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COMMENTARY

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# Curriculum Guidelines for Graduate and Undergraduate Virology Courses

David B. Kushner,[a] Troy D. Cline,[b] Pranav Danthi,[c] Kari M. Debbink,[d] Maureen C. Ferran,[e] Michelle Flenniken,[f] Dylan M. Johnson,[g] Andrew Mehle,[h] Daniel A. Morales,[i] Suchetana Mukhopadhyay,[c] John S. L. Parker,[j] Chelsey C. Spriggs,[k] Lauren A. O'Donnell,[l] Melissa S. Maginnis[m]

[a]Department of Biology, Dickinson College, Carlisle, Pennsylvania, USA
[b]Department of Biological Sciences, California State University, Chico, California, USA
[c]Department of Biology, Indiana University, Bloomington, Indiana, USA
[d]Department of Molecular Microbiology & Immunology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA
[e]Thomas H. Gosnell School of Life Sciences, Rochester Institute of Technology, Rochester, New York, USA
[f]Department of Plant Sciences & Plant Pathology, Montana State University, Bozeman, Montana, USA
[g]Galveston National Laboratory, Department of Microbiology & Immunology, The University of Texas Medical Branch, Galveston, Texas, USA
[h]Medical Microbiology & Immunology, University of Wisconsin-Madison, Madison, Wisconsin, USA
[i]Department of Biological Sciences, Biomolecular Sciences Institute, Florida International University, Miami, Florida, USA
[j]Baker Institute for Animal Health, College of Veterinary Medicine, Cornell University, Ithaca, New York, USA
[k]Department of Cell and Developmental Biology, University of Michigan Medical School, Ann Arbor, Michigan, USA
[l]School of Pharmacy, Duquesne University, Pittsburgh, Pennsylvania, USA
[m]Department of Molecular and Biomedical Sciences, University of Maine, Orono, Maine, USA

**ABSTRACT** Curriculum guidelines for virology are needed to best guide student learning due to the continuous and ever-increasing volume of virology information, the need to ensure that undergraduate and graduate students have a foundational understanding of key virology concepts, and the importance in being able to communicate that understanding to both other virologists and nonvirologists. Such guidelines, developed by virology educators and the American Society for Virology Education and Career Development Committee, are described herein.

**KEYWORDS** curriculum, guidelines, virology

Education in virology is more important than ever, as exemplified by the recent challenges surrounding the coronavirus disease 2019 (COVID-19) pandemic and monkeypox outbreak. However, virology is not just about viruses that can cause disease; it is also about the relationships between viruses, hosts (e.g., animal, plant, fungus, and bacterium), and, broadly speaking, any environment.

There are several challenges regarding virology education. (i) Details of the rapidly expanding volume of information in the field of virology simply cannot be covered in a single course. Understanding concepts and developing higher-order thinking skills, rather than memorizing facts, is recommended to facilitate student learning. (ii) Certain learning goals for undergraduate and graduate students differ. Points of emphasis regarding course content may differ depending on whether the class is composed of students in Biology programs, pre-health programs, and/or an allied health program. Thus, virology courses may need to balance delivery of necessary content with skill development. (iii) Faculty have various backgrounds for teaching virology; for example, at small colleges, there may be no faculty member with formal virology training. Due to the absence of established guidelines for virology education, the development of curriculum guidelines to help faculty focus their teaching on key concepts would help instructors overcome these challenges.

For undergraduate biology as a whole, the breadth of biology meant that curriculum guidance needed to be general. The 2011 Vision and Change report (1) outlined five core

