ESSAY

IBI* SERIES WINNER

Adapting to Osmotic Stress and the Process of Science

"Genetic Analysis of Adaptation to Osmotic Stress in *Salmonella*," the IBI Prize–winning module, uses mutant isolation and DNA sequencing to engage students in bacterial genetics and evolution.

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Inquiry-based approaches to science education improve critical thinking and engagement of students in coursework along with immersing them in the nature of science (*1*, *2*). Involving undergraduates in authentic research is a variation on inquiry-based classes in line with recent education recommendations (*3*, *4*). Adapting a project from the Csonka laboratory (*5*), we developed the "Genetic Analysis of Adaptation to Osmotic Stress in *Salmonella*" module in the framework of the Center for Authentic Science Practice in Education (*6*), which enhances students' scientific understanding and communication skills while introducing them to basic laboratory skills, primary literature, and experimental design. This class has been offered to a total of 32 first-year undergraduate students in 2 years, with 21 additional students currently enrolled this spring.

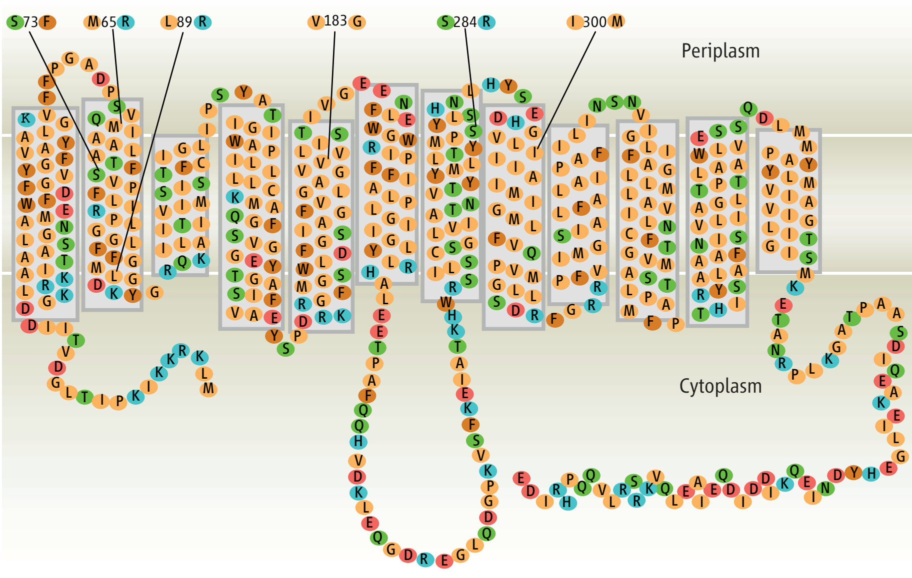
The objective of the student project was to isolate mutations that alter the regulation or substrate specificity of the ProP protein of *Salmonella enterica* serovar *typhimurium* (see the figure). This protein transports proline and glycine betaine, which regulate the tonicity of the cytoplasm in cells (*7*, *8*). Working in teams of two or three, students isolated spontaneous or mutagen-induced derivatives carrying mutations in ProP that increased the activity of the protein with proline as the transport-substrate. Students carried out classical genetic mapping to confirm that the mutations were in the *proP* gene, amplified the gene and flanking sequences with the polymerase chain reaction, and determined the sequence of the amplicons. Amino acid changes in the mutants were deduced by BLASTN comparisons of the DNA sequence of the amplicons against the *S. typhimurium* database sequence. Students obtained mutations resulting in six different amino acid substitutions in the ProP protein (see the figure) and visualized the location of the mutations by constructing three-dimensional (3D) models of ProP (see the figure). At the conclusion of the semester, teams described their results to the class in 10-min PowerPoint presentations and to faculty and students in poster presentations.

Results obtained in these classes led to a scientific publication in a refereed journal with the students as coauthors (*9*). The education component of this course model has been presented at several meetings [e.g., (*10*)].

The intellectual strength of this class is that it introduces the students to the sophisticated mind-set of bacterial genetics, DNA sequencing, and bioinformatic analysis with technically simple and inexpensive experiments. Students see evolution occurring in a Petri dish in a 72-hour time frame. Moreover, they get acquainted with the time-honored practice of classical bacterial genetics of "letting the organism tell you" what is important, without making a priori hypotheses, in this case, which amino acids participate in the regulation or substrate recognition of the ProP protein.

