GUEST EDITORIAL

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The Unseen Microbial World as a Tool for Learning Biology

This is an exciting time in biology education. Important reports such as *Bio2010* and *Vision and Change in Undergraduate Biology Education*, which are based on science education research, are moving biology education practice toward concepts and competencies in undergraduate education. The *Next Generation Science Standards* have established a framework for science education on which to build curricula in the K–12 arena. Current teaching promotes inquiry, problem solving, and other forms of active learning. This special issue of *The American Biology Teacher* highlights the power of microbiology as a tool for teaching these core concepts and competencies.

Microbiology is rising within the public consciousness, opening learning opportunities not only for students who want careers in biology but also for the general public. Microbiology touches every aspect of our lives and influences important decisions that affect our health and environment, making it an ideal way to engage students in biology. This engagement goes beyond the obvious topics, such as infectious diseases like Ebola, measles, HIV, and influenza, to global topics such as climate change, renewable energy, sustainable agriculture, and nutrition. Through discussions of the science behind the headlines, these topics provide approachable introductions to science and ethics. A vast array of resources and case studies are available for teaching these concepts using microbiology. Online tutorials on all these topics, along with online games, hands-on activities, and community science programs, can serve as springboards to launch students and the public into science and technology.

Incorporating microbiology into courses provides an accessible approach to developing instructional materials to address key STEM concepts and skills. For example, the five key Life Sciences topics in the *Next Generation Science Standards* (Natural Selection and Evolution; Structure and Function; Inheritance and Variation of Traits; Matter and Energy in Organisms and Ecosystems; Interdependent Relationships in Ecosystems) parallel the core concepts promoted by the American Society for Microbiology (ASM) Curriculum Guidelines (Evolution; Cell Structure and Function; Information Flow and Genetics; Metabolic Pathways; Microbial Systems and Impact of Microorganisms). Educators who seek engaging ways to teach the five key topics can look to microbiology for relevant, topical, and easy-to-use examples. Students can learn about **Evolution** through hands-on experiments that reenact classic experiments such as Delbruck and Luria's fluctuation test to learn about the spontaneous nature of mutations. They can find activities to observe evolution in action using safe bacteria such as *Pseudomonas fluorescens*. **Structure and Function** is strongly linked to microbiology through the endosymbiotic theory. Simple activities such as the Gram stain can illustrate differences in cell wall structure and function. Examination of protists, algae, and bacteria in pond water is always an effective way to inspire interest in the microbial world and observe the differences in structure and function between the different groups of microorganisms. The first experiments to show that DNA is the genetic material involved bacteria and bacteriophages, so it is not surprising that there are numerous activities that use bacteria to learn about the **Inheritance of Traits**. These can range from experiments that demonstrate bacterial transformation to others that introduce genes for pigments or green fluorescent protein used in cutting-edge research. Many universities are developing programs to enable students to be active participants in genetics research in topics such as genome annotation. Synthetic biology is an exciting and fast-growing field of research that introduces concepts of genetics combined with engineering and is now being introduced at the high school and even middle school level. Programs such as BioBuilder provide activities to teach the core concepts in synthetic biology as well as problem solving. High school teams can even compete with college teams in the annual iGEM Jamboree to develop projects to solve global problems using synthetic biology. **Matter and Energy in Organisms and Ecosystems** can be taught using numerous activities that demonstrate fermentation by yeast and their ability to convert sugars into carbon dioxide (or their inability to metabolize artificial sweeteners). The role of microorganisms in the environment can be observed by studying how soil bacteria degrade starch peanuts but not Styrofoam. There are also programs opening up across the country that provide opportunities to discover new bacteriophages or antibiotics from soil. Having students build Winogradsky columns is a hands-on way to introduce them to **Interdependent Relationships in Ecosystems** by observing the enrichment for phototrophic bacteria. Symbiotic relationships such as nitrogen-fixing bacteria in legume plants, wood-degrading bacteria in termites, and rumen bacteria in cows are all great examples that can be used to show the relationships between microorganisms and their hosts.

Microbiology in the curriculum enables educators to link lessons to other disciplines. Teachers can introduce microbiology through classic literature, science fiction, nonfiction, and the popular press. Discussions of outbreaks, such as the recent Ebola outbreak, are great opportunities to engage students with geography, history, and social sciences. Mathematics and statistics are valuable tools for all microbiologists, and these subjects can be readily integrated into the curriculum through examples in microbiology. For example, explore the Centers for Disease Control and Prevention's Excellence in Curriculum Innovation through Teaching Epidemiology (EXCITE)

for case studies in epidemiology that incorporate math and statistics along with other disciplines in solving disease outbreaks. The National Center for Case Study Teaching in Science offers a wide array of interdisciplinary case studies for teachers to explore antimicrobial resistance, vaccines, infectious diseases, environmental monitoring, and biotechnology.

Every day, we are learning new and exciting information about the impacts of microbes on our lives, and once students discover the microbial world, they are going to want to learn more. The ASM offers a rich collection of activities (http://www.asm.org/classroomactivities) that just about anyone can try on their own or contact a local microbiologist to help. These activities highlight the microbial world for not only science courses but also community-based events and other programs for the public. All activities come from classroom teachers and microbiologists and have been reviewed for scientific and educational content, active learning and engagement, alignment with the *Next Generation Science Standards*, and clarity of accompanying instructions regarding performance and safety.

Of course, safety is critically important when handling microorganisms in the classroom, but this should not be a deterrent. Many microorganisms can be used safely in the classroom with proper guidance and precautions. Teachers at all educational levels should review the ASM Guidelines for Biosafety in Teaching Laboratories (http://www.asm.org/safety-guidelines), and if any questions arise, consult a microbiologist. You will find many ASM members delighted to serve as mentors to budding microbiologists. We encourage everyone to explore new ways to teach core biology concepts by using the power of the microbes that live in and around us.

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