

IBI* SERIES WINNER

Integrating Inquiry-Based Teaching with Faculty Research

Tadashi Fukami

The need for inquiry-based instruction in undergraduate education is well recognized (1, 2), but it has not been adopted widely in place of traditional “cookbook” instruction, where students follow lab manuals to reach known answers (3). One problem hindering the change may be insufficient time and resources for faculty to undertake new ways of teaching when they are under pressure to maintain productive research (3–5). Recently, my colleagues and I argued that one solution might be to build inquiry-based courses on faculty research programs, essentially combining teaching and research as synergistic activities (5). Here, I describe how I became involved in such an effort, in the hope that sharing my experience might help accelerate the spread of inquiry-based instruction.

Before joining the Stanford faculty, I struggled to juggle teaching and research in my first faculty position elsewhere. Because of this experience, the idea of designing teaching and research in ways that make the two mutually beneficial, suggested by Stanford’s Center for Teaching and Learning staff during new faculty training sessions, made an impression on me. I thought of this suggestion when I was later invited to participate in a reform of introductory biology laboratory courses. In response to student feedback in a curriculum assessment, the Biology Department was seeking to turn their two-course laboratory series—Biology 44X, on cellular and molecular biology, and Biology 44Y, on ecology and evolutionary biology—into modern inquiry-based classes, and my task was to design and teach a new Biology 44Y.

To ease the transition, the department concurrently offered, for 2 years, the original cookbook-style course taught by the existing instructional team—consisting of an instructor, 10 graduate students working as teaching assistants (TAs), a coordinator, and a laboratory manager—and the new inquiry-based course taught by a smaller team led by me. Concurrent offering served two purposes. First, implementing the new class with gradu-

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Study organisms. *Mimulus aurantiacus* flowers visited by an Anna’s hummingbird, *Calypte anna*. Hummingbirds and other pollinators transport nectar-inhabiting microorganisms from flower to flower as they feed on floral nectar.

ally increased numbers of students allowed us to try various pedagogical methods. Second, the two versions could be simultaneously assessed and directly compared by colleagues at Stanford’s School of Education (6, 7).

In 2010, we had 20 students enrolled in the new course, and they were taught by two TAs and me. In 2011, we expanded the new class to 34 students, and they were taught by an instructor, four TAs, and me. We then went full-scale in 2012, when the entire staff, consisting of three instructors, five TAs, two coordinators, a laboratory manager, and me, joined forces to teach all 132 registered students. Despite the big jump from 34 to 132 students, our experience during the initial 2 years helped us better manage the large class. By 2012, we had a good sense of the logistical challenges that each activity would entail and could plan accordingly. That year, we also made efforts to maintain close communications among the instructional team members. Also, I taught the first lab section of each week so that other instructors could come to observe at least part of the activities to ensure that the multiple sections were consistent and well coordinated for data collection.

Biology 44Y, an IBI prize-winning module, helps students do science by practice, with a focus on plant-pollinator-microbe interactions as a model system.

Building on one of my research group’s projects, the course focuses on ecological interactions among a species of flowering plants, the hummingbirds and insects that pollinate the plants, and the microorganisms that inhabit the floral nectar of the plants and move from flower to flower by hitchhiking on pollinators (8–10). Our aim is to use these interactions (see the first photo) as a case study for the students to practice as many of the same approaches taken by professional biologists as possible. The primary goal is not to gain specific knowledge of the organisms that the students study, but to develop understanding of how experiments are designed, how data are interpreted, and how the level of certainty in

scientific knowledge can be evaluated. We believe this is an important goal for all students, even those who will not continue in biology, because many environmental, agricultural, and medical issues that are relevant to every citizen today require a high level of scientific literacy.

The course is structured around a 1-hour lecture and/or discussion session and a 4-hour lab or field session each week. Each lab section is guided by an instructor and a TA and contains 14 to 20 students. Stanford’s Jasper Ridge Biological Preserve is our field site, located 15 min from the main campus (8). The students visit the preserve once a week during the lab session by a university bus during 8 of the 10 weeks of the course.

Over the first few weeks, students are introduced to the natural history of the plant-pollinator-microbe interactions. They also review the methods of hypothesis testing by basic statistical analysis, with real examples from peer-reviewed journals used as a guide. After that, each pair of students choose, as the focus of their project, one of the following abiotic factors: light, temperature, and water; and one of the following biotic fac-

tors: plants, pollinators, and herbivorous insects. Each pair then formulates two or three testable hypotheses regarding the relation between nectar-inhabiting microorganisms and the two factors (one abiotic and one biotic) of their choice. For example, one student pair hypothesized that increased ambient temperature would result in a larger number of flowers on a plant, which would, in turn, increase pollinator visits and microbial abundance in nectar.

