CBE—Life Sciences Education
Vol. 5, 1–6, Spring 2006

Feature

Approaches to Biology Teaching and Learning: On Integrating Pedagogical Training into the Graduate Experiences of Future Science Faculty

Kimberly Tanner* and Deborah Allen†

*San Francisco State University, San Francisco, CA 94132; and †Department of Biological Sciences, University of Delaware, Newark, DE 19716

UNDERGRADUATE SCIENCE TEACHING—THE GREAT UNTRAINED PROFESSION

"Good luck on your first day as an assistant professor, Dr. Tanner! Have a great class!" On the wall above my desk, these words scream out from an otherwise encouraging note that is adorned with many exclamation points. This note has hung on my wall since my very first day as an Assistant Professor of Biology. As I was charging off to teach my first class, a senior faculty member who had been on my hiring committee slipped this note under my office door. In moments of pause years later, I still stare up at that note and breathe a sigh of relief that I had much more than luck to guide me on my first day as a college-level teacher. Although I continue to have much to learn—as all of us do no matter the number of years of teaching experience—I did arrive at the university with both formal and informal training in science education. I had had plenty of exposure to innovative pedagogical approaches, questioning strategies, and techniques for engaging diverse audiences in learning science. As a scientist educator, I had had the privilege of many years of collaboration with outstanding K–12 educators as well as a postdoctoral fellowship in science education. However, my training has been, to say the least, unconventional compared with that of my fellow junior faculty and unique in its preparation in regard to the teaching and learning of my discipline.

It will not be news to anyone reading this article that university and college teaching is to a large extent a profession with no formal training. It's startling but true that the majority of faculty members—and lecturers who often teach large numbers of students—have no formal training in the teaching and learning of their discipline. In fact, the hiring process in university science departments is structured primarily to evaluate a faculty candidate's ability to be a productive researcher, with success measured in number of publications and magnitude of grant funds raised. Depending on the type of institution, for example, research university, state-level university, or liberal arts college, there may be a component of the faculty interview process that probes a candidate's teaching ability, for example, requesting a statement of teaching philosophy and requiring the candidate to teach a sample lecture class. However, this sample lecture often screens for gross inadequacies, rather than looking for stellar innovations or pedagogical skills.

This lack of formal, accredited training for university and college instructors stands in stark contrast to the requirements for a high school teacher who is charged with the education of students only a year junior to college freshmen. High school teachers in the United States must be credentialed as a secondary science teacher, demonstrate subject matter competency in every subject that they will be teaching, and must continually engage in professional development in the teaching and learning of their discipline throughout their career as a science teacher. With the 2002 federal No Child Left Behind legislation, the onus is upon each precollege science teacher to become "highly qualified" in terms of formal university-level training in science education.

However, no such required professional training or measurable standards for teaching are required in institutions of higher education. Many policy documents have suggested standards of teaching practice in postsecondary science education (National Research Council, 1996, 1997; Siebert and McIntosh, 2001), but the extent of implementation of these ideals is unclear and has gone relatively unstudied, although national and regional accreditation boards do look at outcomes, asking colleges and universities to assess what their students have gained from four years of study at their institutions. Nonetheless, there is a striking reversal of accountability that happens when one crosses the precollege teaching to college-level teaching boundary (Table 1). During the K–12 school years, society expects K–12 teachers to be responsible for student learning. Salaries of teachers in many states are tied to student test scores, and poor student performance can potentially invoke penalties. At a college or university, several variables in the educational universe shift. Students are the ones responsible for learning. The evaluation and compensation of college-level teachers is not

DOI: 10.1187/cbe.05–12–0132
Address correspondence to: Kimberly Tanner (kdtanner@sfsu.edu).

