CBE—Life Sciences Education
Vol. 11, 339–346, Winter 2012

Feature
Approaches to Biology Teaching and Learning

Barriers to Faculty Pedagogical Change: Lack of Training, Time, Incentives, and. . .Tensions with Professional Identity?

Sara E. Brownell* and Kimberly D. Tanner†

*Department of Biology, Stanford University, Stanford, CA 94305–5020; †Department of Biology, San Francisco State University, San Francisco, CA 94132

> The time has come for all biology faculty, particularly those who teach undergraduates, to develop a coordinated and sustainable plan for implementing sound principles of teaching and learning to improve the quality of undergraduate biology education nationwide. (*Vision and Change*, 2011, xv)

Recent calls for reform, such as *Vision and Change: A Call to Action*, have described a vision to transform undergraduate biology education and have noted the need for faculty to promote this change toward a more iterative and evidence-based approach to teaching (American Association for the Advancement of Science [AAAS], 2011). A key challenge is convincing many faculty—not just a handful of faculty scattered across the country but the majority of life sciences faculty in every institution—to change the way they teach.

Few would disagree that this is an ambitious goal. Change is difficult in any setting, but changing academic teaching appears to be especially tricky. Calls for change imply that the pedagogical approaches our own professors and mentors modeled and taught us might not be the best way to engage large numbers of diverse populations of undergraduates in our discipline. This effort potentially also involves telling faculty that what they have been doing for the past 5, 10, or even 30 yr may not the most effective approach, especially for today's students. Widespread change in undergraduate biology teaching—or in any of the sciences for that matter—has been documented to be difficult (Henderson *et al.*, 2011). The general perception is that while there are pockets of change driven by individual faculty, there is little evidence that the majority of our faculty members are reconsidering their approach to teaching, despite dozens of formal policy documents calling for reform, hundreds of biology education research publications on the subject, and the availability and award of substantial amounts of external grant funding to stimulate change toward evidence-based teaching (Tagg, 2012).

In fact, it is somewhat perplexing that we as scientists are resistant to such change. We are well trained in how to approach problems analytically, collect data, make interpretations, form conclusions, and then revise our experimental hypotheses and protocols accordingly. If we are experts at making evidence-based decisions in our experimental laboratories, then what forces are at play that impede us from adopting equally iterative and evidence-based approaches to teaching in our classrooms? What can we—as members of a community of biologists dedicated to promoting scholarly biology teaching—do to identify and remove barriers that may be impeding widespread change in faculty approaches to teaching?

A substantial body of literature has highlighted many factors that impede faculty change, the most common of which are a lack of training, time, and incentives. However, there may be other barriers—unacknowledged and unexamined barriers—that might prove to be equally important. In particular, the tensions between a scientist's professional identity and the call for faculty pedagogical change are rarely, if ever, raised as a key impediment to widespread biology education reform. In this article, we propose that scientists' professional identities—how they view themselves and their work in the context of their discipline and how they define their professional status—may be an invisible and underappreciated barrier to undergraduate science teaching reform, one that is not often discussed, because very few of us reflect upon our professional identity and the factors that influence it. Our primary goal in this article is to raise the following question: Will addressing training, time, and incentives be sufficient

DOI: 10.1187/cbe.12-09-0163
Address correspondence to: Kimberly D. Tanner (kdtanner@sfsu.edu).

to achieve widespread pedagogical change in undergraduate biology education, or will modifying our professional identity also be necessary?

FOCUSING ON THE BIG THREE: LACK OF TRAINING, TIME, AND INCENTIVES

Insufficient training, time, and incentives are among the most commonly cited barriers for faculty change, and the focus of most of the current efforts to understand and promote faculty pedagogical change (Henderson *et al.*, 2010, 2011; AAAS, 2011; Faculty Institutes for Reforming Science Teaching [FIRST] IV, 2012; National Academies of Science/Howard Hughes Medical Institute [NAS/HHMI], 2012).