For hypothesis testing, students are given a large set of shared data (as detailed in the supplementary materials), most of which we have students collect (see the second photo). The data set provides ample room for each team to ask unique questions and design ways to analyze data, while at the same time increasing the common ground on which peer discussion can occur. At the end of the course, each pair presents results in both a talk and a paper. Throughout, we provide step-by-step guidance on how to frame scientific questions, statistically analyze data, and write a paper in a format appropriate for submission to a peer-reviewed journal (5–7).

Over 3 years of course implementation, it has been rewarding to see mutual benefits to student learning and research effort. Assessment by the Stanford School of Education colleagues indicates that our course is achieving our educational goals (6, 7). Moreover, many of the student projects have yielded findings unknown to science. Use of a system and topic with which the faculty member leading the teaching effort is familiar (8–10) helps to ensure that students are collecting data that contribute to new discoveries. At the same time, students often find new ways to collect and analyze data

About the author



Tadashi Fukami is an Assistant Professor in the Biology Department at Stanford University. He studies ecological community assembly, with a focus on historical contingency, or when and why the structure and function of ecological communities are contingent on the past history of species immigration. This work involves various organisms, including the nectar-inhabiting microbes described here. He received a bachelor's degree from Waseda University, a master's degree from the University of Tokyo, and, in 2003, a Ph.D. from the University of Tennessee, Knoxville. After postdoctoral work at Landcare Research, New Zealand, he was an Assistant Professor at the University of Hawaii at Manoa before moving to Stanford in 2008.

that the instructors have not thought about. One example involves data collection initiated by students on the relationship between nectar pH and microbial abundance. Their results were intriguing and later prompted my research group to integrate nectar pH into our work (9). These and other student-collected data have been used in peer-reviewed papers, in which student contributions are acknowledged (8–10).

We recently made six suggestions for successful integration of teaching and research, including (i) a low barrier of technical expertise for students to collect data, (ii) established checks and balances to ensure that student mistakes will not compromise research quality, (iii) a diverse set of variables that present many choices for students to investigate without overwhelming the instructional team, (iv) a central database into which students can upload data, (v) assessment measures that are

representative of real-world science, and (vi) involvement of instructors with expertise in the study system (5). Here, I add one more to the list: (vii) cultivation of a communal experience among students by keeping lab sections small. Inquiry-based learning is most effective when a small number of students work in a collaborative environment, exchange ideas, and ask interrelated questions. Although challenging for high-enrollment classes like ours, implementing our

suggestions is possible if instructors and TAs that lead small sections receive good training beforehand. For example, we meet for 4 hours weekly for 6 to 7 weeks before the course so that the team can learn the field, laboratory, and statistical methods that the students will use. Overall, my experience leaves me optimistic that inquiry-based instruction can become widespread through integration of teaching with faculty research programs.

References and Notes

1. American Association for the Advancement of Science, *Vision and Change: A Call to Action* (AAAS, Washington, DC, 2010).
2. R. G. Duncan, A. E. Rivet, *Science* **339**, 396 (2013).
3. S. E. Brownell, K. D. Tanner, *CBE Life Sci. Educ.* **11**, 339 (2012).
4. W. A. Anderson *et al.*, *Science* **331**, 152 (2011).
5. M. J. Kloser, S. E. Brownell, N. R. Chiariello, T. Fukami, *PLoS Biol.* **9**, e1001174 (2011).
6. S. E. Brownell, M. J. Kloser, T. Fukami, R. J. Shavelson, *J. Coll. Sci. Teach.* **41**, 36 (2012).
7. M. J. Kloser, S. E. Brownell, R. J. Shavelson, T. Fukami, *J. Coll. Sci. Teach.* **42**, 90 (2013).
8. M. Belisle, K. G. Peay, T. Fukami, *Microb. Ecol.* **63**, 711 (2012).
9. R. L. Vannette, M.-P. L. Gauthier, T. Fukami, *Proc. Biol. Sci.* **280**, 20122601 (2013).
10. K. G. Peay, M. Belisle, T. Fukami, *Proc. Biol. Sci.* **279**, 749 (2012).

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Supplementary Materials

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Data collection. Students in the Biology 44Y class collecting data on pollination at the Jasper Ridge Biological Preserve of Stanford University.

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