OVERVIEW

As academic scientists, a major component of our work is educational. Higher education in science can be divided into two categories, depending on the learning goals of the students involved:

- Scientific literacy: the ability to understand and think critically about science
- Scientific proficiency: the ability to carry out the process of scientific discovery

While not every student will pursue a career in science, the ability to make sound decisions based on scientific information is a critical skill for any educated person in the modern world. Microbiology, with its rich history and direct relevance to human health, is an excellent subject for engaging students at all levels.

SCIENTIFIC LITERACY

Science has a direct impact on everyone's life. From the doctor's office to the grocery store to the voting booth, people are confronted with issues where an understanding of science is essential for making good decisions. In order to function in the modern world, an educated person should be able to critically assess scientific claims, know how to find reliable scientific information, and have a general understanding of how the scientific process works. My goal as a teacher of science is to give students not just a library of facts about the world to draw on, but even more importantly, to give them the skills to locate and evaluate new information and ideas.

Microbiology is exceptionally well suited to educating students in scientific literacy. Microbes are central to topics of broad interest including human health, hygiene, and food systems. Microbiology is also key to understanding current debates surrounding issues like vaccination, the emergence of new diseases, antibiotic resistance, the use of probiotics, and the effects of climate change on biogeochemical cycles. Microbiology has a rich history of scientific endeavor, ranging from Koch's postulates and the establishment of causality in germ theory to the demonstration of DNA as the genetic material of cells. These were not just important discoveries, but elegant examples of how the scientific method works, both in the lab and in changing the course of society. All of this creates the potential for broad-ranging discussions of both historical and current scientific debates, relevant to all students, not just those planning careers in science or microbiology. In the course of such discussions, students learn not only how science affects their own lives, but also how to understand and evaluate new discoveries and technological innovations.

SCIENTIFIC PROFICIENCY

In addition to both fundamental and field-specific scientific literacy, a working scientist must be proficient at a complex set of interacting skills, all of which are necessary for successful discovery. These can be subdivided into three fundamental skill sets:

- The art of experimental design: applying statistical principles and technical approaches to create experiments that will meaningfully address specific research questions
- The craft of performing experiments: carrying out experiments at the bench skillfully, in order to generate high-quality data
- The science of interpreting results: both the techniques for visualizing and manipulating data and the knowledge and creativity to make models explaining those data

This is a cycle in which meaningful interpretations of well-designed and well-performed experiments lead to novel discoveries and, inevitably, to new research questions. In addition to these critical laboratory skills, a successful scientist must also develop writing and presentation skills for *communicating* about science, both to their peers and to the general public.

Microbiology has many strengths that lend themselves to training scientific proficiency. Modern microbiology encompasses all of the techniques of the molecular biologist, including genetics, biochemistry, ecology, evolutionary biology, and bioinformatics. Well-designed experiments, including large numbers of controls, can be set up relatively quickly and easily, leading to comparatively straightforward interpretation of results when compared to experiments with more complex model organisms. Similarly, the cycle of experiments is quite fast (with organismal generation times of as little as 20 minutes), which allows projects (and troubleshooting) to progress quickly. In addition, it is possible for a single scientist or small team to make significant discoveries in microbiology using relatively simple and inexpensive methods.

My personal approach to teaching scientific proficiency emphasizes mentorship and one-on-one instruction. I encourage intellectual investment in scientific problems, independent thinking, mastery of techniques, and teamwork. My goal is to encourage students to grow into colleagues and collaborators. This can initially be challenging for students, but ultimately builds confidence and prepares them for independent scientific work. This approach is particularly well suited to real in-lab research experience, but elements can also be incorporated into lab courses, which can be designed to build skills in all three aspects of practical science.