In terms of training, many faculty have indicated they feel ill-equipped to change the way they teach and thus would like access to structured, formal training. Unsurprisingly, we as faculty may not be knowledgeable about what constitutes a student-centered classroom (Hativa, 1995; Miller *et al.*, 2000; Winter *et al.*, 2001; Hanson and Moser, 2003; Luft *et al.*, 2004; Yarnall *et al.*, 2007) or we may be unconvinced as to whether new teaching methods are really more effective than traditional instruction (Van Driel *et al.*, 1997; Miller *et al.*, 2000; Winter *et al.*, 2001; Yarnall *et al.*, 2007). Even if faculty are aware of reform efforts, science faculty will most likely not have had training in these types of teaching methods (Rushin *et al.*, 1997; Handlesman *et al.*, 2004; Ebert-May *et al.*, 2011). *Vision and Change* specifically highlights the need for training of early-career scientists, including postdoctoral fellows and assistant professors (AAAS, 2011). Efforts such as the NSF-funded FIRST IV program and the NAS/HHMI Summer Institutes for Undergraduate Biology Education are examples of programs intended to provide postdoctoral scholars and faculty of all ranks, respectively, with the needed expertise in innovative teaching through hands-on training (FIRST IV, 2012; NAS/HHMI, 2012). Although it is too early to gauge the long-term success of these programs, one wonders whether some of these training efforts may be hindered by the lack of buy-in from the home institutions. After faculty go to nationally or regionally organized training workshops and become excited about implementing new teaching strategies, are they met with support or resistance from their colleagues upon return to their home institutions? Furthermore, trying to achieve pedagogical change through 1-d or even 1-wk training sessions seems incongruent with the notion that pedagogical change for any instructor is an iterative and ongoing process. Even the most well intentioned of us forget what we learned, need extra practice, and often revert to our old habits when we are, inevitably, pressed for time. So although it is necessary to provide scientists with training opportunities demonstrating new ways of teaching, training alone is likely insufficient by itself to achieve lasting pedagogical change.

What about issues of time? With the often-competing demands of research and teaching, faculty often find it difficult to carve out sufficient time to reflect deeply upon their teaching. While faculty at different types of institutions have varying degrees of teaching responsibilities, faculty at most 4-yr institutions are also required to do research and obtain significant external grant funding. Although this expectation is most explicit at R1 research institutions, it also exists at many comprehensive institutions, and even at small liberal arts colleges. Regardless of current faculty teaching loads, there is no doubt that the process of changing an instructional technique is time- and labor-intensive (Krockover *et al.*, 2002; Howland and Wedman, 2004; Stevenson *et al.*, 2005; Schneider and Pickett, 2006; Malicky *et al.*, 2007). Additionally, research has shown that interactive teaching, as compared with traditional lecturing, typically takes more preparation time (Miller *et al.*, 2000; Hanson and Moser, 2003; Pundak and Rozner, 2008). Thus, not only will the actual process of change take more time, but we are asking faculty to shift to a method that might be, by its very nature, more time-consuming. Institutional recognition of this fact, and corresponding allowance in faculty schedules, will thus be critical to accomplishing widespread adoption of evidence-based teaching strategies. In addition, for such changes to be made, there needs to be an incentive for faculty to modify their pedagogical approach; even though time is necessary, time alone is likely not sufficient for widespread change to occur.

Incentives likely drive most of our professional decisions, and teaching is no exception. If we as faculty are indeed provided the requisite training and time to enact changes in our teaching, then there must also be a concomitant reason *why* we should want to change. Research has demonstrated that even if faculty are interested in changing their pedagogical approach, few incentives are available to spur this action (Hativa, 1995; Walczyk and Ramsey, 2003; Gibbs and Coffey, 2004; Weiss *et al.*, 2004; Wilson, 2010; Anderson *et al.*, 2011). Many argue that if change takes time and training, then faculty need to be compensated for their efforts in the form of lower teaching loads, financial benefits, recognition for tenure, teaching awards, or even, at the most basic level, verbal acknowledgment from colleagues and supervisors. Research has shown that in many universities there are few to no rewards for teaching in novel ways or introducing evidence-based strategies (Kember and McKay, 1996; Frayer, 1999; Krockover *et al.*, 2002; Romano *et al.*, 2004). In fact, there are some reports that change in instruction can lead to poor teaching evaluations, due to student resistance to change, which can negatively affect progression to tenure (Anderson, 2002, 2007). Until universities reward teaching as much as research (Hannan, 2005; Porter *et al.*, 2006) or find ways to better integrate teaching and research (Kloser *et al.*, 2011), the pressure is on faculty, in particular pretenure faculty, to spend the majority of their time on research, sometimes at the expense of high-quality teaching or any attention to the constant calls for change in teaching practice.

The needs for training, time, and incentives are the most commonly cited impediments to widespread change in undergraduate biology faculty teaching practice, and indeed these are real and present barriers. However, let us pause. Imagine a university that provides faculty with *all* the training, *all* the time, and *all* the incentives faculty needed—would that be enough for *all* biology faculty or even the *majority* of biology faculty to adopt or build on pedagogical reform? While these "big three" factors are likely *necessary* for change to occur, it is far from clear that they are *sufficient* for it to happen. Focusing our efforts exclusively on training, time, and incentives ignores at least one additional and potentially key barrier to faculty change that is largely absent from change discussions: the role of a scientist's professional identity.

INTRODUCING THE CONCEPT OF A SCIENTIST'S PROFESSIONAL IDENTITY

The process by which we *become* scientists is often so long and arduous that few of us may have actually taken the time to reflect what constitutes our *professional identities as scientists*. In the midst of mastering laboratory techniques and crafting research grants, we are also learning, often subconsciously and implicitly, what professional norms we need to obey, or at least tolerate, to be perceived as successful academic scientists.

