# Challenge your teaching

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**Twenty-first century research in the life sciences is becoming an increasingly interdisciplinary endeavor where teams of scientists use tools and insights from a variety of fields to solve complex biological problems. By and large, our educational system has not kept up with these changes. How can science education and the life sciences curriculum better reflect the way students will do science when they leave the hallowed halls of academia?**



*I have no question that students who learn, not professors who perform, is what teaching is all about: students who learn are the finest fruit of teachers who teach…. I am also clear that… teachers possess the power to create conditions that can help students learn a great deal—or keep them from learning much at all.*

Parker J Palmer, in
*The Courage to Teach: Exploring the Inner Landscape of a Teacher's Life*
(Jossey-Bass, San Francisco, 1998).

The scientific era at the start of the 21st century is referred to by many as a golden age of biology. New tools applicable to biological problems have been developed at a phenomenal pace. These tools have spurred insightful growth in the molecular-level understanding of cellular processes and turned into a powerful force for scientific discovery. It once took months to identify a gene or protein involved in a particular cellular response. Today it can take as little as a few days to go from isolation of a protein to identification and cloning of the requisite gene. This rapid discovery of the players involved in a problem has opened up a vast scientific arena filled with novel questions about increasingly complicated systems.

Modern experiments often target the interplay between cellular processes and their phenotypic ramifications by combining *in vivo* and *in vitro* approaches. Such studies often require a breadth of knowledge spanning several fields. Hence, teams of scientists come together to provide the expertise required to execute the experiments and interpret the results. Each individual must know enough about the neighboring fields to communicate effectively across the boundaries of their disciplinary training. Leaders of these collaborative projects often bring with them keen insights, the recognition of how to solve problems that span diverse fields, and the ability to identify the strengths that more specialized team members bring to the project. What we would probably find is that these key individuals were pushed during their training to make relationships, either in courses or more likely at the bench, among different schools of thought. It is important to understand what educational experiences effectively promote scientific development such that all students are able to reach their full potential and that universities continue to train the individuals necessary to fuel innovation. With that in mind, how should undergraduate and graduate curricula be structured to provide students with the skills they need to be tomorrow's leaders?

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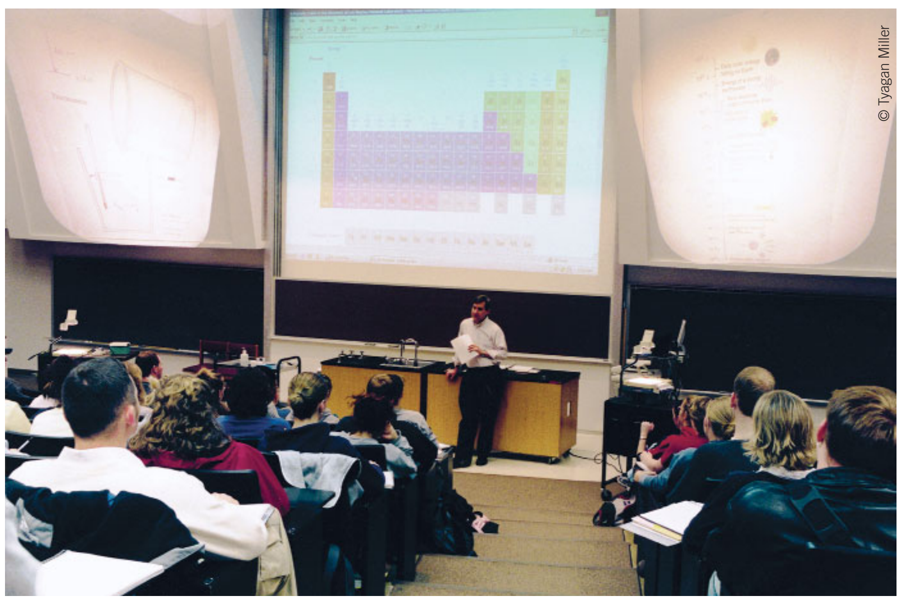


**Figure 1** The traditional classroom experience. The professor stands in front of the students and presents the lecture, with very little input from the audience.

For busy researchers, it is often difficult to find enough time to accomplish all of the tasks on the proverbial to-do list. Professors triage the tasks at hand, devoting effort to those perceived as having the greatest importance. Teaching often suffers during this evaluation, because it tends not to help land the next research grant or contribute to the next publication. Clearly teaching is viewed by tenure and promotion committees as being important (but remember—don't spend too much time on it, it isn't *that* important). Teaching needs our attention, however, and there are things every professor can do to improve the quality of student learning without sacrificing so much time that it impinges significantly on research productivity.

