Presenting Molecular Biology in an Ecological Context
The Maine ScienceCorps Partnership in Rural High School science Education

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Introduction: Structure and Goals of the Maine ScienceCorps
The Maine ScienceCorps (MSC), one of approximately 200 NSF-sponsored “GK–12” (Graduate STEM Fellows in K–12 Education) programs nationwide, provides graduate fellowship support connected with opportunities to work with science teachers in rural Maine high schools to design and implement inquiry-based research projects, interacting with several hundred students each year (NSF, 2009). Fellows have contributed to various courses including biology, astrobiology, chemistry, health, and research methods, working with students at a broad range of ability levels. Students have ongoing interaction with teams of two graduate student Fellows who are in each classroom six to eight times a year and are also available electronically to guide students in using laboratory technology to conduct open-ended research. The project provides significant benefits to all participants that include: (1) Access in rural schools to interdisciplinary laboratory based projects that typically include a synthesis of environmental, microbiological, molecular biological, and immunology concepts and lab activities that would not be otherwise possible in the rural classrooms; (2) connection of diverse students in rural schools with scientific role models; and (3) effective development of each graduate student’s teaching and communication skills while increasing their awareness of their potential for contributions to pre-college science education.
The MSC has been active since 2001, with classroom visits initially centered on self-contained activities that explained pieces of laboratory technology and specific biological concepts (e.g., exploring the role of antibodies in immune response using an ELISA assay). Beginning in 2004, program staff and fellows began developing inquiry-based research projects that could be explored through linked laboratory activities. The goal of these classroom research projects was to present laboratory science in contexts accessible and interesting to high school students. By 2006, projects increasingly were driven by high school students’ questions and focused on using molecular tools to explore particular natural or model environments as year-long frameworks for classroom inquiry.

Model System and Field-based Projects
Teams of MSC Fellows designed low-cost “pond-and-stream” habitats (Figures 1 and 2) that allowed students to observe a simplified ecosystem in the classroom. Systems were stocked with native plants, invertebrates, and organic matter collected from Maine ponds and streams (by students when possible). Fellows avoided using vertebrates due to regulations governing the care and use of research animals, as compliance would have been challenging in a classroom setting.

Projects diverged according to the interests of the students, teachers, and Fellows. However, projects were linked by a commitment to incorporate the concepts and techniques of molecular biology in both ecological exploration and the experimental investigation of environmental change. Elements common to all projects included water quality monitoring, microscopic analysis and identification of protozoan life, and Fellow and USM laboratory assisted isolation of environmental bacteria and bacteriophages followed by molecular analysis in the high school classroom to explore the richness of the microbial world. Fellow’s assistance in microbial cultivation was critical because any handling by high school students of unknown microorganisms would involve unacceptable biosafety concerns. These activities introduced students to the diversity of life from the macroscopic (e.g. plants, mussels, and other invertebrates) to the microscopic (e.g. protists, bacteria, and bacteriophage) organisms.

Students, teachers, and Fellows, in consultation with faculty mentors, developed research questions that applied laboratory techniques to investigate specific issues of environmental change. These techniques included extraction of DNA from soil community biota, phylogenetic analysis of microbial life by ribosomal RNA gene sequencing, and measurement of DNA damage in freshwater mussels via comet assay (Comet

**FIGURE 1.** A simple “pond-and-stream” model system constructed by ScienceCorps Fellows Samuel Frankel and Melissa Hamel. Recirculating water through a PVC “stream” into an aquarium “pond” provided differential habitat for microbial and invertebrate life. Habitats provided a contextual framework for molecular investigation of macroscopic and microscopic organisms.

**FIGURE 2.** A more elaborate habitat, the Mobile Aquatic Research System (MARS) constructed by ScienceCorps Fellow Jon Letendre. “Control” and “Experimental” streams fed into separate ponds for side-by-side comparison of alterations following environmental stress.
Research projects involved comparisons between control conditions and those altered by the application of motor oils, household detergents, and road salt to intentionally reflect contamination problems relevant to aquatic environments in Maine.

