Microbes: Out of the Classroom and into the Field

By Stephanie Schroeder and Cynthia Joseph

“I got to experience a new field of study I had no idea existed.”

- College student after completing the GEM course, Summer 2012

Every summer, sixteen diverse undergraduate students from across the country participate in the Center for Dark Energy Biosphere Investigations (C-DEBI) sponsored Global Environmental Microbiology (GEM) course based at the University of Southern California (USC). The course is a four-week, field-based, residential program where students gain first-hand experience in microbiological sample collection and laboratory techniques. Students finish the course having a new appreciation for the microbial world and of equal importance, collecting data and collaborating with peers. Students’ misconceptions about microbes are challenged through active participation to move their understanding beyond facts to “core concepts” (Bransford et al. 1999). This article outlines some of the conceptual changes microbiology can bring to science education as well as examines the GEM course from tenants of inquiry-based learning.

Our most common perceptions of microbes are almost universally negative: we know them as the causes of diseases such as colds, flus, and infections. The word microbe refers to the size of the organism, usually less than 100 micrometers. These single-celled organisms, too small for the eye to see, are important to virtually all biological processes on the planet. The estimated number of bacteria worldwide is an astounding $10^{30}$ with 99% of those bacteria unable to be cultured in the laboratory for further study (Schloss & Handelsman 2004). Microbes are billions of years old; in fact, it was their production of oxygen that facilitated the evolution of plants, animals, and humans (Madigan et al. 2012). Dr. Eric Webb, USC Faculty and co-instructor of the GEM program along with Dr. John Heidelberg (also USC), explains to the students: “Microbes control many of the processes in ecosystems ranging from biomes to the human body, thus if you really want to understand a system, microbiology is required.”

Microbial life can exist in extreme environments where Earth’s surface life could never survive: locations with no oxygen, intensely cold or hot temperatures, or complete darkness. Light in the ocean is undetectable beyond 1,000 meters, but the average depth of the ocean is 4,000 meters (NOAA website). Yet microbial communities are found throughout the water column. Remarkably, the discoveries do not stop at the seafloor but extend deep into the ocean floor’s sediments and rocks known as the deep subsurface biosphere. Not only does life exist in extreme conditions, but estimates predict these environments contain between 0.6-30% of the Earth’s biomass (Kallmeyer et al. 2012). This life includes all three domains—bacteria, archaea, and eukaryotes (Orcutt et al. 2011).

C-DEBI scientists are asking fundamental questions about these microbes. What are they? Are they alive and reproducing or are they dormant, awaiting ideal conditions? What are they doing? What role do they play in Earth’s elemental transformations such as the carbon cycle or the nitrogen cycle? Because these organisms are found in extreme conditions, this intraterrestrial world can potentially provide clues to how life on Earth first evolved, but also what could lie beneath the surface of other planets with harsh environments such as on the planet Mars (Edwards 2004).
Exploration of this ocean “basement” is a recently emerging research field; the technology with which to study it has only been developed within the past forty years. This technology includes the research vessel JOIDES Resolution, a scientific drilling ship owned by the U.S. and operated by the International Ocean Drilling Program. Scientists study the sediment and rock samples collected by drilling into the ocean floor. Within the past 25 years, a technological tool called a CORK (Circulation Obviation Retrofit Kit) has been developed to run long-term experiments in the subseafloor boreholes that remained after drilling (Becker & Davis 2005). A CORK seals off the borehole from the seawater above to allow the subseafloor environment to return to pre-drilling conditions. By deploying instruments throughout the depths of the borehole, CORKs enable scientists to monitor and collect water samples for physical and chemical properties.

ABOUT THE COURSE

A college student with microbiology training has a skill set that is directly transferable to the job market in a variety of careers or that can serve as a foundation for graduate school in the pursuit of a higher-level career in research. Because many students are unaware of the possibilities of a career in research, our Center has focused on expanding the pool of undergraduates who are exposed to STEM subjects via programs such as the GEM course. GEM students are nationally recruited, and we encourage women, first-generation college, and underrepresented students to apply. Students with limited science backgrounds are targeted and many come from community or technical colleges that are often isolated from large research programs. C-DEBI covers the entire cost of the course so that students may attend regardless of their financial status.

The GEM course began in 2011 and introduces undergraduate students to environmental microbiology over four weeks of instructor-directed classroom learning coupled with field investigations and laboratory analyses. Students learn fundamental microbiology principles that they use to describe and characterize microbes from many environments including the subseafloor.

