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Bridging the gap: pathway programs for inclusion and persistence in microbiology

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Microbiology plays an important role in most sectors. Future progress in critical areas requires diverse workforce development. We outline a pathway program that aims to provide equitable exposure to high-impact research experiences and course-based instruction to provide crucial training in growing areas of microbiology (phage discovery, synthetic biology and data science/AI).

Commentary

Microbiology is an interconnected discipline. It provides insights into mechanisms of infection, facilitates sustainable agriculture, and is critical for environmental conservation. Thus, it plays a crucial role in tackling public health concerns, addressing food security and climate-change-associated challenges. Indeed, microbiologists are at the forefront of combating emerging health crises such as pandemics and antimicrobial resistance. Microbiologists contribute to advancing food security through soil health microbiome science, and sustainable farming practices [1]. In environmental science, microbiologists help with the understanding and mitigation of climate change impacts, such as carbon cycling and pollution remediation [2]. However, despite these contributions, microbiology as a field, like many areas in STEM, is often inaccessible to marginalized and under-represented groups.

According to the 2023 World Economic Forum's Global Gender Gap Report[i], women constitute approximately 39.5% of the global workforce but remain under-represented in key frontier industries, including engineering (20%) and data and AI (32%). Additionally, the 2023 report from the UNESCO[ii] Institute for Statistics highlights that women occupy only about 31% of global R&D roles. While global race and ethnicity data in STEM fields are harder to gather, particularly in specific disciplines like microbiology, US data provide some insight. The 2023 National Science Foundation's Diversity and Science, Technology, Engineering, and Mathematics (STEM): Women, Minorities, and Persons with Disabilities report[iii] indicates that under-represented groups – including Black, Hispanic, American Indian, and Alaska Native individuals – collectively comprise roughly 24% of the STEM workforce in the USA, though representation varies across fields. The American Society for Microbiology (ASM) Diversity Task Force report has statistics specific to microbiology that are relevant to the focus of this article: a self-reported survey of ASM members shows that membership is 65% White, 12% Hispanic, 5% Black, 11% Asian, and 7% Other. Additionally, 55% of ASM membership identifies as women.

Significant gaps remain in the efficiency and equity of microbiology education and preparation. In line with this, in 2020, the US President's Council of Advisors on Science and Technology (PCAST)[iv] underscored the urgent need for inclusive STEM training and education opportunities that promote access for under-represented and underserved populations, particularly in fields like microbiology, to enhance workforce readiness amidst the challenges of COVID-19. Building on this, the 2023 Global Education Monitoring (GEM) Report by UNESCO[v] highlighted the importance of supporting marginalized learners and called for thoughtful integration of generative AI into curricula to complement, rather than replace, educator-led instruction.

In this commentary, we propose that pathway programs in microbiology will support and propel under-represented minority students along their STEM educational journey by providing programming related to research, career and life preparation [3]. We have identified two key ingredients (Figure 1) that, when incorporated in a pathway program, can facilitate the successful recruitment, retention, and eventual success of students in STEM – (i) equitable exposure to high-impact research experiences, and (ii) 'up-to-the-minute' programmatic instruction.

Equitable exposure to high-impact research experiences

To drive innovation, it is vital to enable undergraduate and graduate students at all universities and colleges, not just resource-rich institutions, to engage in inclusive, high-impact research. Okochi *et al.* [4] analyzed data on the impact of Research Experience for Undergraduate (REU) programs on community college students and demonstrated that students developed a sense of identity as a scientist, with increased interest and excitement for graduate school following the program. Course-based undergraduate research experiences, CUREs [5], offer similar benefits to students by providing active, real research experience in a course-based collaborative context [6]. The SEA-PHAGES CURE is an exemplar CURE course providing first-year students with a research experience in phage discovery, characterization, and gene annotation which overall enhances their STEM experience and increases students research process knowledge, science writing, and independent work [7]. However, the persistent implementation of such opportunities to undergraduate and graduate students at all universities and colleges is often not feasible due to challenges such as budget