Recently many of the student projects have involved gathering environmental field samples and in some cases, projects have been significantly integrated with a graduate Fellow’s research interests. For example, several 2008–2009 GK–12 Fellows at USM pursued thesis research projects investigating microbial and viral ecology in acidic and metal-rich environments. Students at three rural high schools near historical mining sites or unmined massive sulfide deposits chose to work with graduate Fellows to extract DNA from these environments to investigate the microbial biodiversity present using molecular analyses.

MSC partnerships enable the use of university laboratory resources to expand classroom possibilities. For example, USM’s transmission electron microscopy services have been available to extend classroom observations to the nano scale. More routinely, microbes isolated by the graduate Fellows from class samples were subjected to enzymatic inactivation under appropriate biosafety conditions at USM and then brought to the classroom for subsequent analysis. Thus, university facilities allowed projects to incorporate more advanced technologies as well as use techniques that could potentially involve risk to students if conducted without appropriate facilities and equipment.

Model System–based and Field Sample–based Projects as Contextual Frameworks for Scientific Inquiry

MSC Fellows recognized that students required an intuitive framework to organize abstract scientific information such as concepts of molecular biology. Projects based on model systems were made relevant by the ongoing presence of these simplified ecosystems throughout the school year while field sample based projects provided direct but intermittent connections with natural habitats. Model systems used were constructed to represent pond-and-stream environments that would be familiar landscapes for students in rural Maine and that, unlike natural environments, could be subjected to experimental manipulation to stimulate and facilitate scientific inquiry into problems of environmental contamination.

One goal of the MSC is to develop students’ relationship to scientific inquiry and the use of science in daily life. Thus there is significant overlap between the approach of the MSC and the goals of the SENCER program, which have informed project development. The SENCER model of science education attempts to explore public issues from a scientific perspective, and in the context of that exploration effectively convey scientific information (SENCER, 2010). We have found that in high school classrooms modeling ecological systems to discuss issues of local environmental change can provide a powerful, accessible context to convey observational and experimental science.

Although the SENCER approach has been predominately aimed at undergraduates, situating laboratory science within a contextual framework greatly benefits younger students as well. High school students develop a greater depth of cognitive understanding regarding the world and its interrelationships during adolescence. Part of that development is a gradual transition from thinking that is predominately concrete to the progressive integration of more complex, abstract concepts (Santrock, 2001).

From a student’s perspective, scientific information can be very abstract. Presenting molecular biology in the context of a public issue like environmental contamination provides a narrative structure in which to deliver information regarding the tools and concepts of experimental science. We have found this approach to be effective in teaching students who are in a process of learning to integrate these more abstract ideas.

Scientific Communication and Assessments of Student Learning

The approach of the MSC emphasizes that communication is vital to the practice of science. Students are given the opportunity to design scientific posters that present the results of their research projects. Teachers help students determine what information posters contain, but they are primarily written by students and reflect their understanding of the research projects and their findings. This provides an opportunity to identify misconceptions in student understanding of biological concepts and laboratory techniques.

Students during the past three years have been given the opportunity to present their posters to the USM community at USM’s annual “Thinking Matters” research symposium. At the most recent April 2009 event, twenty-five students from
four participating high schools also presented their projects to each other orally. The presentation of research projects and responses to questions asked by conference attendees have provided opportunities for students to demonstrate their understanding, as well as to experience ways that scientists communicate experimental findings. Posters were printed at USM, presented at Thinking Matters, and then returned to teachers for use in presentations to school boards and groups of parents, offering other opportunities for students to discuss their projects outside the classroom.

Maine ScienceCorps Commitment to Civic Engagement and Responsibility
The MSC promotes civic engagement and responsibility for high school students and Fellows. Students are introduced to scientific research by participating in an active investigation of model real-world problems. They also learn that scientists are responsible for communicating their findings.

