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From SARS-CoV-2 to Influenza: Modern Pedagogical Approaches for Teaching Virology in Undergraduate Classrooms

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ABSTRACT

Purpose of the study: The COVID-19 pandemic and influenza highlight the global necessity to enhance virology education within biomedical curricula. Conventional lectures often fail to facilitate critical thinking. This review aims to synthesize contemporary pedagogical approaches such as active learning and virtual laboratories to improve scientific reasoning.

Methodology: A comprehensive literature search was conducted in PubMed, ERIC, Scopus, and Web of Science databases for the period 2015–2025. Keywords used included virology education and active learning. Out of 425 articles screened, 127 peer-reviewed papers met the eligibility criteria. Data were extracted regarding instructional design and student outcomes.

Main Findings: Active learning increases STEM performance by 30% compared to passive lecturing. Case-based learning (CBL) improves critical thinking by 27% and enhances long-term retention. Virtual laboratories produce learning outcomes equivalent to traditional labs while reducing costs. Gamification and collaborative projects significantly boost student motivation, engagement, and self-efficacy.

Novelty/Originality of this study: This review provides a new framework for integrating real-time pandemic data into undergraduate curricula. It uniquely addresses the gap between molecular virology and global health responses in resource-limited settings. By synthesizing recent digital advancements, it offers a roadmap for creating a scientifically literate workforce capable of managing future viral outbreaks.

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1. INTRODUCTION

The emergence of SARS-CoV-2 and the ongoing circulation of influenza viruses globally have underscored the need to rethink how virology is taught at the undergraduate level. Future healthcare, veterinary, and life science professionals will require not only contextual virology knowledge but also the ability to translate that knowledge to health challenges in the real world [1]-[3].

Conventional methods of lecturing are effective for imparting content but often encourage compelling, or passive, learning and do not promote student engagement with higher-order thinking skills (analysis, synthesis, evaluation, etc.) [4]-[6]. Many undergraduates consider virology abstract and hard to grasp, especially when delivered using static images and requiring memorisation of viral families or replication cycles [7]-[9]. The invisible and baffling qualities of viruses and understanding the relationships between mathematical modelling, genomic data, and the definition of immunology to viral behaviour make this field of study one of the hardest to teach [10].

The COVID-19 pandemic changed educational contexts around the world, showcasing the necessity and viability of education using interactive, technology-rich modes of teaching [11]. As scientists learnt more about SARS-CoV-2, educators integrated real-time epidemiological data, dashboards of genomic sequencing, and status updates on vaccine development into classroom teaching [12]-[14].Likewise, in light of the historical example of influenza, with its antigen shift and drift, zoonotic transmission, and seasonal patterns, it is an example making it an adaptable comparative case for thinking about molecular evolution.

Contemporary educational philosophy favours student-centred learning, with students engaging more as active participants than passive receivers of knowledge [15]-[17]. Active learning, case-based teaching, and collaborative projects engage learners through inquiry, dialogue, and reflection in ways that promote understanding rather than choosing to memorise [18]-[20[.

Virtual laboratories and gamification facilitate the bridge between theory and practice used to allow students to replicate viral infection cycle responses and actively respond without any risk of exposure [21], [22]. Yet, effective delivery of these approaches must occur in an adequate infrastructure, with trained instructors, and evaluations must happen continuously [23]-[25]. Low- to middle-income countries, such as Bangladesh, do not often have the necessary resources to implement these approaches, despite their proven effectiveness [26].

This review presents a synthesis of available evidence from 2015 to 2025 of one way to integrate SARS-CoV-2 and influenza case studies into modern pedagogical models to improve learning outcomes related to virology course expectations. The intent is to present evidence-based, practical approaches aimed to better prepare students for health-related challenges on a global level.

2. RESEARCH METHOD

A comprehensive literature search was conducted in PubMed, ERIC, Scopus, and Web of Science databases across the years 2015–2025 using the following keywords: virology education, COVID-19 pedagogies, influenza teaching, active learning in microbiology, case-based virology, and virtual labs. The search was limited to peer-reviewed research articles, review articles, and teaching cases concerning teaching and learning at the undergraduate level in virology or microbiology. We did not include non-peer-reviewed commentaries, blogs, or unpublished reports.

For each article meeting eligibility criteria, we extracted descriptive data concerning instructional design, context of implementation, assessment strategies, and implemented outcomes concerning student engagement, understanding, and retention. The pedagogical strategies were categorised and included active learning, case-based learning, virtual labs, gamification, and collaborative projects.

We analysed SARS-CoV-2 and influenza as model case study scenarios representing an acute pandemic viral system and an endemic viral system. These viruses served as contrasting examples of an outbreak, vaccination, variability, and One Health interactions concerning the two viruses.