Identity is most often thought about in the social sciences in terms of personal identity or how a person thinks of himself or herself in the context of society. Based on the ideas of Mead (1934) and Erikson (1968), identity is not a stagnant property, but rather an entity that changes with time, often going through stages, and is continuously modified based on the surrounding environment. It has been described as "being recognized as a certain kind of person in a given context" (Gee, 2001, p. 99).

For the purposes of this article, we consider scientists' professional identities to be how they view themselves and their work in the context of their disciplines and how they accrue status among their professional colleagues as academic scientists. These aspects are heavily influenced by the training specific to academic scientists, including course work, laboratory experiences, and the everyday culture and rewards of the scientific profession. Peer acceptance, or more formally the process of peer review, is also closely tied to the development of a professional identity in the sciences. Both the publication of the research we accomplish and garnering the resources we need for experimental work, either at our institution or from national funding agencies, are generally dependent on positive peer review and a shared professional identity with these peers.

Thus, the development of a professional identity is not unlike the development of a personal identity but is situated in the context of a discipline and thus framed by the "rules of membership" of that discipline. If you are an academic scientist, then it is likely you were either explicitly told the rules of academic science, or you were able to somehow infer them and make choices to fit in or at least make others think that you fit in. Frustratingly, these rules of professional membership are not always obvious or intuitive, sometimes inadvertently keeping out those who are not afforded opportunities to learn the rules, expectations, and currencies of status within a particular discipline. This has been previously documented as a pivotal problem in the sciences, in particular in attracting and retaining women and people of color in the field (Carlone and Johnson, 2007; Johnson, 2007).

While a professional identity is by definition an internalized identity, it guides our external actions and decisions in our profession, including the decisions we make about how we teach. If a scientist has a professional identity that does not encompass teaching at all, or if a scientist has a professional identity he or she feels could be put at risk in his or her discipline and among his or her peers by embracing innovative approaches to teaching, then professional identity becomes a critical barrier in efforts to promote widespread change in undergraduate biology education.

WHAT ARE THE TENSION POINTS BETWEEN MAINTAINING ONE'S SCIENTIFIC PROFESSIONAL IDENTITY AND PARTICIPATING IN PEDAGOGICAL CHANGE?

Several lines of inquiry support why a scientist's professional identity might interfere with his or her willingness to participate in pedagogical change. We describe here three tension points that individual faculty may commonly encounter when deciding whether or not to participate in biology education change efforts: 1) training cultivates a primarily research identity and not a teaching identity, 2) scientists are afraid to "come out" as teachers, and 3) the professional culture of science considers teaching to be lower status than research and positions scientists to have to choose between research and teaching. Each of these tension points, along with research literature that explores its origins, is presented below.

TRAINING CULTIVATES PRIMARILY A RESEARCH IDENTITY AND NOT A TEACHING IDENTITY

The first tension point between professional identity and pedagogical change efforts is that scientists are trained in an atmosphere that defines their professional identities primarily as research identities to the exclusion of teaching identities. A scientist's professional identity is shaped by a number of factors, but this socialization into the discipline of science often begins in graduate school (Austin, 2002). For undergraduates who spend considerable time in research labs for summer research projects or honors theses, socialization may begin earlier. However, graduate school is when all future scientists formally enter a learning period about the scientific profession and the cultural norms of the profession, often leading aspiring young scientists to adopt the values, attitudes, and professional identities of the scientists who trained them. Graduate school is the shared playground, where scientists learn the culture and values of the field, as well as how to play the game of professional science.

Over the past 30 yr, doctoral and postdoctoral training at research institutions has put a tremendous emphasis on research, immersing students in the culture of research for a scientific discipline, while often ignoring teaching (Fairweather *et al.*, 1996; Boyer Commission on Educating Undergraduates in the Research University, 2002). While some time spent as a teaching assistant may be required, in general there is no requirement for evidence of developing competency in teaching. Consequently, it has been asserted that there is a profound disconnect between the training that students are receiving in doctoral programs and the careers that many of these students will ultimately enter (Tilghman, 1998; Golde and Dore, 2001; Austin, 2002; Dillenburg, 2005; Dillenburg and Connolly, 2005; Fuhrmann *et al.*, 2011). Faculty positions at most colleges and universities are primarily teaching positions, and even faculty positions at research institutions require some teaching, but the majority of graduate students in the sciences are only taught how to do research.

What support is given to those graduate students who are interested in developing teaching skills in graduate school? A growing number of institutions have graduate student and

faculty teacher-training programs (Rushin *et al.*, 1997; Austin *et al.*, 2008; Ebert-May *et al.*, 2011). However, despite recommendations for the implementation of pedagogy-focused training in graduate school, programs focused on innovative teaching strategies are often voluntary and serve only a small percentage of the overall population of graduate students. Currently, there are no federal mandates associated with training grants that would require pedagogical training for future scientists.