An integral aspect of the MSC is that Fellows conduct their graduate bioscience research while engaging with the educational community outside the university. This interaction is demonstrably “two-way” with several affiliated teachers subsequently choosing to pursue graduate study through the MSC. Graduate students from other backgrounds are introduced to the challenges and rewards of teaching and communicating science. Also, Fellows specifically develop educational research projects that emphasize the role of laboratory biology in studying public problems, stressing the importance and immediacy of these connections for themselves as well as their students. University faculty mentors provide advice and guidance for developing research projects and periodically accompany Fellows on classroom visits. They share their expertise with students and demonstrate the role of scientists in mentorship, research and education.

Ongoing Program Development
Development of model system and field sampling based projects continues each academic year and includes studying the effects of climate change on plants, further exploration of aquatic ecosystems, the role of wetlands in filtering contaminants, and further exploration of aquatic ecosystems and metal sulfide deposits. MSC Fellows, university faculty, and teachers continue to work to improve delivery of scientific knowledge in context, as well as expand opportunities for assessment of student learning through scientific presentations and development of a sustained online component utilizing the “Manhattan” virtual classroom (Western New England College, 2010).

A professional external evaluation team focuses much attention upon the MSC project’s impacts on graduate Fellow’s communication and teaching skills and on classroom activities and resources for participating teachers. The inquiry-based learning fostered through classroom research experiences clearly assists teachers in meeting state learning standards that address “skills and traits of scientific inquiry and technological design; the scientific and technological enterprise; the physical setting; and the living environment.” (Maine Department of Education, 2007) The project brings connection with the scientific world to high school students in rural communities where exposure to scientific role models is otherwise rare and where there are few cultural expectations that higher education is important for future success. Observations by teachers, fellows, and others have indicated that frequently students who do not typically excel academically are highly engaged in the classroom research process. Several years of sustained experience in collaboration with some of the rural high schools have demonstrated benefits to all participants, which are encouraging MSC program staff efforts to continue integrating this program into USM graduate education.

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Samuel E. Frankel earned a B.S. degree in psychology and a M.S. degree in biology at USM. As a M.S. student studying the effects of arsenic on neuronal development, he served for two years as a NSF GK–12 Fellow in the Maine ScienceCorps and was advised by co-author Douglas Currie. Upon completion of his M.S., he entered the Peace Corps through which he has been working in Ghana on an agricultural development project exploring innovative cash and food crops such as Moringa oleifera.

Frank E. Riley, a native of a small town in mid-coastal Maine, earned a B.S. in biology at the University of Maine and an M.S. in applied medical sciences at USM. He was employed in the biotechnology and biomedical diagnostics industry prior to his graduate research investigating microbes and viruses in environments with high or low pH conditions. He served for two years as a NSF GK–12 Fellow in the Maine ScienceCorps and was advised by co-author S. Monroe Duboise. Frank currently is employed by Carolina Health Care System and is involved in research on adipose tissue–derived mesenchymal stem cells.

Darrin Ramsdell is completing M.S. thesis research at USM investigating the role of osteopontin in breast cancer development and progression in the laboratory of co-author Ah-Kau Ng. A native of Maine and a graduate of Saint Joseph’s College, he served for two years as a NSF GK–12 Fellow in the Maine ScienceCorps working with rural high school students and teachers in northern Maine.

Douglas A. Currie is associate professor in the Department of Biological Sciences at USM. A developmental neurobiologist with research interests in cell signaling in the developing mammalian brain, Currie earned his Ph.D. at University of Cambridge, pursued post-doctoral training at the University of Washington in Seattle, and joined the USM faculty in 2003. He has been active as a faculty mentor for MSC fellows including co-author Samuel E. Frankel.

Ah-Kau Ng is professor in the Department of Applied Medical Sciences at USM with a Ph.D. in microbiology/immunology from Temple University. The focus of his work has been in immunology (in areas of infectious disease, cancer, transplantation and autoimmune diseases), cancer biology and, more recently, nanomaterials. In addition to his devotion to undergraduate and graduate science education in biomedical sciences and biotechnology, since 1990 Ng has been actively involved in pre-college science education. He has served as faculty mentor for MSC fellows including co-author Darrin Ramsdell.

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