**Editor** Felicia Goodrum, University of Arizona

Address correspondence to David B. Kushner, kushnerd@dickinson.edu, Lauren A. O'Donnell, odonnel6@duq.edu, or Melissa S. Maginnis, melissa.maginnis@maine.edu.
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concepts for general literacy in biology: (i) evolution, (ii) structure and function, (iii) information flow, exchange, and storage, (iv) pathways and transformations of energy and matter, and (v) systems (living systems are interconnected and interacting). In 2012, a working group of the American Society for Microbiology (ASM) produced guidelines for undergraduate courses in microbiology, and a second set of guidelines for those teaching nursing/allied health majors (2–4). The ASM guidelines for an undergraduate microbiology course focus on concepts and statements connected to the five core concepts from the Vision and Change report and add a sixth category: impact of microorganisms. The microbiology guidelines also list a set of competencies and skills (scientific thinking and lab skills) that should be covered in an undergraduate course. These guidelines have been very useful for the microbiology community (5), but they are centered on concepts in bacteriology. Viruses are mentioned only occasionally in the ASM guidelines; this is not unexpected because these guidelines are for a microbiology course, and bacteria would be the focus. Thus, creating a separate set of guidelines for education in virology courses will provide instructors with additional guidance to design a course focused on the central concepts in virology that align with the American Association for the Advancement of Science (AAAS) Vision and Change report.

Due to the ever-growing importance of viruses in science and society, it has become imperative to establish curricular guidelines for both undergraduate and graduate virology courses. Graduate students interested in virology come from broad educational backgrounds and may or may not have had prior coursework in virology, which provides an additional challenge to instructors when developing a virology course. Learning objectives for a graduate virology course should focus on content, skill building, and approaches to content delivery. Such guidelines would provide a framework for faculty to best prepare students for successful graduate training and a career in virology and/or related fields.

To that end, members of the American Society for Virology (ASV) Education and Career Development Committee, along with a few community members, developed guidelines for undergraduate and graduate courses in virology. The guidelines were presented at the 41st annual ASV meeting held in Madison, Wisconsin, in July 2022, to obtain feedback. The guidelines are publicly available on the ASV website (6); here, we provide an overview of the guidelines. We strongly encourage anyone who teaches virology (or would like to teach virology) at the undergraduate and/or graduate levels to review the materials herein and at the ASV website to help as many students as possible acquire an understanding of viruses. It is hoped that these guidelines will help faculty who already teach virology to enhance their courses and also serve as a foundation to help faculty (especially those without formal training in virology) to design courses.

## UNDERGRADUATE GUIDELINES

The undergraduate guidelines working group built a set of learning outcomes and content recommendations. Nine key learning outcomes were identified; a summary of these nine outcomes is noted below (for details, see reference 6):

1. Define/describe viruses in terms of their nucleic acid and basic structural composition.
2. Convey that viruses are obligate intracellular pathogens that infect a broad range of hosts.
3. Explain the life cycles for diverse RNA and DNA viruses, with consideration of attachment, entry, gene expression, genome replication, assembly, and release.
4. Describe established therapies for limiting viral infection; consider steps in the virus life cycle that can be targeted by antivirals.
5. Describe the host immune response to viruses and how that understanding allows for development of antivirals and vaccines.
6. Connect the principles of virus transmission, pathogenicity, and evolution to virus emergence, especially regarding occurrences of outbreaks and pandemics.
7. Explain how viruses impact ecology and evolution of all life, including how viruses help us understand the biology of the infected cell.
8. Discuss that virology is a continuously and rapidly evolving field and that knowledge of this can result in development of research tools and therapeutics.