As a result, most graduate students still learn how to teach through an "apprenticeship of observation" (Lortie, 1975; Borg, 2004). They model their own teaching approaches after their professors. Students without explicit training tend to teach "naively" (Cross, 1990), often relying on inaccurate assumptions about teaching and learning. Most college classes in the sciences are taught in the traditional lecture format, so the majority of beginning science instructors equate teaching with lecturing, both linguistically and conceptually (Mazur, 2009). Without explicit training during graduate school, postdoctoral training experiences, or even early faculty years, these inaccurate assumptions about teaching appear to persist and become solidified. Additionally, even if a scientific trainee or early-career faculty member is interested in adopting pedagogical approaches different than the norm, there may be peer pressure from scientific colleagues to conform to traditional methods of teaching (Van Driel *et al.*, 1997; Gibbs and Coffey, 2004).

Not only is teaching not a formal or recommended component of postdoctoral training, some faculty advisors even view teaching as completely ancillary to, and a distraction from, the training that postdoctoral scholars need, ostensibly to become professors. The National Institutes of Health's Institutional Research and Academic Career Development Awards (NIH IRACDA) postdoctoral program is a notable exception to this. IRACDA postdoctoral fellows conduct research in basic science at R1 institutions and concurrently have formal, mentored teaching experiences at minority-serving institutions (IRACDA, 2012); however, IRACDA currently serves only a limited number of postdocs. Additionally, the FIRST IV program also seeks to provide postdoctoral fellows with training and mentored teaching experiences as they transition to faculty roles, but again, this is an option for a limited number of postdocs (FIRST IV, 2012). Both of these programs could serve as models for the more widespread integration of teaching and research into the scientific training and professional identity development of postdoctoral fellows. If scientists do not consider teaching part of their professional identities, then how can we expect them to change their own teaching and, even more importantly, support and encourage others to change as well?

SCIENTISTS ARE AFRAID TO "COME OUT" AS TEACHERS

A second tension point between maintaining one's professional identity and participating in pedagogical change is that embracing a teaching identity as part of one's scientific professional identity can be perceived as a liability and something to be hidden. Mark Connolly and colleagues have documented that some graduate students who are interested in teaching are afraid to "come out" as teachers (Connolly, 2010). They fear that they will be marginalized and discriminated against by their scientific peers and mentors. Some faculty advise graduate students to hide their interest in teaching; these mentors worry that the rest of academia will not take such students seriously as researchers (Connolly, 2010). There have been reports that some research professors, upon learning their graduate students are interested in teaching, no longer spend the same amount of time mentoring them. Significantly, some doctoral students have faculty advisors who do not allow them to engage in any activities outside laboratory work (Wulff *et al.*, 2004). Some advisors are of the mentality that graduate students should always be at the bench and that any time devoted to teaching negatively affects research, despite a recent study indicating that teaching while doing research might improve research skills (Feldon *et al.*, 2011). Unfortunately, this approach leaves students with both a skill set and perspective on science that is very narrowly focused. Postdoctoral scholars often face similar problems but often without the larger support structure that many graduate students have. Because postdocs tend to be fairly isolated in individual labs, they are even more dependent on their research mentors for guidance about career paths.

If graduate students and postdoctoral scholars fear the ramifications of admitting that teaching is part of their identity, an interest in teaching can be internalized as something illicit, to be kept hidden from peers and mentors. Even those who are interested in continuing in academia to become professors are encouraged to limit the amount of teaching they do. This implicit, if not explicit, research-centric norm of graduate school can result in a student's internal conflict between developing a professional identity as a research scientist and a desire to also develop part of a professional identity as a teacher. As students struggle to reconcile these aspirations, they can fall prey to believing that teaching is inherently inferior to research and that if they are to succeed in the academic world of science, they should focus exclusively on research. For a graduate student with a strong interest in teaching, this could even result in doubts about his or her ability as a scientist. In the process of embracing a teaching identity, budding scientists potentially risk their status as researchers, as well as their professional identities, status, and even membership within the scientific community.

THE PROFESSIONAL CULTURE OF SCIENCE CONSIDERS TEACHING TO BE LOWER STATUS THAN RESEARCH AND POSITIONS SCIENTISTS TO HAVE TO CHOOSE BETWEEN RESEARCH AND TEACHING

Finally, a third tension point between maintaining one's professional identity and participating in pedagogical change is that teaching is often regarded as lower status than research in the scientific disciplines (Beath *et al.*, 2012). A large part of this disparity in status originates from the culture of individual laboratories, departments, institutions, and even the discipline as a whole (Cox, 1995; Quinlan and Akerlind, 2000; Marbach-Ad *et al.*, 2007). However, it is also reinforced by the general salary and status structures with regard to teaching within our society, in which teaching is generally considered to be not as well compensated for or afforded as much respect as many other professions.

