IBI* SERIES WINNER

A Season for Inquiry: Investigating Phenology in Local Campus Trees

Campus Trees, the IBI Prize–winning module, uses local phenology to create authentic inquiry experiences in undergraduate biology.

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Michigan State University rightfully claims one of the most beautiful campuses in the Midwest. Each spring, we anticipate a commencement gilded with tulips and crabapple blossoms. In autumn, the campus beams with golden oaks and fiery maples. As a potential subject for inquiry learning, phenology, the study of recurrent natural events, is appealing for many reasons.

Phenologic studies have relatively few logistical constraints compared with many topics in biology. Virtually every habitat imaginable undergoes cyclical or seasonal changes that can be observed through local plants, animals, or other organisms. Documenting phenological patterns can be a straightforward and cost-effective strategy for engaging students in the science of observation with little need for additional equipment or supplies.

The subject of phenology is both timely and scientifically relevant. Interannual variability in factors such as temperature and precipitation can shift the timing of phenologic events by days to months, with real-world impacts ranging from ecosystem function (e.g., plant-pollinator interactions) to regional economies (e.g., agriculture and tourism). Larger-scale trends over long periods of time serve as important indicators of environmental changes, including climate change (*1*).

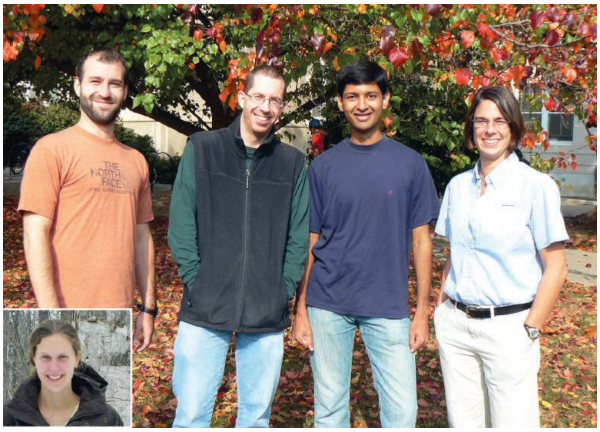
Finally, phenology is complex. Seemingly simple processes, such as the changing color of leaves, actually result from myriad interactions occurring across molecular- to ecosystem-level scales. As a complex system, phenology encompasses multiple biological processes that can be explored from diverse disciplinary perspectives across scales of space and time (*2*, *3*) (see the first photo).

Our introductory labs are taught by graduate teaching assistants (TAs) ranging in both teaching experience and disciplinary expertise. As the real face of the lab, TAs bear immediate responsibility for motivating student learning and bringing new instructional strategies into the classroom. They recognized that the labs we had been teaching, in which students followed protocols to confirm known outcomes, did not reflect the biology that motivated each of us to become biologists. We believed that in order to change both the content and culture of our labs, we would need to fully engage TAs as collaborators in the reform process.

Inquiry investigation. Students worked with collaborative teams to develop innovative methods for quantifying leaf color change and abscission in campus trees. Most groups combined both new technology and lower-tech approaches in their data collection strategy.

In summer 2008, we invited TAs to a 2-day "boot camp" to learn about evidence-based teaching practices (*2*, *3*) and to provide input about goals for reforming labs. TAs said that labs should provide students opportunities to experience how science is done—not as a series of methodological steps, but as a way to ask questions, test ideas, and evaluate evidence. In addition, TAs wanted labs to be more authentic and to reflect the uncertainty of science as it is practiced. Students would pursue questions in which a "right" answer might not be known.

To incorporate these goals, TAs worked in small groups to rewrite existing labs, framing them as inquiry investigations with explicit and measurable learning objectives. Five TAs collaborated with us to take on the larger task of developing a new, semester-long phenology study, Campus Trees (see the second photo). Inspired by the citizen-scientist model of the National Phenology Network (*4*), we envisioned the outgrowth of a long-term, student-generated database documenting phenology in our local cam-



Curriculum developers. Graduate TAs, Jeffrey Pierce, Todd Robinson, Mridul Thomas, Sherry Martin (left to right), and Kristen Schmitt (inset) collaborated in the original design and implementation of the phenology project in Fall 2008 and contributed as authors on supporting lab materials.

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

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pus trees. Our primary challenge was how to engage students in original inquiry, while at the same time, ensuring consistency and reliability in the student-generated data. Ultimately, we decided that students would mirror authentic ecological research by working collaboratively to design, field-test, and evaluate original methods for quantifying phenologic change.

In order to embed replication within the project design, we restricted the study to 200 trees representing four genera: *Acer*, *Quercus*, *Malus*, and *Ginkgo*. The Office of Campus Parks and Planning provided maps with locations and identification codes for all trees in the study (*5*). Students working in groups of four were assigned three trees to study for the semester; each tree was independently sampled by at least three different student groups across different lab sections. Students would not know that others were studying "their" trees until later in the semester.