**TABLE 1** Undergraduate curriculum guidelines: content topic areas and subtopics

| Topic area | Subtopics[a,b] |
|---|---|
| I. Virus evolution and ecology | -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.<br>-Virus emergence and spread can be impacted by a variety of environmental, viral, and social factors.<br>-Although viruses are ubiquitous in nature and infect all forms of life, much of the global virosphere remains unstudied.<br>-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. |
| II. Virus structure and function | -Viruses come in a variety of shapes and sizes, from giant mimiviruses to tiny circoviruses.<br>-Viruses are composed of viral nucleic acids surrounded by a protective protein shell and in some cases a lipid envelope.<br>-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 mRNA is synthesized.<br>-All viruses are obligate intracellular parasites that must utilize a host cell's molecular machinery (e.g., ribosomes) to complete a productive replication cycle.<br>-Subviral agents (viroids, satellites, prions, etc.) can have important environmental and disease impacts. |
| III. Virus replication cycle | -Viruses are obligate intracellular pathogens and require living host cells in which to replicate.<br>-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.<br>-Virus replication cycles vary, impacted by their unique structures, genome organization, and host-cell specificity.<br>-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.<br>-Virus gene expression and replication are coordinated through dynamic spatiotemporal interactions with host cell factors. |
| IV. Host-virus interactions | -Not all viral exposures result in infection or disease.<br>-Some host-virus interactions can be beneficial for the host.<br>-Virus infections can be acute, latent, or persistent; some are oncogenic.<br>-The processes by which viruses cause disease involve interactions of virus and host factors at the cellular and organismal levels.<br>-After a nonlethal exposure to a virus, the host often develops a protective immune response against the virus (in some cases also against related viruses).<br>-Vaccines also elicit a protective immune response.<br>-Virus infection and disease can be prevented and/or treated using a variety of biological, chemical, and physical approaches.<br>-Vaccination has led to reduced morbidity and mortality for a wide variety of human and animal diseases. |
| V. Impact of viruses | -The study of viruses has been key to the understanding of cell and molecular biology, immunology, and infectious disease processes.<br>-Viruses and their proteins can be used to develop research tools, products, and therapeutics.<br>-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.<br>-Human lives and economics are impacted by viral diseases in humans and other organisms.<br>-Viruses have large-scale effects on ecosystems and the environment. |

[a]Adapted from https://asv.org/curriculum-guidelines with permission.
[b]Underlined items are recommended when virology content is a subset of another course, such as a Microbiology course.

9. Build skills to assess accuracy of virology information (e.g., in the news and via social media).

Based on the recommendations provided in the Vision and Change report and the ASM microbiology curriculum guidelines, the above learning outcomes can be achieved by focusing content on these five recommended topic areas (Table 1; also see reference 6):

1. Virus evolution and ecology.
2. Virus structure and function.
3. Virus replication cycle.
4. Host-virus interaction.
5. Impact of viruses.

Each of the five recommended content topic areas feature four or five subtopics that should be covered in a stand-alone virology course (Table 1) (6). Given that at certain undergraduate institutions (especially small colleges) it may not be possible to offer a stand-alone virology course, the working group selected the most relevant subtopics (one or a few subtopics for each of the five recommended topic areas) that would be ideal to introduce when students learn about viruses as part of a larger course (typically a microbiology course but possibly within a cell biology or immunology course).

The summary of the guidelines (see above and Table 1) provides a framework to help faculty develop a course in virology or refine an existing one. However, the working group recognized that instructors of an undergraduate virology course will need to consider the background of the students; for example, are prerequisite courses in cell/molecular biology required? The answer to this might dictate how much foundational background content would be necessary before delving into virus-specific content. Furthermore, the recommended guidelines feature the virus life cycle/key concepts approach, as opposed to the virus-by-virus approach. We recommend that the life cycle/concepts approach be followed, with examples from varied viruses to illustrate the concepts. Once students understand the concepts, then the students can apply those concepts to most any virus. The working group does recognize that emphasis on specific viruses may be necessary in an introductory virology course for undergraduates in allied health programs but encourages conceptual understanding of the key virology principles as foundational content. Also, the guidelines do not address aspects of a laboratory component of an undergraduate virology course (an informal survey indicated that it is atypical to have a lab component in an undergraduate virology course); however, some examples for lab activities have recently been reviewed (7), and, when possible, employment of a course-based undergraduate research experience (CURE) is a best practice (8, 9). Finally, these guidelines also identify the most important subset of virology concepts that can be provided to those teaching a general microbiology course to undergraduate students to help refine the limited amount of virology content that can be covered in those courses.