Faculty members who want to be perceived as successful and "real" scientists may have purposely avoided integrating

teaching into their professional identities, because they feel it could undermine their scientific status with their colleagues, their departments, and their institutions. These actions might even be subconscious, a natural result of years of being surrounded by other faculty who view research as superior to teaching and hearing the age-old adage "those who can, do; those who can't, teach." This contributes to a professional identity that deemphasizes teaching specifically to maintain high professional status, both within the confines of the institution and within the larger context of the discipline.

It is perhaps unsurprising then that the community of science itself does not generally assume that a research identity and a teaching identity can coexist within the same individual. Unfortunately, participation in teaching or research is often seen as a choice, as a set of alternatives rather than an integrated whole. A recent finding from the Longitudinal Study of STEM Scholars (Connolly, 2012) concluded that graduate students are interested in pursuing careers that involve teaching. However, when this finding was reported more widely, it was misinterpreted to mean that these students did not want to do research. Quite the contrary, these students were expressing an increased interest in teaching that was independent of their commitment to or interest in research (M. Connolly, personal communication).

Similarly, a recent publication in *PLoS One* also reinforced this tension point through a survey asking graduate students to rate the attractiveness of certain career paths and gave the choices of "a faculty career with an emphasis on teaching" and "a faculty career with an emphasis on research" with no option for "a faculty career that involves equal amounts of teaching and research," thereby, likely unknowingly, setting up the mutually exclusive choice between teaching and research (Sauermann and Roach, 2012). Many scientific trainees and current faculty may want careers that involve a balance of both, and the perception that they need to choose one or the other makes it even harder for them to adopt teaching identities without feeling they must sacrifice their research identities, which are likely their primary source of professional status. Unfortunately, in the professional culture of science, an emphasis on teaching in one's professional career can often be mischaracterized as a choice made because one either cannot do research or does not want to do research.

BRINGING PROFESSIONAL IDENTITY TO THE FOREFRONT OF CHANGE DISCUSSIONS: SHIFTING FROM AN INSTITUTIONAL DEFICIT MODEL TO A DISCIPLINE DEFICIT MODEL

Given the tension points described above, professional identity may not be just *one* additional barrier to faculty pedagogical change; it could be hypothesized to be a key *underlying reason* why change strategies addressing training, time, and incentives have to date had only limited success in engaging broad groups of faculty in widespread biology education reform. If biology faculty are potentially entrenched in a professional identity grounded in a research identity to the exclusion of a teaching identity, then it would behoove us, as a community, to consider the possibility that professional identity could undercut all our efforts centered on the "big three" change strategies. As a scientist grounded in a research identity, one may view pedagogical training with skepticism, considering it to be a waste of time and effort, in particular if the training tries to promote teaching methods that depart from the cultural teaching norm in science: lecturing. In addition, it follows that extra time might not be the answer to promoting faculty change, if tensions with professional identity are at play. If we have extra time in the day, we may more likely spend that time on research activities that raise our status with professional colleagues and are aligned with our professional identities. Finally, tensions between a professional scientific identity and teaching reform may, unfortunately, trivialize any teaching incentives that are developed. If scientists have professional identities that are predominantly research identities, then a *Nature* report or *Science* article will always be viewed as higher status than a departmental, university-wide, or even a national teaching award. Giving incentives for teaching will likely only have positive effects if we, as a scientific community, somehow begin to value those incentives to the same degree as research-based incentives.

A common approach when we think about the reasons why faculty might not change the way they teach is to raise questions about the culture of individual institutions. We assume that the department or institution does not offer training opportunities, release time to develop new courses, or incentives for teaching in scientific ways. This could be broadly classified as an "institutional deficit model," in which the institution lacks what is needed for reform. Certainly such problems can be inhibiting, and where they exist, institutional reform may be necessary to promote widespread involvement of faculty in pedagogical change. Many of the current pedagogical change strategies and frameworks operate within this model (Henderson *et al.*, 2010, 2011).

However, if we approach the issue of faculty change through the lens of professional identity, we will also want to consider a "discipline deficit model." Faculty are not only members of their campuses, but also of their national professional societies and the professional community of scholars working in their particular fields. Perhaps it is not only a matter of institutions needing to provide training, time, and incentives, but also a need for a disciplinary culture shift, such that there are both a sufficient level of status attached to teaching and a critical mass of individuals who have professional identities that include teaching. Some might argue that regardless of what institutions offer, most faculty will not change the way they teach, because they view teaching as accessory to their professional identities, derived not from their institutions, but rather from their disciplines, which are cross-institutional.

Finally, there is clearly a need for much more empirical research on all the potential barriers to faculty pedagogical change, but especially on the role of professional identity in determining whether a scientist chooses to participate in biology education reform efforts. Would efforts to broaden the professional identities of scientists to include teaching accelerate pedagogical change? To what extent do graduate or postdoctoral pedagogical training programs alter the professional identities of these early-career scientists? What are the long-term impacts of programs such as FIRST IV, NIH's IRACDA, or the HHMI/NAS Summer Institutes, in particular in terms of whether participants are more or less likely to engage in pedagogical reform compared with others? How would biologists—with a range of involvement in teaching

and biology education reform efforts—themselves describe their professional identities and how these identities shape their professional choices and aspirations?