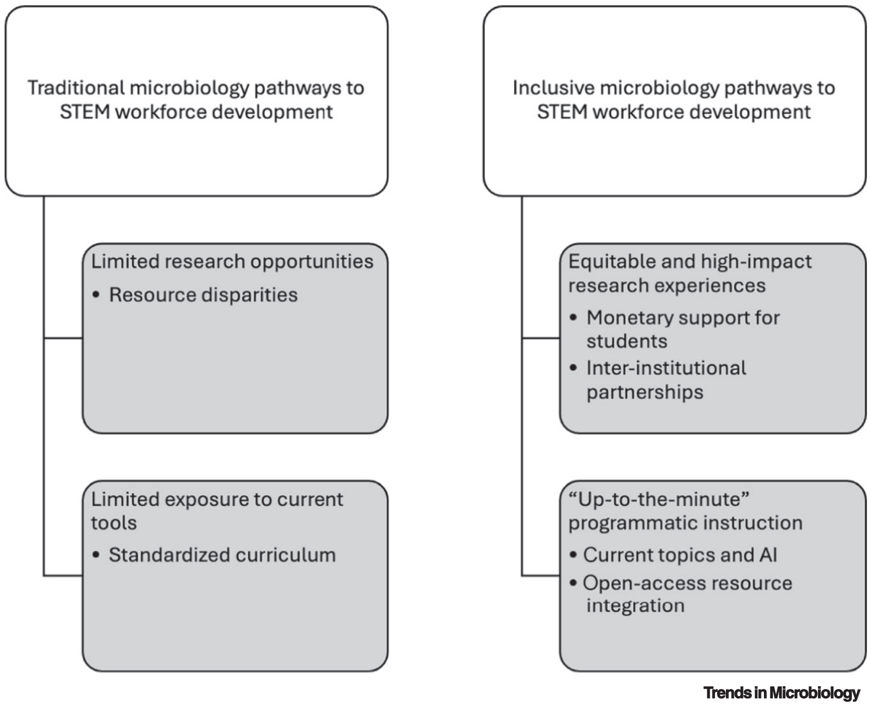

Figure 1. Traditional versus inclusive microbiology pathways to Science, Technology, Engineering, and Mathematics (STEM) workforce development. This schematic compares two different approaches to microbiology pathways for STEM workforce development: traditional (left) and inclusive (right). Left: resource disparities exist in traditional settings, limiting student access to valuable research experiences, and standardized curricula provide little exposure to modern, cutting-edge tools or techniques, constraining skill development. Right: inclusive pathways offer equitable access to research, including monetary support for students and partnerships between institutions, ensuring broader access to opportunities. Instruction is updated to cover current topics, including artificial intelligence (AI), with integration of open-access resources, ensuring that students learn relevant, in-demand skills.

constraints, availability of, and accessibility to, fewer resources to support extensive research programs [8]. Several institutions around the world, including those in low- and middle-income countries, though intrinsically diverse and home to hardworking and curious individuals, often have fewer resources to support extensive research programs. This lack of resources limits their ability to provide students with the same level of research opportunities available at more resource-rich institutions.

A multi-faceted solution includes monetary support and inter-institutional partnerships to increase funding dedicated to research programs at under-resourced institutions with a focus on scholarships and stipends for under-represented students. The Centre for Policy Research and Strategy in the American Council on Education found that most students in Minority Serving Institutions (MSIs, which are known for their potential to boost income mobility over non-MSIs) attend part-time due to work obligations, and higher education debt. Thus, offering paid research opportunities could greatly alleviate their financial burdens and prepare them for careers. There are successful examples of partnerships between research-intensive universities and minority-serving institutions that aim to increase the success of under-represented students in STEM fields, such as NSF's Alliances for Graduate Education and Professoriate (AGEP), European Union's Erasmus+ program, and the Howard Hughes Medical Institute's Inclusive Excellence Initiative. Additionally, monetary support programs in countries such as Brazil and India offer valuable models: in Brazil, the Federal Universities system provides paid research opportunities through Scientific Initiation Scholarships which are particularly beneficial for first-generation college students, and in India, the Indian Institutes of Technology (IITs) and Anna University offer research assistantships that support students from lower-income, often rural, backgrounds. Lastly, conference-based mechanisms targeting students such as the Gordon Research Symposia, that are usually aligned with Gordon Research Conferences, offer support and cost-effective modes for engagement of students with global leaders in specific areas.