Below are some thoughts on the state of higher education and teaching at research universities today. They derive from my personal experiences as an assistant professor at a major research university. I freely admit that I hold a utopian vision of academia. What could be accomplished if each of us were to focus a portion of our creative efforts on the educational mission of our respective schools? Were we to focus on teaching students to be good scientists rather than collectors of facts, they would become independent in the laboratory more rapidly and be better equipped intellectually to design and interpret their experiments. Thus, improved teaching should correlate with increased research productivity.

## Education lags behind research

Despite the rapid shifting of research priorities to the interface between disciplines, the curricula we present to our students have changed very little over the last several decades. The majority of undergraduates who enter science, mathematics, engineering and technology (SME&T) disciplines at American colleges and universities still enroll in rather traditional lecture-style classes (**Fig. 1**) that embody the divisional paradigm of 20th-century education. Students might take introductory courses in chemistry, physics, biology and calculus—courses very similar in structure and content to those our parents or grandparents might have taken 30–50 years ago. At least two factors contribute to this arrangement and reinforce its existence. Modern American universities are conservative institutions, built on a highly divisional structure. Although the organizational details may vary from one university to the next, faculty appointment and tenure depend integrally on association with a department and sometimes even with subdisciplinary groups within such units. Control of teaching assignments and the curricula for a given major generally fall under the purview of these departments—providing little impetus to reach out and innovate between academic units. Thus, the fundamental organizational structure provides a barrier to the teaching of courses at the interface between disciplines.

Textbook choices also strongly influence curricula in entry-level classes. For the busy faculty member, it is easiest to teach along the outline set forth by a textbook. The consistency between textbooks provides a barrier to teaching innovation, however. The solution can be to use a custom text or to forgo textbooks altogether. The need to gather the necessary resources to teach in a textbook-free classroom can be time consuming and energy intensive for the faculty involved. Thus, it proves to be a significant hurdle for professors at research universities who are repeatedly told by mentors to give precedence to their research. Who, if not the faculty, should spend the time necessary to ensure that our universities provide cutting-edge educational opportunities?

Several recent reports commissioned by the US National Research Council and others have looked in detail at SME&T education in general[1,2] and life sciences education in particular[3]. These reports identified crucial areas where educational programs have fallen woefully behind the changes in our research infrastructure. The consensus is that many recipients of SME&T degrees no longer obtain the core skills necessary to ensure their future success in life sciences research. All three reports identified students deficient in their ability to interface across multiple disciplines and to integrate knowledge between subjects. They also found a lack of quantitative skills among life-science majors, which is disturbing because the interdisciplinary nature of modern biology hinges on the ability to perform complex mathematical and statistical analyses. The life sciences curriculum cannot be expanded to include additional courses because these majors typically require the maximum number of credits allowed by universities. This limitation means either (i) material must be removed from the curriculum so that it can be replaced with new, more pertinent content, or (ii) existing classes must be used more efficiently to teach the topics and skills essential for understanding modern biology. Programs should not simply provide broad subject matter to the exclusion of depth and mastery of any individual field. The challenge is to provide thorough exploration of a subject while also stimulating an understanding of the relationships between life science and the allied disciplines with which it borders. My belief is that achieving these goals will require a combination of faculty willing to focus a little more of their efforts on effective teaching and a rethinking of how the curriculum and coursework are structured.

### BOX 1 FIVE PRACTICES YOU CAN IMPLEMENT IN YOUR CLASSROOM TOMORROW

1. **Stop lecturing.** Ask students in class to interpret a finding or data figure by discussing it with their neighbors for a few minutes. Bring the class back together to compare their observations.
2. **Listen to your students.** Ask students at then end of class what the single most important concept or skill was that they learned. If more than three different answers come back, think about ways to better focus the discussion.
3. **Build relationships between subjects.** Left on their own, students cannot always see the relationships between fields. However, once the students have these illustrated, they will continue to look for these ties.
4. **Talk to a colleague about teaching.** Make teaching a regular part of your discussions with colleagues, including common goals for student development and ways to improve student learning.
5. **Focus on learning.** Remember that the goal in the classroom should be for students to gain knowledge and attain new skills. Teaching is only a tool used to facilitate the learning process.

## Don't be a talking head

Novel coursework alone will not stimulate long-term reform in science education. Attention must focus on how science is taught and how faculty who embody the ideal of the teacher-scholar are rewarded. There are very simple classroom techniques every teacher can use to promote better learning (**Box 1**). The lecture format, for instance, derives from a time when access to information was limited. It was efficient for an expert to stand before an audience of several hundred students and act as the medium of information transfer. Today, with the ready availability of books and electronic media, are lectures really an effective method to facilitate the intellectual development of our students? A classroom session need not be a recapping of material one could have read in a textbook. We often hear that students do not read their texts (see http://www.textrev.com). Maybe we, the faculty, are at fault. Have students come to expect lectures that simply reiterate concepts from the book and hence find the text superfluous? We must consider whether our educational goals center on the transfer of information or whether higher-order skills are also important agenda items. Course content, graded exercises and classroom time should be spent in proportion to the relative weight assigned to each goal and the means by which a given experience contributes to one or more of the desired learning outcomes[4].