LOOKING FORWARD: HOW COULD WE ALTER OUR PROFESSIONAL IDENTITIES TO BE MORE INCLUSIVE OF TEACHING?

To achieve widespread pedagogical change toward more iterative and evidence-based approaches, it appears that we need to find ways to challenge the assumption that a scientist's professional identity should be primarily research-focused and consider ways in which teaching could become more integrated into the fabric of the discipline. Three possible areas for action are explored below.

First, one place to start would be to broaden the goals and content of doctoral and postdoctoral training. Instead of having a handful of unstructured teaching requirements, students could be enrolled in training programs specifically designed to give them mentorship and support to teach in scientific ways. Specific faculty could be identified as teaching mentors for graduate students, who in turn could be given increased teaching opportunities and responsibilities as they progressed through the program. An important caveat is that these teaching mentors would themselves need to be properly trained in scientific teaching. In addition to excellence in research, excellence in teaching would also be an expected outcome of graduate education. One could envision a requirement in which dissertations included a chapter that provided evidence of scholarship and achievement in teaching. Those agencies and foundations that fund graduate education in the life sciences could take the lead in requiring such pedagogical training and deep experiences with teaching for the graduate students they support. By better integrating teaching within the current structure of scientific training, one could provide the next generation of scientists with a better foundation and skill set and also foster a teaching identity as part of their professional identities.

A second way to better align professional identity with the goals of widespread pedagogical change may be to target the place where many faculty derive and maintain their professional identities: scientific journals. Publication and peer review in these journals is an important aspect of professional identity. Some scientific journals are beginning to include education sections, but these are often commentary, rather than research articles. An exception to this is *Science* magazine, in which a number of education articles have appeared as research reports over the past few years. By including articles about scholarly teaching and education research, scientific journals can influence scientists to view scientific teaching as a part of their professional activities. Notably, a number of scholarly journals that maintain high standards of peer review and national/international distribution have been developed in recent years that provide biologists with a venue for publication of their pedagogical research. *CBE—Life Science Education*, supported by the American Society for Cell Biology and the HHMI, is a good example of growth in this area. There has been a recent push to integrate peer-reviewed education articles from journals such as *CBE-LSE* into the tables of contents of scientific journals of professional societies, to provide more faculty easier access to education articles most relevant to their fields. This may enable scientists to view education articles and often by association, teaching, as important characteristics of their professional identities.

Third, a key venue in which scientists construct and maintain their professional identities is at scientific professional meetings. These meetings were generally founded with a research focus, but many professional societies now have education sections within their annual meetings. Unfortunately, these are often not well integrated into the rest of the scientific meeting—sometimes entailing additional costs and being located in different venues and held on different days—reinforcing the concept that the education meeting is distinct from the research meeting. In addition, how are education research findings presented at these conferences? Ironically, the oral presentations are almost always presented as lectures, even when the topic of the talk is about how lecturing is not very effective! This illustrates how prevalent and influential the assumptions are about the expected norms of behavior and interaction at a scientific conference. Even biologists who have strong teaching identities and are well aware of more effective ways to present findings choose, for whatever reason (professional culture? professional identity?), not to employ evidence-based teaching and communication methods in the venue of a scientific conference. And while workshops and poster sessions would allow a higher level of interaction and dialogue—both generally more effective means of conveying information than oral presentations—these venues are often perceived as less important, lower status, and less stringent for high-quality data in the culture of scientific conferences.

IN CONCLUSION. . .

The challenge of addressing tensions between professional identity and pedagogical reform is a complicated issue. Importantly, we need to keep in mind that we as scientists ourselves are the ones responsible for the current state of our professional identities. We as academic scientists set up the tenure structure, publication requirements, and training requirements and dictate the group norms and expected modes of interaction in our own disciplines. We have created and contributed to a culture of science in which research generally has higher status than teaching. Some faculty continue to perpetuate the myth that a researcher should not want to teach and broadcast that value judgment to new graduate students, who are trying to forge their way as scientists. But we, as a professional community, also have the opportunity to take steps to broaden our professional identities and in doing so, address a potentially critical barrier in achieving widespread biology education reform.

REFERENCES

American Association for the Advancement of Science (2011). Vision and Change: A Call to Action, Final report, Washington, DC.

Anderson RD (2002). Reforming science teaching: what research says about inquiry. J Sci Teach Educ *1*, 1–12.

Anderson RD (2007). Inquiry as an organizing theme for science curricula. In: Handbook of Research on Science Education, ed. SK Abell and NG Lederman, Oxford: Taylor and Francis, 807–830.

Anderson WA *et al.* (2011). Changing the culture of science education at research universities. Science *331*, 152–153.