## GRADUATE GUIDELINES

The graduate guidelines working group considered several factors prior to assembling a set of guidelines. Input was gathered from educators with experience in graduate virology education and paired with input collected from a survey of ASV trainees at various stages of undergraduate and graduate education. This information was used to shape the framework for these guidelines. As alluded to above, it was recognized that graduate students have significantly varied educational backgrounds. For example, some students have taken a virology course as an undergraduate student, but many (if not most) have not, yielding a broad range of student backgrounds that should be considered when designing the course. Also, in a graduate course, some (perhaps most) of the students aim to pursue virology research, while others will not; the former group therefore may be more interested in virology-specific methodology. In some courses, the student population is a mix of advanced undergraduate and graduate students. Overall, it is important to ensure that students in a graduate-level course are well prepared to move forward with virology in their education or career trajectory. As such, recommended content topics are similar to those seen in undergraduate courses but with more emphasis on use of critical-thinking exercises and problem-based activities while reviewing content (especially using the primary literature while being careful of how to assess preprints). Ultimately, the graduate curriculum guidelines working group developed learning goals and recommended content and approaches to content delivery, recognizing that some adjustments may be necessary based on background of the students (prior coursework), alignment with faculty/institutional expertise, and particular methods and techniques that, currently, would be most useful to the student group (6).

Learning goals were created (Table 2; also see reference 6) that focus on the learning process (to hone higher-order thinking skills), content (provide foundational content via experimental approaches used), and skill building (to help the students with professional development [10]). As a faculty member works to meet these learning goals, the graduate students should be exposed to (at a minimum) the following virology concepts, using examples of specific virus families and ensuring that there is an introduction to viruses of plants, animals (including humans), and non-eukaryotes.

1. Virus structure.

**TABLE 2** Graduate curriculum guidelines: learning goals

| Topic area | Goals[a] |
|---|---|
| I. Process | -Synthesize basic concepts in virology to coherently describe complex virologic processes.<br>-Apply knowledge of virologic principles to primary literature to gain a deep understanding of discovery-based science.<br>-Critically read and critique primary literature in the field of virology.<br>-Explain current topics and new advances in the field of virology. |
| II. Content | -Describe the principles of virus structure and viral genomes.<br>-Explain the replication strategies of multiple viruses from attachment to exit.<br>-Explain how virus-host cell interactions lead to infection and viral pathogenesis.<br>-Explain how the host innate and adaptive immune systems defend against viral infection.<br>-Describe how viruses successfully evade the host innate and adaptive immune systems to establish infections. |
| III. Skill-building | -Effectively communicate virology research-based findings in a group setting to both scientific and lay audiences.<br>-Identify new insights by gathering information from the virology literature, formulating new hypotheses, and developing effective, feasible strategies to test new virology research questions.<br>-Discuss ethical and responsible conduct in virology research. |

[a]Adapted from https://asv.org/curriculum-guidelines with permission.

2. Viral attachment and entry.
3. Virus trafficking and uncoating.
4. Viral replication.
5. Virus assembly.
6. Viral egress/exit.
7. Viral pathogenesis.
8. Innate and adaptive immune responses to viral infection.
9. Evasion of the immune response by viruses.
10. Viruses, transformation, and cancer.
11. Antiviral treatments.
12. Vaccines.
13. Viral emergence and evolution.
14. Classic and modern technologies to study viruses.

Regardless of the graduate student audience, it is recommended that content delivery (concepts noted above) should focus on knowledge building, continued development of critical-thinking skills, and skill building (especially regarding oral and written communication). However, because the goals of graduate students in a virology course may vary, the committee defined several approaches regarding content delivery. A few of these include lecture-based active learning approaches, journal club-style courses, learning about current methods that drive advancements in virology, possible incorporation of computation, inclusion of an ethics component, and careful examination of preprints and their path through peer review (see reference 6 for the complete list). Ultimately, both an integration of practical higher-order thinking skills along with acquisition of core content will be of great benefit to graduate students (also see section 4 within reference 7).

## CONCLUDING COMMENTS

It is hoped that having these guidelines will help instructors develop or refine their virology course. We reiterate that these are, simply, guidelines, and that adjustments in learning goals and/or content may be necessary based on the background of the students, the short- and long-term goals of the students, and the expertise of the faculty. Nevertheless, having these guidelines can allow faculty to devote more time to plan active learning approaches for the course to enhance student learning as well as mechanisms to enhance inclusivity (11), which are equally important in the academic success and satisfaction of students.

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