Students began by locating their trees in the field, making detailed sketches about location and identifying characteristics, and recording tree height and diameter. Students had 2 weeks to brainstorm alternative approaches for quantifying color change and leaf fall and then present their proposals in class. Feedback from classmates and TAs helped students clarify study objectives and solidify their data collection plans.

For the next several weeks, students applied their methods in the field and managed all logistical and troubleshooting issues that arose. After leaves had fallen, students uploaded their final data and methods to our course-management system, LON-CAPA (*6*). Students used their tree codes to search for and retrieve the data and methods of other groups that had studied the same trees. In a final presentation, students evaluated alternative methods and compared the quality of data produced. Groups wrote short papers based on their analyses and proposed an "ideal" method that would best meet the criteria for (i) producing reliable and accurate phenologic data, (ii) generating high-quality data that can be used in future research, and (iii) feasible implementation in a course enrolling large numbers of students (up to 1000 per semester).

What did we learn from this experience? First, students are capable of achieving far more than we expect. Our concern that students might converge on a common approach was not realized. In fact, students used diverse and innovative methods for data collection [e.g., determining which branches to sample using a Twister spinner, quantifying leaf color with electronic colorpickers and RGB (red-green-blue) codes] and for troubleshooting (e.g., What should you do if the landscaping staff prunes the branches you were sampling? Should a leaf be counted in your sample if it's half eaten?). Another concern—that students would regard their own method as "best" and not critically evaluate alternatives—was also not realized. In their final analyses, few groups suggested that they had developed an ideal method and, instead, weighed strengths and weaknesses of multiple methods. TAs noted that by the end of the semester, students better understood how nuances in experimental approach could have an impact on both the nature and interpretation of data—an important benchmark in the development of science literacy (*7*).

Second, TAs have much to offer in terms of innovating curricula and providing insights that can improve students' learning experiences. Our TAs cared deeply about the quality of their students' learning and took pride in their successes. However, in order to realize the potential of TAs to rejuvenate labs, programs must be willing to liberate some creative control and to provide substantial mentoring along the way. Inquiry teaching is not easy and represents a significant departure from traditional, lecture-based instruction. TAs' transition to inquiry teaching involved discussing real examples in practice. Iterative feedback and a supportive network of peers also helped TAs develop confidence in their classrooms. Our program included TAs in decision-making about curricula and acknowledged authorship on TA-developed materials. This can do much to illustrate the value of TA input, not to mention bolstering TAs' curriculum vitae and teaching portfolios.

Finally, we advocate for including creativity in the reward structure of college-level biology. Confirmatory labs do not provide sufficient opportunities for students to experience the cycles of failure and recovery that practicing scientists experience as an ordinary part of scientific inquiry. Indeed, learning how to deploy creative strategies for managing the unexpected is a critical part of becoming a scientist yet is rarely reflected in most lab curricula. If we truly want to cultivate a nation of problem-solvers, we must allow students opportunities to wrestle with real problems and be rewarded for conceiving creative strategies for solving them. Our students have shown us they are ready for the challenge.

About the authors

Tammy Long is an assistant professor in the Department of Plant Biology at Michigan State University. She earned her Ph.D. at the University of Michigan for her work on the impact of CO_2 enrichment on resource allocation in plants. Her current research evaluates the long-term impacts of reforming introductory biology and explores how students use models and visual representations to reason about complex biological systems. **Sara Wyse** is an assistant professor of Biological Sciences at Bethel University and a collaborator with Long on this project and others. Sara earned her Ph.D. at Michigan State University, where she explored the impacts of alternative professional development models on graduate TAs' classroom performance. In addition, she researches student understanding of biological systems and the impact of collaborative learning on student understanding.

PHOTO CREDITS: (LEFT) KRISTEN KOSTELNIK; (RIGHT) ADAM WYSE

References and Notes

1. C. Parmesan, G. Yohe, A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **421**, 37 (2003).
2. National Research Council, *BIO 2010: Transforming Undergraduate Education for Future Research Biologists* (National Academies Press, Washington, DC, 2003).
3. C. A. Brewer, D. Smith, Eds., *Vision and Change in Undergraduate Biology Education: A Call to Action* (American Association for the Advancement of Science, Washington, DC, 2011).
4. USA National Phenology Network, (www.usanpn.org).
5. Detailed tree records are not a constraint for this project. At Bethel University, students identified trees on campus, mapped their trees in Google Maps, and provided verbal descriptions of how to locate their tree from a campus landmark.
6. The Learning Online Network with Content Management and Assessment System, www.lon-capa.org.
7. Project 2061, *Benchmarks for Science Literacy* (American Association for the Advancement of Science, Washington, DC, 1993).

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