Data collected were then narrated and synthesised to identify themes, strengths, and challenges in implementation. The emerging framework drew on the principles of constructivist learning theory with respect to learner engagement, situated context, and collaborative reflection.

Table 1. Summary of Database Search Results and Article Screening Process (2015–2025)

Database	Years Covered	Keywords Use	Number of articles Screened	Number of included
PubMed	2015-2025	Virology education, Covid-19 pedagogies,influenza teaching,active learning microbiology	134	42
Scopus	2015-2025	Virology teaching, microbiology, SARS-CoV-2,teaching modules,blended learning, virology	118	36
Web of Science	2015-2025	Gamification in microbiology, digital virology education, virtual laboratory, virology	97	28
ERIC	2015-2025	Microbiology education, STEM active learning, Case – based learning virology	76	21

Total article screened : 425
Total included : 127

3. RESULTS AND DISCUSSION

Active learning focuses on replacing students sitting passively through lectures with some type of participatory approach. Active learning activities can include discussions, problem solving, or reflective assignments. Evidence suggests that active learning boosts student performance in STEM courses by an alarming 30% over traditional, passive lecturing forms of class style [27].

Flipped classrooms, or classes where students review material, usually in video format, before coming to class and then engage with problem-solving when in class, have shown great success during the era of COVID-19 [28]. For example, students can explore open-access data sets to analyse SARS-CoV-2 genome sequences or simulate the transmission dynamics of a viral intrusion into a population. Through these activities, instructors promote the development of both data literacy and epidemiological reasoning.

Problem-based learning (PBL) is a similar approach that allows learners to engage with real virulent problems, in which virology interacts with both immunology and molecular biology. Through PBL, students can move away from simply memorising replication cycles to applying mechanisms to outbreaks such as avian influenza [29].

Case-based learning (CBL) concentrates on the application of theoretical knowledge in the practice of real-world scenarios [30]. With virology, outbreak-based cases, like discussing the differential spread of a pathogen such as SARS-CoV-2 in urban compared to rural places, or tracing an antigenic shift over timeIn influenza cases, assist learners in constructing their diagnostic and analytical reasoning.CBL has been shown to improve long-term retention of knowledge as well as clinical thinking abilities that connect molecular mechanisms to patterns of epidemiology. A study revealed that students who learnt with cases in virology found a 27% improvement in the assessments of critical thinking than students in the traditional (control) cohorts [31].Interactive group discussions also encourage empathetic/ethical reasoning skills, as students respond to thinking about issues about global equity or vaccination access, in addition to how to limit misinformation, during outbreaks [32].

Virtual labs offer an alternative to physical experiments that are safe, affordable, and scalable. Labster is a virtual lab platform that allows students to engage in viral replication and mutation and drug-testing experiments in an interactive digital platform [33]. For example, Labster's "Coronavirus Replication Simulation" allows students to visualise how spike proteins bind to ACE2 receptors. These simulations motivate students to engage with and to understand scientific research, but they may do so while students do not have to use biohazard precautions with coronavirus replication .

Meta-analyses indicate that virtual labs can produce learning outcomes equivalent to traditional labs while increasing accessibility and reducing institutional costs . Students also develop computational skills that are crucial in modern virology, where bioinformatics is central to genomic surveillance.Gamification incorporates game-like aspects (e.g., points, competition, and simulations) into educational contexts . In the case of virology, such methods help to represent previously abstract subject matter. Interactive outbreak games like "Viral Outbreak Simulator" require students to use and manage containment strategies, distribution of vaccines, and communication in practice closely resembling common decision-making processes during outbreaks.

AI-assisted quizzes and AR (augmented reality) apps can provide adaptive feedback to help reinforce conceptual gaps in real time. Gamification has been shown to consistently support both motivation and retention of facts, especially as it pertains to first-year undergraduate students. Both pre- and post-pandemic, global levels of collaboration have increased as a result of participating in cross-institution projects online. Virtual meetings also facilitate collaboration, as they provide an opportunity for universities or collaborators having varied laboratory capacity to share work and resources.

Even with the advancements made, there are barriers for the adoption of innovative pedagogy. Limitations of resources – such as limited computers, internet, or lab/field space and supplies, continue to be a barrier in many developing countries . Faculty may not have experience in digital pedagogy, and faculty development opportunities are often limited. Another large issue is assessment – while interactive formats are more engaging for learners than lectures, it is difficult to assess whether learners are learning through something other than memorisation of facts. Institutions need to create rubrics to assess competencies such as critical thinking, communication skills, and teamwork skills.

