IBI* SERIES WINNER

Students Propose Genetic Solutions to Societal Problems

The Genetic Engineering Proposal Project, an IBI prize–winning module, teaches biology students to devise innovative bioproducts or solutions to environmental or health problems.

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In the *Foundations of Biology* sequence for entering biological sciences majors at the University of Minnesota, inquiry-based learning is woven throughout the classroom and laboratory. During the first semester lecture and discussion, students work in teams on a Genetic Engineering Proposal in which they propose a gene-based solution to a societal problem of their own choosing. Instructors coach the teams throughout the semester on experimental design and resources, as well as on data analysis, presentation strategies, team work, and research ethics. On the basis of outcomes from the nearly 3000 students who have taken the course over the past 6 years, the project has succeeded in engaging students in the intellectual work of biologists and the experience of science as creative inquiry.

Our approach emphasizes both scientific teaching (*1*), an evidence-based approach to course design that applies principles of how people learn (*2*), and the importance of integrative biology courses (*3*). We also stress the higher-order skills in Bloom's taxonomy of cognition: synthesis, evaluation, and creation (*4*). As in the University of Oregon's "Workshop Biology" (*5*), we encourage student creativity by enabling teams to choose their own project topics. Our course design acknowledges the evidence that team-based learning delivers high learning gains and facilitates development of important life skills (*6*). This team-based class structure supports the growth of collaborative skills, including giving and receiving constructive feedback, and necessitates organization, initiative, and communication. As instructors, we are research mentors for teams and coaches for individuals. Moreover, with students in teams of nine working in a SCALE-UP (student-centered active learning environment for undergraduate programs) (*7*) classroom, we can ask students to accomplish collectively what would be beyond individual capabilities.

A team plans their project poster (top); team members at the poster presentations (bottom).

The Genetic Engineering Proposal begins with each student in the team identifying a socially important issue for which genetic engineering could provide at least part of the solution, such as bioremediation of contaminated soil by enhanced plants or microbes, improved nutritional value in crops or livestock, or diagnosis and treatment of a disease. After literature searches, team discussions, and feedback from the faculty instructors, the team settles on a topic that they will jointly pursue for the remainder of the semester (see the top photo). The team must then use primary scientific literature, databases, and, sometimes, interviews with expert researchers to create a compelling argument for the value of the proposed project, to develop an experimental protocol to achieve the end product, and to describe the broader implications of the project, including ethical issues. They must also complete a phylogenetic analysis of their gene of interest or the donor or recipient organisms to address potential methodological problems, environmental impacts, or logical future studies.

Students do not carry out the proposed experiments, which would typically take years to accomplish. However, the proposal enables students to do the sophisticated intellectual work typical of biologists and explore how science relates to society. They innovate, collaborate, and communicate at a level that transforms their experience of introductory biology and their relationships with one another and with their instructors. They apply what they are learning to solve real-world problems that are important to them and thus experience the relevance of biology concepts. Moreover, the project is inherently integrative, bringing course topics together with information that students locate themselves. Expecting students to begin doing the intellectual work of a biologist inspires them and helps them understand early in their education what a biologist does.

Students have tackled a range of socially important issues [see supplementary materials (SM)]. Even though some project themes

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*IBI, *Science* Prize for Inquiry-Based Instruction; www.sciencemag.org/site/feature/data/prizes/inquiry/.

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PHOTO CREDITS: (TOP) PAUL BAEPLER; (BOTTOM) PATRICK O'LEARY recur, each project is unique and each team's path of inquiry varies. Many projects require students to propose methods not discussed in class or found in their textbook, such as use of retroviruses in gene therapy.

As a result, instructors serve the role of project consultants who also encounter new areas of biology in the process. Thus, the instructors develop collegial relationships with students that demonstrate how biologists work collaboratively in the face of the unknown. Those interactions make this project a highlight for the instructors as well as for the students.

Throughout their work, students maintain intellectual property (IP) notebooks to record the team's conceptual journey and to assure individual accountability. In addition, student evaluations of their own contributions and those of other team members are shared anonymously with the entire team (see SM). The initial formative feedback is used to help team members improve their performance during the semester, and the summative peer evaluation also factors into the individual project grade, as described below, decreasing problems with "free riders."

Consistent with the theme of helping students begin to engage in the professional behaviors of biologists, the culminating poster presentation is similar to those at professional meetings (see the bottom photo). The mood is both intense and celebratory, with students discussing the proposals with rigor and teams enjoying a sense of tremendous accomplishment. Aside from the poster, the completed project includes additional team-created products (a written component, a bibliography, and a critique of another team's written proposal), as well as individual products (a reflection on the project and records of each individual's contributions in the IP notebook; see SM). All components of the project are evaluated by means of detailed evaluation rubrics (see SM) that are provided to students at the beginning of the project. Each individual's grade is subject to decreases based on the evidence provided in the IP notebooks and the final peer evaluation.

Our class sections typically include about 125 students, a number that would create an impossible consultation and/or grading burden for two instructors if students undertook projects individually. The grading workload is reduced to manageable levels because most feedback is given to 14 teams rather than to 125 individuals. In addition, we devote ~40% of class time to project work. Thus, students need to schedule only minimal outside-of-class meetings, and instructors can provide real-time feedback during class, in addition to evaluating written materials outside of class.

Because the focus is on student collaboration, problem-solving, and active involvement, this type of project is easily adaptable to other courses and institutions. For example, similar projects could be implemented in classes ranging from seminars to large-enrollment courses. Ideally, students would be in active learning classrooms with access to online resources, including databases and primary literature sources, but such access could be via computer labs, personal computers, or classroom-dedicated laptops. The total direct cost of the project is that of printing a poster for each team of nine.

The evidence for project success is apparent in the quality of the products. We evaluate student work with rubrics that include scientific and effective communication criteria. Even with rigorous standards, average project grades are typically between a B+ and A–. Also, the ability of our students to ask significant questions and to propose logical solutions becomes vividly clear when we find industrial, academic, or federal labs pursuing projects similar to those proposed by our students. For example, a team in 2009 planned to genetically modify a patient's cardiac stem cells to treat heart disease; a similar approach was published 2 years later. In 2008, a team proposed to express a squid reflectin gene in microorganisms to incorporate into a camouflage suit for military use; in 2012 a publication on recombinant reflectin–based camouflage materials appeared. Most important, in final course evaluations, students consistently rate the project as being of critical importance in achieving learning and development gains in key areas, including scientific reasoning and team work.

About the authors




All are in the College of Biological Sciences at the University of Minnesota. **Sue Wick** (*left*) is a Morse-Alumni Distinguished Teaching Awardee and professor of Plant Biology and director of undergraduate studies for the Biology Major. Her interests are in fostering inquiry and examining the effectiveness of active learning in kindergarten through grade 16 education. **Mark Decker** (*center left*) is codirector of and teaching associate professor in the Biology Program. He is interested in the influence that pedagogical approach and use of technology have in developing an understanding of science and critical thinking skills. **David Matthes** (*center right*) is a teaching associate professor in the Biology Program investigating the function of semaphorin proteins in regulating cell migration in the immune system. **Robin Wright** (*right*) is a professor of Genetics, Cell Biology, and Development, associate dean for Faculty and Academic Affairs, and a leader within the National Academies Summer Institutes for Undergraduate Biology Education.

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Acknowledgments: We extend our thanks to the thousands of students who have completed Biol 2002 for continuing to demonstrate how much a first-semester biology student can achieve when presented with high expectations.

Supplementary Materials
www.sciencemag.org/content/full/341/6153/1467/suppl/DC1

10.1126/science.1230002