For the faculty member, it is easy to revert into lecture or performance mode. One has notes or prepared overheads to fall back on, and class will end 50 minutes after it starts.

Although there are unlikely to be any surprises, unfortunately there may be very little learning going on either. So what can be done? The simplest thing is to stop talking, ask the students questions, and then wait for them to answer, even if the silence is uncomfortable. If the question is complicated, ask the students to consult with the people around them and seek a consensus. Then bring the group back together to discuss the issue, letting the students provide their insights. The class as a whole should weigh the responses. This approach works particularly well if the students are asked to analyze a small data set. Let them discover a concept through their own analysis rather than being told the finding as if it were a historical fact. Not only does this approach make the classroom more active for the students, it also allows them to practice the intellectual skills they will need to be effective scientists.

### Use capstone experiences

Independent research with a faculty mentor is one of the most educational capstone experiences available to undergraduates. Laboratory research promotes a transition from being a person who absorbs knowledge to one who uses observation to generate new knowledge. The experience often has a dramatic impact on the student. It provides a practical context for the abstract concepts learned in a classroom. It also helps students to understand the limits of book learning. Undergraduate research programs are particularly common at universities, where the research infrastructure can accommodate large numbers of students. However, only a fraction of SME&T majors take advantage of these opportunities. The US National Science Foundation supports numerous undergraduate research programs to bridge the gap between colleges and universities by providing access to equivalent experiences during the summer for students who lack access to the necessary faculty or infrastructure at their own schools. A goal for SME&T curricula should be to provide all interested students access to a research experience as part of their undergraduate education.

An alternative capstone experience comes in the form of seminar courses. Typically, these seminars allow students to follow their personal interests in the preparation and presentation of a final project that culminates their studies. This format allows students to demonstrate their mastery of the curriculum as a whole but falls short of demonstrating the ability to learn through experimentation and observation, a fundamental aspect of experimental science. Both capstone experiences have their merits. Because they serve the needs of different student populations, in an ideal world, both types of culminating experience should be available to students.

In isolation, a capstone program provides only a glimmer of interdisciplinarity and curricular integration. By their senior year, students may already possess ingrained learning patterns or misconceptions distilled from their earlier courses. A second problem is that students encounter some of the captivating scientific challenges only at the end of their studies. For a variety of reasons, a significant dropout rate occurs in the sciences, with lateral movement to other fields of study. By front-loading the curriculum with a discussion of important research questions, it might be possible to inspire students and help them understand the relevance of basic concepts to their long-term goals. The interdependence of scientific inquiry and the relationships between fields may well be one of the more important messages we can impart to students early in their educational careers. These ideas provide the framework from which details must hang if facts and data are to be built into a coherent knowledge base.

### Make the most of entry-level courses

An alternative approach to instilling a basic philosophy of scientific interdisciplinarity might arise from the entry-level coursework. This approach can be quite informal—achieved through the cooperation of faculty from different departments. SME&T majors generally take a common trajectory through their introductory courses. These students often enroll in chemistry, biology and calculus during their freshman year. As sophomores, they might enroll in physics, organic chemistry and molecular biology, and so forth. Professors can use this knowledge of typical schedules to spotlight relationships between disciplines that might not be self-evident to the students. This approach to improving the interdisciplinarity of education requires little more than a desire on the part of the professor to reach out and explore the boundaries between subjects. Informal discussions between instructors might be sufficient for them to keep each other knowledgeable about their respective course content and allow examination of these interfaces.

Several colleges and universities are exploring experimental courses to introduce the fundamental interdependence of modern life science research. Unconventional classroom experiences can help develop rich intermingling of the subject matter and show how fields build on one another. Examples of this approach include the Integrated Freshman Learning Experience at Indiana University (Bloomington, Indiana, USA) funded by the Howard Hughes Medical Institute (HHMI; http://hhmi.bio.indiana.edu/ifle/) or the Interdisciplinary Laboratory at Harvey Mudd College (Claremont, California, USA) funded by the National Science Foundation (http://www2.hmc.edu/~karukstis/idlab/2003_2004/index.html)[5]. Both programs provide students with a fertile learning experience by actively exploring scientific topics in a fundamentally integrated manner—tearing down the boundaries between department-centered teaching. Incoming freshmen enter these courses as novices. They begin their exploration of college-level science with the idea that subject matter will transcend any given course. The transfer of ideas and concepts between classes then stimulates broader discussion of course material. Such introductory experiences also build a mental framework or scaffold for students' future learning. They help students develop an understanding of how the content of individual courses fits into a broader scientific context. Under this model, science is presented as a melding of ideas from different disciplines. Individuals, like disciplines, bring to a problem their distinct approaches and the students can learn how these work together to build insight and understanding.

