization (2018). *Disease X* is considered by scientists to be the next unknown and unnamed pathogen that may cause some epidemiological problem. This is important for our citizens of the future to respond to and plan for possible newly emerging infectious diseases that may not be fully understood in terms of origin, transmission, and effects.

○ Undergraduate & Graduate Virology Curriculum

Unless more attention is provided at the high school level to teach some principles of virology, the level of content knowledge/information in our society will be influenced profoundly by modern science and technology (Mormina, 2019). The current high school biology

Table 2. Principles of the American Society for Virology undergraduate curriculum.

Virus Evolution and Ecology
Virus Structure and Function
Virus Replication Cycle
Host–Virus Interaction
Impact of Viruses

Table 3. Principles of the American Society for Virology graduate curriculum.

Virus Structure
Viral Attachment and Entry
Virus Trafficking and Uncoating
Viral Replication
Virus Assembly
Viral Egress/Exit
Viral Pathogenesis
Innate and Adaptive Immune Response to Viral Infection
Evasion of the Immune Response by Viruses
Viruses, Transformation, and Cancer
Antiviral Treatments
Vaccines
Viral Emergence and Evolution
Classic and Modern Technologies to Study Viruses

curriculum, therefore, must prepare our students for the rapidly changing society, as society changed during the 2009 H1N1influenza A pandemic and the COVID-19 pandemic. Curriculum guidelines to teach high school students principles of virology are needed to best guide student learning. When designing a curriculum to teach virology at the high school level, it's essential to cover both theoretical concepts and practical applications. The principles of the ASV undergraduate and graduate curriculum are shown in Table 2 and Table 3.

Online resources, containing the curriculum guidelines and the learning objectives for both undergraduate and graduate courses, are accessible using the following links. These materials are also available as Supplemental Material with the online version of this article.

- **Undergraduate Virology Curriculum** https://asv.org/wp-content/uploads/2022/08/Undergraduate-Curriculum-Guidelines.pdf
- **Graduate Virology Curriculum** https://asv.org/wp-content/uploads/2022/08/Graduate-Curriculum-Guidelines.pdf

○ Virology Education Across the Paradigms of Teaching & Learning

In high school education, several paradigm shifts guide curriculum, pedagogy, and learning (Alam et al., 2022), and these paradigm shifts provide educators with different views of how students learn and how educators should facilitate that learning. Although the COVID-19 pandemic has increased our awareness of the social impact of viral diseases, some research has shown that viruses and their characteristics are not well understood by some biology students (Simon, Enzinger, & Fink, 2017). Virology is grounded in all domains of STEM education (Kushner & Pekosz, 2021) and, therefore, is a useful topic to integrate broad STEM-related principles in the biology curriculum. During their formal education in biology and general science, high school, undergraduate, and graduate students can be introduced to the principles and pragmatic aspects of virology without enrolling in a virology course, per se.

In Austria, the biology curriculum in grades 6, 8, and 9 includes basic principles of viruses and viral diseases (Simon, Enzinger, & Fink, 2017). The research of Simon, Enzinger, and Fink (2017) describes how educating high school and undergraduate students in viral biology, virus structure, and health-education issues increased and helped them retain their content knowledge pertaining to virology, while also increasing interest in the topic and motivation to progress with learning new virology concepts. "However, even many first-year biology students had a high number of severe misconceptions, e.g., defining a virus as a pro- or eukaryotic cell, or falsely naming malaria as a viral disease" (Simon, Enzinger, & Fink, 2017, p.21).

○ Educational Resources Supporting Virology

Virology has indeed taken center stage in public health, especially following the COVID-19 pandemic. The COVID-19 pandemic highlighted the critical importance of understanding viruses, their transmission, and their impact on human health. This has led to several significant developments in the field (Olesińska et al., 2025) as listed hereafter. Recently, post COVID-19, virology has become a very fundamental part of the public health industry for useful and pragmatic health applications in many hospitals, clinics, and research fields (Imperiale & Casadevall, 2015).

The *Science Journal for Kids* has developed formal hands-on pedagogical activities and online simulations that help students learn about bacterial and viral diseases. These materials are accessible using the following link: https://www.sciencejournalforkids.org/articles/lesson-ideas/teaching-infectious-diseases/.

The *Howard Hughes Medical Institute* (HHMI) is widely known for their biointeractive instructional materials encompassing general biology, microbiology, virology, pathology, and diseases. These materials are accessible using the following link: https://www.biointeractive.org/classroom-resources/virus-explorer.

A group of science educators at the Center for Science and the Schools (CSATS) at Penn State University, including a group of experts in science and instructional design, have written, piloted, and revised a free online course ("The Science of COVID-19") for secondary school educators to use with their students (Johnson et al., 2023). These materials are accessible using the following link: https://www.csats.psu.edu/science-of-covid19.

The National Human Genome Research Institute of the National Institute of Health has published an online educational resource "Genomics and Virology" that addresses basic virology and the role of viruses in the transmission and infection of human viral diseases. These materials are accessible using the following link: https://www.genome.gov/about-genomics/fact-sheets/Genomics-and-Virology.