'Up-to-the-minute' programmatic instruction

Firstly, traditional microbiology curricula often overlook research in emerging fields such as phage discovery, and synthetic biology. In recent years, bacteriophages (viruses that infect bacteria) have gained traction as an alternative/adjuvant to antibiotics [9], they are abundant in soils and water, and have key roles in biogeochemical cycling [10]. However, phages are the most persistent threat to large-scale dairy fermentation [11]. Isolating phages from environmental samples is a straightforward microbiology training module that provides students with quick and rewarding results. The visible zone of clearance on a bacterial lawn not only brings a sense of achievement but also serves as a clear marker of student progress. This module is especially valuable in resource-limited institutions. Synthetic biology, another emerging field, offers transformative approaches to engineer microorganisms for diverse applications [12] including bioremediation, sustainable biofuel production, and the development of novel therapeutics. Introducing students to synthetic biology through hands-on modules, such as constructing and testing synthetic gene circuits, can foster creativity and equip them with cutting-edge skills. However, the absence of fundamental training such as environmental sample collection, phage enrichment, isolation, genome extraction, and sequencing leaves many students without the essential skills needed for careers in microbiology.

Secondly, the integration of data science and AI in microbiology education remains limited. Data science techniques, including bioinformatics and machine learning, are transforming microbiology by enabling researchers to analyze vast amounts of biological data uncovering insights that were previously inaccessible and permitting analyses that traditionally would take very long periods of time to complete. The emergence of open-access computational databases and FAIR (Findable, Accessible, Interoperable, and Reusable) data resources opens the potential for empowering diverse communities to educate students in foundation biological data science and engage them in cutting edge research in the structure, function and ecology of microorganisms.

Resources such as iVirus [13], IMG/VR [14], NMDC [15], and KBase[vi] provide access to comprehensive data, tools and free computational resources available to anyone with an interest in analyzing biological data. These platforms have been successfully used to generate published studies, even without the need for extensive command-line expertise.

For example, iVirus has facilitated groundbreaking insights into global viral biogeography, while IMG/VR has enabled large-scale analyses of viral diversity by both researchers and students. KBase, in particular, has been instrumental in coordinating communities of educators and students in creating research-driven manuscripts. Class-based projects leveraging KBase tools have resulted in peer-reviewed publications such as the integration of the Distilled and Refined Annotation of Metabolism (DRAM) tool within KBase, which allowed for comprehensive metabolic profiling of microbial genomes. Additionally, KBase has been helping to create curricula accessible and effective for the widest group of students possible backed by a new NSF RCN-UBE incubator project #2316244.

Synthetic biology platforms, such as Benchling[vii], SynBioHub[viii], and the iGEM Registry of Standard Biological Parts, provide accessible and powerful tools for designing and analyzing engineered biological systems. These resources have been effectively utilized in CUREs, where students analyze microbial genomes and integrate findings into collaboratively authored papers, and students design and test synthetic gene circuits resulting in practical applications.

Current lessons cover mostly general genome and metagenome analysis, assembly, annotation, and modeling but provide access to, and could be easily extended to, systems for discovery and analysis of prophage and phage genomes, their annotation and machine-learning tools for predicting host/phage interactions and synthetic biology applications. Implementing pathway programs that offer equitable research experiences and up-to-date instruction in microbiology with sustained funding is crucial for catalyzing a revolution in scientific thought from pandemic prevention to climate mitigation.

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Declaration of interests

The authors declare no conflict of interests.

Additional declaration

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Resources

[i]www.weforum.org/publications/global-gender-gap-report-2023/

[ii]https://en.unesco.org/gem-report/

[iii]https://ncses.nsf.gov/pubs/nsf23323/

[iv]www.whitehouse.gov/pcast/

[v]www.unesco.org/gem-report/

[vi]www.kbase.us

[vii]www.benchling.com

[viii]https://synbiohub.org

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