Austin A (2002). Preparing the next generation of faculty: graduate education as socialization to the academic career. J Higher Educ *73*, 94–122.

Austin AE, Connolly MR, Colbeck CL (2008). Strategies for preparing integrated faculty: the Center for the Integration of Research, Teaching, and Learning. New Dir Teach Learn *113*, 69–81.

Beath J, Poyago-Theotoky J, Ulph D (2012). University funding systems: impact on research and teaching. Economics *6*, 2012-2.

Borg M (2004). The apprenticeship of observation. English Lang Teach J *58*, 274–276.

Boyer Commission on Educating Undergraduates in the Research University (2002). Reinventing Undergraduate Education: Three Years after the Boyer Report, Stony Brook, NY: Stony Brook University.

Carlone HB, Johnson A (2007). Understanding the science experiences of successful women of color: science identity as an analytic lens. J Res Sci Teach *44*, 1187–1218.

Connolly M (2010). Helping future faculty come out as teachers. In: Essays on Teaching Excellence: Toward the Best in the Academy, vol. 22, Nederland, CO: Professional & Organizational Development Network in Higher Education. http://wvufaculty.wvu.edu/r/download/117872.

Connolly M (2012). Longitudinal Study of STEM Scholars. http://lsfss.wceruw.org/.

Cox MD (1995). A department-based approach to developing teaching portfolios: perspectives for faculty and department chairs. J Excellence Coll Teach *6*, 117–143.

Cross KP (1990). Teaching to improve learning. J Excellence Coll Teach *1*, 9–22.

Dillenburg P (2005). A Report on Attitudes and Aspirations Related to College Teaching Held by Postdoctoral Employees in STEM at University of Wisconsin–Madison, Madison, WI: Center for the Integration of Research, Teaching, and Learning.

Dillenburg P, Connolly M (2005). A Report on Attitudes and Aspirations Related to College Teaching Held by Doctoral Students in STEM at University of Wisconsin–Madison, Madison, WI: Center for the Integration of Research, Teaching, and Learning.

Ebert-May D, *et al.* (2011). What we say is not what we do: effective evaluation of faculty professional development programs. BioScience *61*, 550–558.

Erikson EH (1968). Identity: Youth and Crisis, New York: Norton.

Faculty Institutes for Reforming Science Teaching IV (2012). FIRST IV home page. www.msu.edu/∼first4/Index.html (accessed 1 September 2012).

Fairweather J, Colbeck C, Paulson K, Campbell C, Bjorklund S, Malewski E (1996). Engineering Coalition of Schools for Excellence and Leadership (ECSEL): Year 6, University Park, PA: Center for the Study of Higher Education, Penn State University.

Feldon DF, Peugh J, Timmerman BE, Maher MA, Hurst M, Strickland D, Gilmore JA, Stiegelmeyer C (2011). Graduate students' teaching experiences improve their methodological research skills. Science *333*, 1037–1039.

Frayer DA (1999). Creating a campus culture to support a teaching and learning revolution. Cause Effect *22*, 10–17, 50.

Fuhrmann CN, Halme DG, O'Sullivan PS, Lindstaedt B (2011). Improving graduate education to support a branching career pipeline: recommendations based on a survey of doctoral students in the basic biomedical sciences. CBE Life Sci Educ *10*, 239–249.

Gee JP (2001). Identity as an analytic lens for research in education. Rev Res Educ *25*, 99–125.

Gibbs G, Coffey M (2004). The impact of training of university teachers on their teaching skills, their approach to teaching and the approach to learning of their students. Active Learn Higher Educ *5*, 87–100.

Golde CM, Dore TM (2001). At Cross Purposes: What the Experiences of Doctoral Students Reveal about Doctoral Education, Philadelphia: Pew Charitable Trusts.

Handlesman J *et al.* (2004). Scientific teaching. Science *304*, 521–522.

Hannan A (2005). Innovating in higher education: contexts for change in learning technology. Br J Educ Technol *36*, 975–985.

Hanson S, Moser S (2003). Reflections on a discipline-wide project: developing active learning modules on the human dimensions of global change. J Geogr Higher Educ *27*, 17–38.

Hativa N (1995). The department-wide approach to improving faculty instruction in higher education: a qualitative evaluation. Res Higher Educ *36*, 377–413.

Henderson C, Beach A, Finkelstein N (2011). Facilitating change in undergraduate STEM instructional practices: an analytic review of the literature. J Res Sci Teach *48*, 952–984.

Henderson C, Finkelstein N, Beach A (2010). Beyond dissemination in college science teaching: an introduction to four core change strategies. J Coll Sci Teach *39*, 18–25.

Howland J, Wedman J (2004). A process model for faculty development: individualizing technology learning. J Technol Teach Educ *12*, 239–262.