Assessment of learning outcomes is a key component of developing the course. Working with an external evaluator, Center staff have created pre- and post-tests using matrix-style questions along a Likert scale to assess student exposure to, and comfort with, key foundational components of the course. Additional open-ended questions measure criteria-referenced learning of key concepts in microbiology. The results from pre-tests are used to direct course instruction for the current program, while post-test results guide changes in the course for the following year.

TYPICAL COURSE PLAN

“Clearly, the contemporary view of how students learn implies content that is deeper than facts and information, a curriculum that is richer than reading, instruction that is longer than a lesson, and teaching that is more than telling.” (Bybee 2002)

In the first week, students are exposed to the historic roots of microbiology. This historical context is complemented by the teaching of basic laboratory techniques, such as pipetting and filtration, which are foundational to microbial research. Hundreds of years ago, Antonie van Leeuwenhoek, amateur microscope maker, first discovered “wee animalcules” while studying pepper-water infusions (Madigan et al. 2012). While the historical beginnings of microbiology may seem to pale in the light of today’s whole genomic sequencing, it is important for students to understand the small steps that researchers take in understanding organisms first and complex systems later. These discoveries are continually supported, defended, re-evaluated, and modified by the scientific community in the light of emerging evidence. While the course begins with instructor-lead classroom learning of initial ideas, it quickly shifts to incorporate the five essential features of classroom inquiry: engagement, evidence, explanations, knowledge, and communication/justification (National Research Council 2000).

After mastering essential lab techniques, students travel as a cohort to the Eastern Sierra Mountains to gather evidence (data) related to these initial ideas in diverse environments such as lakes, salt mines, and hot springs. Instructors guide students in the process of collecting and recording environmental characteristics including temperature, pH, and salinity, and collecting microbial samples so that they can compare the microbes from each environment. Students make predictions about differences in microbial communities from their sampled environments.

The final leg brings students to the USC Wrigley Marine Science Center on Santa Catalina Island, located off the coast of Los Angeles. While taught standard molecular biology protocols, students analyze the data, recording results and formulating explanations. Students extract DNA, conduct polymerase chain reactions (PCR), run gel electrophoresis, practice cloning techniques, and build phylogenetic trees with their environmental samples. Students build their own trees comparing their specimens to previously identified organisms, allowing them to connect their results to the larger body of scientific knowledge. Finally, students communicate what they learn in presentations to the group on specific microbiology research topics. This synthesis of learned principles allows for a summative assessment of this active learning process.

The experience of hands-on science while learning principles of science had a significant effect on the GEM class of 2012. In the post-test, students identified that this program significantly influenced their educational goals (the mean impact score was 71.6% on a bound continuous scale of 0 to 100), and 27% of the students indicated that they had a “new goal.”

After the course was over, we received an email from a former GEM student with the subject line, “Thanks a million!” Here’s an excerpt from the email:

“Going into this course I really didn’t know what to expect. All I knew was that I had to prepare myself for a lot of learning.
Heading to Mammoth was another new experience. I had never been to a mountain before much less climbed one! I had worked with microscopes before, but I had never gathered samples and then looked at them.

My favorite place would have to be Catalina Island. That is when we started doing all sorts of labs and cool projects. Learning about PCR and then actually doing it was awesome! Going a step further and sequencing the samples we gathered was also exciting!!...Again, it was an incredible, amazing, and wonderful program. I’m going to take in every single piece of information I learned from the course and apply it to my microbiology class this coming fall.”

CONCLUSION

Sometimes when teaching science in the classroom, the content can seem rigid and all the answers prescribed. Through a balance of teacher-led and inquiry-based instruction, students participating in the GEM course go beyond the learning of science facts to acquiring scientific understanding.

The classroom may seem a long ways from the mountains, islands, and laboratories of a field station, but this is the Center’s way of implementing learning through doing. Whether that means looking for current research that will expand students’ understanding of classroom topics, finding ways for students to conduct research or participate in project-based learning, or reaching out to a university, museum or aquarium to invite a guest to present to students, the exposure of students to scientists matters.

In the end, education at any level is about engaging the student to nurture sufficient passion and drive that they commit to the work needed to learn and grow. For many students, doing science is the key. It takes a National Science Foundation Science and Technology Center to run the GEM course, but the principles can be applied to any classroom. And when you teach students about the ecosystems of the ocean, remember the subseaflower and check back with C-DEBI. We’d be glad to tell you our latest discoveries exposing you and your students to the excitement of science.

REFERENCES


ADDITIONAL RESOURCES

To find more about C-DEBI and its educational resources, visit its website: www.darkenergybiosphere.org

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PHOTO CREDIT

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