THE PIPELINE

Scientific Teaching in Practice

A new generation of university scientists is learning to teach using a scientific teaching approach.

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The United States educates and trains outstanding scientists. Doctoral students emerge as rigorous experimentalists and strong analytical thinkers, intellectually prepared for the diverse employment opportunities that await them. Problems persist, however, in two areas: preparing undergraduate students as scientists and preparing graduate students to teach (*1*, *2*). Both deficiencies can be addressed by implementing programs that train graduate students to teach. Although there have been repeated calls for such programs (*1*–*3*), and descriptions of some (*4*), little work has assessed their impact on the practices and philosophies of the participants.

In contrast to graduate education, undergraduate science education is based largely on facts rather than analytical thinking. Effective teaching methods based on how people learn are known (*5*, *6*), but are not often applied in undergraduate classrooms. Similarly, graduate students and postdoctoral researchers (postdocs) who will become teachers of undergraduates are not taught how to use these teaching methods. Graduate students and postdocs who learn how to foster scientific curiosity, reasoning, and problem-solving will be prepared to produce a generation of science undergraduates who think scientifically.

Here, we describe a program that trains graduate students and postdocs to practice scientific teaching. Hallmarks of scientific teaching are methods that encourage students to construct new knowledge and to develop scientific ways of thinking, provide both students and instructors with feedback about learning, and foster success for all students. Scientific teaching aims to create classrooms that reflect the true nature of science and promotes teaching as a scholarly endeavor.

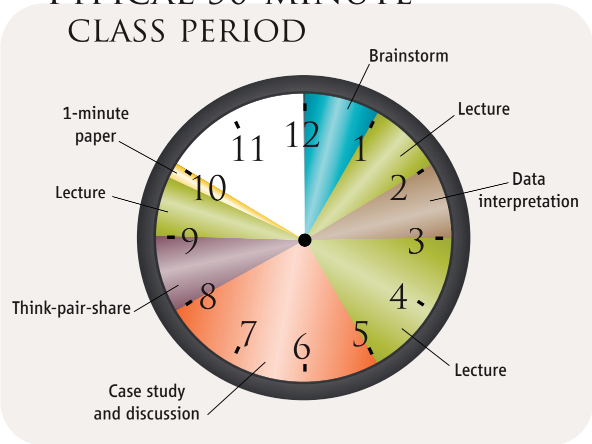
The Teaching Fellows Program

At the University of Wisconsin–Madison, we developed the Teaching Fellows Program, which is an 8-week course entitled, "Teaching Biology," followed by development of teaching materials and their implementation in the classroom. Fellows partner with UW-Madison biology instructors to develop teachable units, built on a scientific teaching framework (*5*), that address challenges in the instructors' courses. As they develop their materials in teams of two to three, fellows learn an iterative process of instructional design: develop concrete learning goals, design activities to meet the goals, and revise instruction based on evaluation of progress toward the goals. Peer review and dissemination are embedded in the process. Details about coursework, the teachable-unit design (see table, below) and evaluation rubric, evaluation instruments, and data collected are provided (*7*).

Since 2003, all 63 fellows who have completed the Teaching Fellows Program have been named "Howard Hughes Medical Institute (HHMI) Teaching Fellows." The fellows worked with 21 faculty and staff to create 35 distinct instructional materials for undergraduate biology courses, designed or redesigned two complete courses, created two instructional videos, developed two online learning modules, and produced a series of video podcasts. Collectively, the fellows have used these materials to teach over 1900 undergraduate students in 14 courses (ranging from 15 to 250+ students per course) at UW-Madison.

Here, we report the impact of the Teaching Fellows Program, based on assessment of the 44 fellows who participated between 2004 and 2007 and the 17 teachable units they developed and posted online. These fellows were graduate students (89%) and postdocs (11%) from diverse fields of biology, mostly white (91%), and of both sexes (66% female, 34% male). Most aspired to careers as faculty at small undergraduate colleges (63%) and/or large research universities (31%).

TYPICAL 50-MINUTE CLASS PERIOD



Classroom implementation. Analysis of teachable units developed by fellows for lecture-style classes revealed that 66% of class time was devoted to active learning events.

Examples of Teachable Units

Influenza—active learning exercises in which students learn about virus structure and life cycle; students model the epidemiology of outbreaks of viral diseases based on hypothetical viruses with various quantitative features

The Bacterial Side of the Story—case study in which students learn how horizontal gene transfer, mutations, selection, and human behavior lead to widespread antibiotic resistance

Statistical Tools for Biology—active learning exercises in which students learn how to use statistics to guide experimental design; links to inquiry-based lab experiments on behavior and population biology of *Daphnia magna*

http://scientificteaching.wisc.edu/materials

Assessment Methods

To determine whether and to what extent the fellows put scientific teaching into practice, we used a mixed-methods design (*8*) with both qualitative and quantitative data collection and analysis. We analyzed the materials created by the fellows (teachable units, evaluation reports, publications, and teaching philosophies) and deployed electronic surveys. First, we coded each teachable unit for evidence of active learning and assessment events, statements of diversity considerations, indications of quantitative or reflective approaches to teaching, and inclusion of methods that foster discovery. Examples of active learning included students engaging in small-group discussion; analyzing a case study; and responding to clicker questions, multiple-choice, and conceptual questions that can be answered individually by students with a wireless hand-held device during a lecture. We included as evidence of active learning only instances in which the exercise necessitated engagement of most or all students

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(i.e., not a question posed by the instructor and answered by only one student). Second, we determined how many fellows published papers about their teachable units. Third, fellows completed exit surveys about their level of knowledge and skill before and after (*9*) participating in the Teaching Fellows Program, rating their ability to develop active learning strategies, myriad assessments, and inclusive classrooms.