Institutional Research and Academic Career Development Awards (2012). IRACDA home page. www.nigms.nih.gov/Training/CareerDev/TWDInstRes.htm (accessed 15 October 2012).

Johnson A (2007). Unintended consequences: how science professors discourage women of color. Science Educ *91*, 805–821.

Kember D, McKay J (1996). Action research into the quality of student learning—a paradigm for faculty development. J Higher Educ *67*, 528–554.

Kloser MJ, Brownell SE, Chiariello NR, Fukami T (2011). Integrating teaching and research in undergraduate biology laboratory education. PloS Biol *9*, e1001174.

Krockover GH, Shepardson DP, Eichinger D, Nakhleh M, Adams PE (2002). Reforming and assessing undergraduate science instruction using collaborative action-based research teams. School Sci Math *102*, 266–284.

Lortie D (1975). Schoolteacher: A Sociological Study, Chicago: University of Chicago Press.

Luft JA, Kurdziel JP, Roehrig GH, Turner J (2004). Growing a garden without water: graduate teaching assistants in introductory science laboratories at a doctoral/research university. J Res Sci Teach *41*, 211–233.

Malicky DM, Lord SM, Huang MZ (2007). A design methodology for choosing an optimal pedagogy: the pedagogy decision matrix. Int J Eng Educ *23*, 325–337.

Marbach-Ad G *et al.* (2007). A faculty team works to create content linkages among various courses to increase meaningful learning of targeted concepts of microbiology. CBE Life Sci Educ *6*, 155–162.

Mazur E (2009). Farewell, lecture. Science *323*, 50–51.

Mead GH (1934). Mind, Self and Society, Chicago: University of Chicago Press.

Miller JW, Martineau LP, Clark RC (2000). Technology infusion and higher education: changing teaching and learning. Innov Higher Educ *24*, 227–241.

National Academies of Science/Howard Hughes Medical Institute (2012). National Academies Summer Institutes on Undergraduate Education. www.academiessummerinstitute.org (accessed 1 September 2012).

Porter AL, Roessner JD, Oliver S, Johnson D (2006). A systems model of innovation processes in university STEM education. J Eng Educ *95*, 13–24.

Pundak D, Rozner S (2008). Empowering engineering college staff to adopt active learning methods. J Science Education and Technol *17*, 152–163.

Quinlan KM, Akerlind GS (2000). Factors affecting departmental peer collaboration for faculty development: two cases in context. Higher Education *40*, 13–24.

Romano JL, Hoesing R, O'Donovan K, Weinsheimer J (2004). Faculty at mid-career: a program to enhance teaching and learning. Innov Higher Educ *29*, 21–48.

Rushin JW *et al.* (1997). Graduate teaching assistant training: a basis for improvement of college biology teaching and faculty development? Am Biol Teach *59*, 86–90.

Sauermann H, Roach M (2012). Science PhD career preferences: levels, changes, and advisor encouragement. PLoS One *7*, e36307.

Schneider R, Pickett M (2006). Bridging engineering and science teaching: a collaborative effort to design instruction for college students. School Sci Math *106*, 259.

Stevenson CB, Duran RL, Barrett KA, Colarulli GC (2005). Fostering faculty collaboration in learning communities: a developmental approach. Innov Higher Educ *30*, 23–36.

Tagg J (2012). Why does the faculty resist change? Change *44*, 6–15.

Tilghman S (1998). Trends in the Early Careers of Life Scientists, Report by the Committee on Dimensions, Causes, and Implications of Recent Trends in the Careers of Life Scientists, National Research Council, Washington, DC: National Academies Press.

Van Driel JH, Verloop N, van Werven HI, Dekkers H (1997). Teachers' craft knowledge and curriculum innovation in higher engineering education. Higher Educ *34*, 105–122.

Walczyk JJ, Ramsey LL (2003). Use of learner-centered instruction in college science and mathematics classrooms. J Res Science Teach *40*, 566–584.

Weiss TH, Feldman A, Pedevillano DE, Copobianco B (2004). The implications of culture and identity: a professor's engagement with a reform collaborative. Int J Sci Math Educ *1*, 333–356.

Wilson R (2010). Why teaching is not priority no. 1. Chronicle of Higher Education, September 5, 2010.

Winter D, Lemons P, Bookman J, Hoese W (2001). Novice instructors and student-centered instruction: identifying and addressing obstacles to learning in the college science laboratory. J Scholarship Teach Learn *2*, 15–42.

Wulff DH, Austin AE, Nyquist JD, Sprague J (2004). The development of graduate students as teaching scholars: a four-year longitudinal study. In: Paths to the Professoriate: Strategies for Enriching the Preparation of Future Faculty, ed. DH Wulff and AE Austin, San Francisco: Jossey-Bass, 46–73.

Yarnall L, Toyama Y, Gong B, Ayers C, Ostrander J (2007). Adapting scenario-based curriculum materials to community college technical courses. Commun Coll J Res Pract *31*, 583–601.