The National Association of Biology Teachers (NABT) published a position statement on "The Role of Biology Education in Addressing HIV & AIDS." Their statement includes curriculum topics such as: "All aspects of the biology of the virus and its impact on human health, with emphasis on preventing further spread of the virus and the current and future impact of biomedical research on the spread of the virus and the treatment of the disease." These were published online and are accessible using the following link: https://nabt.org/files/galleries/Role_of_bio_ed_HIV-AIDS.pdf.

○ Virology in High School for the 21st Century

The concept of teaching high school students virology is a topic increasingly emphasized in recent publications. Kushner and Pekosz (2021) present an interesting and comprehensive review of the current status of virology content covered in high school biology courses and present useful recommendations for improving virology in high school and undergraduate college courses. Mortimer (2020) highlights the trajectory of virology since the 1900s and the need for students to better understand how virology is an interdisciplinary subject, as well as the concepts that students should be learning from virologists. The research by de Souza et al. (2020) demonstrated positive results of their "Virus Goes Viral" educational kit, which included material encompassing 13 different viruses and 17 miscellaneous effects on host cells. This kit has been used to teach virology in both high school and undergraduate classes in Brazil.

Virology, despite its importance, may be insufficiently covered in standard state curricula. Unless states sufficiently emphasize and implement virology in the biology curriculum, this important topic may be too frequently overlooked. Biology educators, therefore, may need to consider including topics of virology as an enrichment in their lessons.

It is important for biology and health educators to integrate principles of virology in their teaching as a way to encourage high school students' interest in this scientific field, its applications for their health, and opportunities for possible future professional roles. With modern scientific and technological advances in viral genomics, drugs, vaccines, and pharmaceutical biotechnology, biology and health educators have the opportunity to enhance students' broader understanding of virology and improve high school learning outcomes.

○ Beyond the Human Health & Diseases Aspects

There is an entire area of research on the role of viruses in the natural environment and in ecosystems (Rohwer, Prangishvili, & Lindell, 2009) because viruses are ubiquitous on Earth and these pathogens are found in most ecosystems (Harris & Hill, 2021). Beyond human and animal diseases, an important area of ecological research deals with viruses that infect algae. This is a very important aspect of aquatic communities. Viral lysis of algae releases soluble nutrients that support additional biological primary productivity in a process that is known as the microbial loop (Short, 2012). Viruses that attack bacteria are known as "bacteriophages," and these viruses are very selective about the species of bacteria they are able to infect. Bacteriophages cannot infect and replicate in human cells; however, they are important for research and development beyond the medical field, including their use for research on humans and the human microbiome, with topics such as symbiosis, environmental food applications, industrial applications, and research tools (García-Cruz et al., 2023).

○ Beneficial Viruses?

Although some viruses are serious pathogens, other viruses have positive effects in the environment. Small marine and freshwater algae that form algal blooms that eventually decay are known to deplete the water of oxygen causing harm to aquatic organisms. Some algicidal viruses stop algal blooms by infecting and killing the algae (Coyne, Wang, & Johnson, 2022).

Recent research has indicated that viruses that infect plants and become integrated in their genome may improve plant growth, including those used for drug development. This occurs by replicating the viral genome within the plant's genome that increases certain characteristics that promote the desirable plant characteristics (Roossinck, 2015). "Many applications of viruses have been used for agricultural purposes, namely concerning plant breeding and plant protection" (Varanda, Félix, Campos, & Materatski, 2021, p. 2).

Furthermore, viruses are involved in many biological processes that have revolutionized some areas, particularly gene editing, which is attributed to the discovery of CRISPR/Cas9 (Uddin, Rudin, & Sen, 2020). Genome editing methods are used to develop changes in a specific genome sequence to omit, correct, or replace a defective gene or sections of a gene. Since 2012, CRISPR has been the main genome editing tool in the world. CRISPR was discovered by scientists trying to better understand how bacteria interact and combat viral infections (Escalona-Noguero, López-Valls, & Sot, 2021). This genome editing tool is used to identify a specific segment of a viral genome, extract/cut the segment of the genome, or insert a new genome segment in cultured cells or in a whole organism (Saha et al., 2019). Because of its pragmatic applications many scientists are utilizing CRISPR applications genome editing.

○ Discussion

The primary aim of introducing principles of virology in high school teaching of biology, whether it be in the established curriculum or as an elective course, is to introduce modern, relevant, and pragmatic principles of virology and their applications. If we as a society want our high school students of today to become better scientifically informed citizens and to encourage more students to become scientists of tomorrow, students need to understand the interdisciplinary concepts between viruses, modes of pathogenic disease transmission, disease prevention, and the need to raise public awareness. For students who enter professional careers in virology-related fields of STEM, they will need to, at some point, understand and apply their understanding of virology to new contexts and construct new knowledge to solve real-world problems.

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ADAM STEFANILE (adam.stefanile@temple.edu) is an assistant professor at Temple University in Philadelphia, Pennsylvania.