This particular project is sustainable as long as students keep finding new mutations in *proP* or outside of this gene. The specific objectives and experiments can evolve from semester to semester as the project builds on findings from previous students. For example, the current students in the class explored isolating mutants in high-salt environments and using different mutagens, both of which may result in unique mutations. Our selection was designed to identify mutations in *proP*. However, there were mutations in other loci whose identity could be determined by whole-genome sequencing.

We encountered both successes and challenges in involving first-year undergraduates in research projects. With opportunity and guidance, students can be creative in designing experiments and interpreting data, and they immediately see the utility of basic skills, like dilutions and aseptic techniques. Our approach introduces them to several aspects of scholarly activities, including working in teams to solve problems, reading



Amino acid mutations obtained by students (*9*). The amino acid changes are overlaid on the proposed secondary structure of the *Escherichia coli* K-12 ProP (*8*), modified to show the 5% sequence divergence of the ProP protein of *S. typhimurium.* Some mutations were isolated multiple, independent times.

CREDIT: ADAPTED WITH PERMISSION FROM *DNA AND CELL BIOLOGY* (*9*).

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Students constructing a 3D model of the ProP protein.

and discussing primary literature, designing experiments, writing research proposals, communicating results in written and oral formats, and, finally, the process of writing, submission, and review of a refereed, scientific paper. Students left the poster sessions stating that they felt empowered, energized, and accomplished.

Constructing a first-year laboratory course around authentic research involves unique practical considerations. Planning and implementation of the module demand greater instructor time than standard lab courses. Successful guidance of the students in this specific project requires that the instructors be familiar with standard techniques of bacteriology and phage biology. Another demand comes from overseeing four to six different components of the project. We have found that keeping the class size small (<21 students) and having students work in groups of three allows productive group work while giving each team member an opportunity to practice techniques. Development of the students' ability to communicate their thoughts and experimental findings in written and oral assignments requires extensive feedback and guidance.

Offering this class requires the instructional staff to act as facilitator and mentor to help the students navigate the uncertain nature of research. It is imperative to provide students with clear, specific objectives regarding practical lab skills and the process of science that are introduced on the first day and reinforced throughout the semester. Students must transition from the mentality of getting the "right answer" for a good grade to being thoughtful and careful. Instructors need to communicate that, if experiments were done accurately and carefully—whatever their outcome, data are what they are, and this is considered a success! As such, students are graded on the quality of their thought and method, based on objective evaluation of lab notebooks and written and oral reports, regardless of whether they obtained novel mutations.

We used two methods to assess the impact of our course on student attitudes about science and the development of critical thinking skills. Pre- and postsemester surveys revealed that students recognized that they were involved in the process of discovery with a positive impact on their sense of confidence and interest in conducting scientific research. We used the Critical Thinking Assessment Test developed at Tennessee Tech University to assess the effectiveness of our course in fostering critical thinking skills and observed significant improvement in scores at the end of the semester compared with the beginning. Long-term impact will be evaluated by following the performance and choices of students in this course, compared with students in the traditional lab course, as they move through their undergraduate careers.

First-year research experiences such as these are adaptable at other educational institutions in a variety of subjects by designing simple, low-cost experiments that take advantage of Web resources and faculty expertise. A neurobiology module has been developed using this approach (*11*). By providing tomorrow's scientists with an early opportunity to contribute to scientific discovery, generate interesting data, and develop their analytical and communication skills, tomorrow begins today.

About the authors

Authors from left to right: **Dennis Minchella** is a professor of Biological Sciences, associate dean in the College of Science, and director of the HHMI Science Education Program at Purdue University. **Stephanie Gardner** is a continuing lecturer in Biological Sciences and is a National Academy of Sciences Education Fellow and Mentor. **Brittany Gasper** is a visiting assistant professor at Florida Southern College in Lakeland, FL, where she teaches Microbiology, Cell Biology, and Introductory Biology. **Gabriela Weaver** is a professor of Chemistry and the director of the Discovery Learning Research Center. **Laszlo Csonka** is a professor of Biological Sciences. His research interests include the adaptation to osmotic stress and high temperature in bacteria.

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