To assess philosophical aspects of the fellows' approaches to teaching, we analyzed their written teaching philosophy statements and responses to survey questions. We used a teaching philosophy rubric (*10*), adapted to include components of scientific teaching and learner-centered approaches. Statements of teaching philosophy from the beginning of the program (submitted as part of the applications) were compared with those written 9 months later, at the end of the program. In addition, surveys measured the fellows' attitudes after participating in the program. Respondents indicated their level of agreement with statements such as: "I am a good teacher" and "I feel that I am part of a community of scientific teachers." Averages were calculated from responses of three cohorts of fellows.

Evidence of Practice

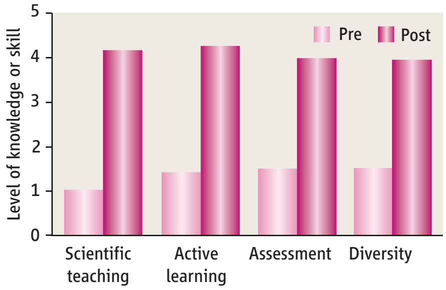
Fellows created teachable units that devoted, on average, >66% of class time to active learning events (see figure, page 1329). Each class period contained an average of four to five discrete active learning events, and 82% of fellows explained in their written description of the teachable units how the activities served the dual purposes of actively engaging students and assessing their knowledge or skill.

Teaching fellows included teaching methods to reach diverse students. Active learning and assessment events ranged from single clicker questions to multipart case studies; 71% of teachable units accounted for diverse learning styles; and 53% referred to race, ethnicity, culture, gender, socioeconomic issues, or international and/or global contexts. For example, Cloud-Hansen, *et al*. (*11*) stated as a learning goal, "Students will be able to critically analyze information to support a position on a complex and current scientific issue, while also justifying the political and socio-economic impact." No units, however, mentioned accommodating disability (e.g., physical, learning, or psychological) as a way to create inclusive classrooms, although this element of diversity was addressed in "Teaching Biology."

All teachable units described learning goals for one or more content areas; most teachable units (76%) also stated the expectation that students would learn one or more aspects of scientific discovery, such as the scientific method, science as an iterative process based on empirical evidence, historical context of science, group problem-solving, critical thinking, or communication of scientific ideas.

Nearly every teachable unit (94%) included some form of baseline data collection to assess students' prior knowledge or misconceptions; 47% followed up with a post-unit survey to gauge learning gains. Homework assignments and exams typically involved questions that represented multiple levels of understanding from knowledge to evaluation and reflected the established learning goals.

All fellows evaluated learning, and many (41%) generated a report about the results, four of which were published in peer-reviewed journals (*11–14*). These publications provide evidence that the undergraduate students who were taught by the teaching fellows gained knowledge in specific subject areas, learned skills in solving complex problems, and retained what they learned months later.



Learning gains for fellows. (n = 25; $P < 0.05$.)

Fellows reported significant gains in skill or knowledge for the core elements of scientific teaching. Across all categories, fellows reported an average skill or knowledge level of 1.7 ("low") before and 3.8 ("high") after completing the program (see chart above).

A Philosophy of Scientific Teaching

A comparison of teaching philosophies written before and after participation in the program ($n = 31$), demonstrated a shift in fellows' focus on the teacher to focus on the learner, as evidenced through comments in the philosophies about the responsibility of students for their own learning, the role of the teacher as guide, and the importance and implementation of a variety of teaching methods to facilitate student engagement in learning. For example, using a scale of 1 to 3, the average fellows' score shifted significantly ($P < 0.05$) from a baseline number of 2.0 ("average") to an exit score of 2.5 ("average" to "superior") in the category "View of the Learner," which demonstrated a deeper understanding of the learners and their role in their own classroom success. An excerpt from a fellow's statement illustrates a typical learner-centered philosophy:

> Although the teacher is present and engaged in the activities, active learning exercises place the learning responsibility into the hands of the student and require that the student come to class prepared to learn. This attitudinal shift alone will enhance learning because the student is ready and willing to participate.

After participating in the program, most survey respondents indicated that scientific teaching is a difficult but worthwhile effort (86%), that they were confident they are good teachers (96%), and that they felt part of a scientific teaching community (96%).

Conclusions

This study indicates that the Teaching Fellows Program effectively trains scientific teachers, as reflected through practice, philosophy, and the products created. Fellows learned the key elements of scientific teaching (active learning, assessment, and diversity) and integrated them into their teaching practices. Fellows acquired a scholarly approach to teaching, developed classrooms that reflect the nature of science, moved from teacher-centered toward student-centered teaching philosophies, and contributed to the development of a community of scientific teachers through partnerships with other instructors, online teaching materials, and peer-reviewed publications.

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Supporting Online Material

www.sciencemag.org/cgi/content/full/322/5906/1329/DC1

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