### Start slowly toward ongoing reform

The novel introductory courses described above provide a stepping stone to more comprehensive reform projects that promote education at the curricular interfaces. It is important to start slowly, however, and develop a culture that really promotes teaching excellence. Some exemplary programs are already in place and can be used as models for where the field might be going. One is the HHMI-funded Interdisciplinary Science Scholars Program at Haverford College (Haverford, Pennsylvania, USA; http://www.haverford.edu/biology/HHMI/biology.hughes.info.html). It illustrates how comprehensive these reforms can be and how pedagogical changes affected the careers of these students. Since the inception of this program, the number of students from Haverford who chose to pursue PhD or MD/PhD degrees after graduation has increased significantly relative to those students who completed the standard majors offered by the allied departments (biology, chemistry, mathematics, physics and psychology). These students are also much more likely to pursue interdisciplinary studies at the graduate level than are students completing more traditional programs. An additional byproduct of the program noted by both the faculty and the students is the increase in research collaborations among its participants. Thus, the increased interactions of the faculty across disciplinary boundaries has translated into improved research productivity.

### One size doesn't fit all

Curricular reform projects at both the undergraduate and graduate levels are underway at universities across the United States. Changes must reflect the environment, faculty and students at each school. No single solution will meet every institution's needs. By looking carefully, however, one is likely to find common experiences and challenges. Even the modest contribution a single faculty member makes by improving his or her classroom helps elevate the role that teaching plays in university culture. By disseminating individual experiences in creative teaching, the insights of teacher-scholars can be shared so that the community as a whole can benefit from these innovations. Small steps taken by faculty in many departments and at universities across the country will help to refocus our collective perspective on teaching and make it an activity to be proud of rather than just a burdensome obligation.

### Share your educational tools

Sharing the insights obtained through research is second nature to those active in the life sciences. Why, then, have we as a community applied different standards to the creative and intellectual aspects of teaching? It is essential to pay attention to the educational innovations underway in the community at large and to use these programs as launchpads for new ideas. Reporting on both the successes and shortcomings of pedagogical experiments and the dissemination of novel classroom materials will improve student learning. This approach requires that faculty involved in curricular reform projects assess their programs critically and make such data available to the community through publication, presentations at the meetings of their professional societies, or electronic distribution of course portfolios, for instance, that document student learning resulting from teaching innovation.

Compare this dissemination to the review process used for publication of research findings. Introduce the problem. Explain your approach to solving it. Show the data that support the results and make it possible for others to build upon the work. If the results are compelling and clearly disseminated, other instructors will take notice. An example of this process can be seen in a set of bioinformatics exercises developed for use in undergraduate biochemistry courses (http://www.indiana.edu/~c484/afeig/bioinformatics.htm)[6]. Because these materials were made available to others, the effort spent developing pedagogical exercises has affected students well beyond Indiana University and made the project visible for others to use directly or adapt to their own needs. Enhancing the visibility of teaching and curricular reforms promotes a productive dialog on classroom experiences that provide students the greatest learning opportunities. With ready access to pedagogical insights, it becomes easier for faculty to incorporate new teaching ideas and methods into their own classrooms by alleviating the need to develop individually all of the necessary materials.

### A challenge to all teachers

My love affair with science started not in the classroom but in the laboratory. I doubt that my experience is unique. It came from the realization and excitement of learning something that no one had ever known before. We should strive to bring that level of discovery into the context of our classrooms. If we accomplish this feat, we will have succeeded in changing education forever. I challenge you to challenge your teaching. Try something new in the classroom and explore ways to engage your students in the learning process. To become a scientist, a student needs to practice his or her powers of inquiry, observation, interpretation and deduction. Let students learn what it is to be a scientist by allowing them to revel in the epiphany of discovery.

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1. Committee on Undergraduate Science Education. Transforming undergraduate education in science, mathematics, engineering and technology (National Research Council publication no. 113, National Academies Press, Washington, DC, 1999).
2. The Boyer Commission on Educating Undergraduates in the Research University. Reinventing undergraduate education: a blueprint for America's research universities (Carnegie Foundation for the Advancement of Teaching, Menlo Park, California, USA, 1998).
3. Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century. *Bio2010—Transforming Undergraduate Education for Future Research Biologists* (National Academies Press, Washington, DC, 2003).
4. Harwood, W.S. *Int. J. Dev. Biol.* **47**, 213–221 (2003).
5. Van Hecke, G.R., Karukstis, K.K., Haskell, R.C., McFadden, C.S. & Wettack, F.S. *J. Chem. Ed.* **79**, 837–844 (2002).
6. Feig, A.L. & Jabri, E. *Biochem. Mol. Biol. Ed.* **30**, 224–231 (2002).