Further, there must be an awareness of the balance of technology innovations and accessibility/inclusivity concerns. Digital tools may inadvertently place students at a disadvantage if they do not have adequate internet connectivity or disabilities. Also, educators must not unintentionally induce cognitive overload of visual and interactive experiences. Therefore, successful implementation of these innovations requires investments at a policy layer in education to create equitable learning contexts, institutional investment in technology, and educator professional development support as approaches to support practice change. Blended pedagogical models (incorporating lectures, digital labs, and active learning) will also be a sustainable avenue to developing innovative pedagogy, etc.

Research collected following the last ten years of active, case-based, and technology-enhanced learning demonstrates significant enhancements in student learning in the field of virology. These methods follow a constructivist and experiential learning model, where students learn effectively by doing, reflecting and applying . SARS-CoV-2 and influenza provide two educational framework examples, one following a pandemic model and the other endemic, from which students can learn about viral evolution, vaccine development, and global health. Incorporation of these viruses presents students with the opportunity to integrate molecular biology content with epidemiology, immunology, and the societal nature of health and disease .

Gamification and virtual labs allow or even democratise access to learning using live organisms, where the biosafety of the course model may create boundaries in hands-on training opportunities. Engagement in collaborative projects provides students with transferable skills in teamwork, leadership, and communication across both community and scientific virology.There are still challenges: teachers' preparedness, equity with technology and assessment strategies. Nevertheless, the literature demonstrates, in some cases, that blended pedagogies continually find positive outcomes compared to traditional models in terms of engagement, understanding, and retention.

Next steps could look like the implementation of adaptive learning that is powered with artificial intelligence and personalises every student's instruction as they progress and/or the increased use of open-access virtual laboratories for institutions with low resources . Additionally, interdisciplinary approaches that develop virology within the context of informatics and public health will be valuable in preparing graduates to respond to and study outbreaks in the real world. In summary, transforming the way virology is taught using contemporary pedagogy will ensure graduates have the ability to critically assess viruses as threats, communicate science effectively and contribute to One Health agendas across the world.

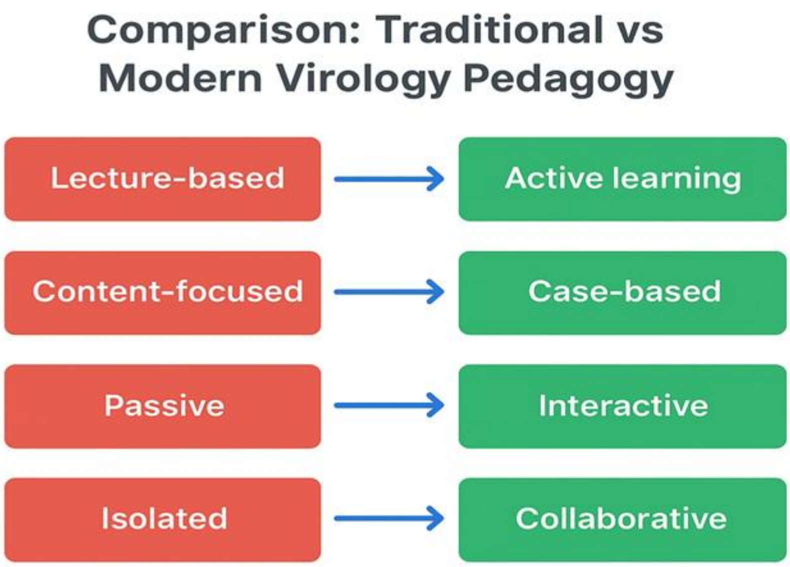

Figure 1. Transforming Virology Learning: From Traditional to Modern Approaches

4. CONCLUSION

Contemporary pedagogical methodologies are altering virology education by emphasising engagement, conceptual understanding, and collaboration skills in addressing virology. Active learning, case-based learning, virtual labs, gamification, and team-building activities all enhance the extensive knowledge domain around viruses and their relevance to society. SARS-CoV-2 and influenza provide relevant hypothesising case studies that support discrete or global health perspectives while linking molecular virology to public health. These pedagogical methodologies for virology education are effective for improved learner outcomes and the preparation of students for contribution to research, diagnostics, and response strategies in outbreaks of viral communicable infectious diseases. While access to resources and training may provide barriers to innovation of the practices described, incremental model integration of small numbers of active learning modules and online lab skills can provide measurable success. Institutional commitment to developing respective educators, research and scholarship with professional learning creates an environment that provides sustainability. Modern pedagogical methodologies for virology pedagogy ultimately ensure academic undergraduate trainees evolve as a scientifically literate workforce that provides capacity for policy, decision-making, management of health systems, epidemiology and effectiveness of novel vaccines and pandemic preparedness.

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