Table 1. Differing emphases in the training and accountability of K–12 and undergraduate science teachers

Differing emphases	
K–12/precollege	Undergraduate/postsecondary
Teacher responsible for student learning	Students responsible for their own learning
Poor student performance tied to teacher quality	Poor student performance tied to poor student motivation, preparation, and quality
Professional reputation and rewards tied to student achievement	Professional reputation and rewards tied to research publications and grant funding
Mandated training and professional development requirements at local, state, and national levels	No mandated training and professional development requirements at local, state, and national levels

tied to student performance, and poor student performance is blamed on students being unmotivated, lazy, or poorly prepared by those science teachers in the precollege arena. This difference no doubt has its roots in the past, when K–12 education was compulsory, but college/university attendance only optional and assumed to be market driven. Students would attend an institution of higher learning only if they felt that such attendance was of value to them, and they could judge the product and value for themselves. But times have changed; as our economy becomes more knowledge driven, there is an overflow of students at the doors of colleges and universities seeking a coveted and much needed college degree for advancement in the world. The need to provide a much larger percentage of the population with higher education has put a further strain on the system, leaving college-bound students with fewer options. Under these circumstances, the contrast between historically compulsory K–12 education and now necessary higher education begins to dim. Universities and colleges thus have a special obligation to provide the best possible learning environment for all students, even in the face of limited resources, particularly at underfunded state institutions. That said, real progress might be made in the teaching of the sciences by integrating pedagogical training into the graduate experiences of future science faculty. By providing our budding Ph.D.s, our future faculty, with meaningful exposure to "best practices" in a variety of teaching settings, we could begin to articulate the science education pathway for students, K–16, and transform college and university-level teaching into a significantly better trained profession.

THE LIMITATIONS OF TRADITIONAL GRADUATE TEACHING ASSISTANTSHIPS

Participation in the teaching enterprise is to a certain extent already part of the fabric of the science graduate school experience. Indeed, the majority of scientific trainees are used at some point in their graduate career as a graduate teaching assistant (Golde and Dore, 2001). A recent cross-disciplinary survey of doctoral students revealed that graduate students in the sciences, more than in any other discipline, are required to participate in a teaching assistantship as part of their graduate degree. In fact, more than 70% of molecular biology graduate students are required to serve in these positions during their graduate career (Golde and Dore, 2001). However, as stated in this survey report (entitled *At Cross Purposes: What the Experiences of Doctoral Students Reveal about Doctoral Education*), the authors find that "... a program's requirement that its students serve as teaching assistants may be the result of educational concerns and a genuine desire to help students learn how to construct a course, deliver lectures, grade work, and help undergraduates learn. However, teaching assistantships are also a mechanism for financial aid and create a labor pool of junior instructors" (Golde and Dore, 2001).

Depending on the level of funding available to support graduate training, individual students may teach only minimally for one semester—as is common in graduate programs at medical schools without undergraduate populations—or more commonly, may be engaged throughout their scientific training in continuous employment as a teaching assistant as the primary source of their livelihood.

However, experiencing teaching as a graduate teaching assistant is not in and of itself equivalent to the integration of pedagogical development into graduate study. Many teaching assistantships are "sink-or-swim" experiences for graduate students, with little or no formal training in science education, no theoretical grounding in general teaching methods, and often no training in discipline-specific classroom strategies. Teaching assistantships have traditionally been trial-and-error opportunities to teach. Even the most dedicated student would be hard pressed to learn about the intricacies and research base of science-specific pedagogy in an unsupported teaching assistantship.

BEYOND THE TRADITIONAL GRADUATE TEACHING ASSISTANTSHIP: ALTERNATIVE APPROACHES TO INTEGRATING PEDAGOGICAL DEVELOPMENT INTO GRADUATE TRAINING

Encouragingly, more than 80% of graduate students pursuing their doctoral degree were interested in seeking a faculty position because of their interests in and often passion for teaching (Golde and Dore, 2001). Given this strong interest among doctoral students, the need to train future science faculty in the art of teaching and, most importantly, the critical need to reform undergraduate science education, it would seem that integration of pedagogical development into the graduate science training experience would be beneficial on multiple fronts. There has already been a recognition of the need to better prepare graduate teaching assistants, and a variety of strategies have been proposed and tried across many disciplines to provide support for these faculty-in-training as they participate in educating undergraduate students (Barrus *et al.*, 1974; Clark and McLean, 1979; Travers, 1989; Lawrence *et al.*, 1992; Druger, 1997; Bartlett, 2003). Here, we consider some alternative approaches to integrating pedagogical development into the training of future scientists as well as progressive steps toward improving the traditional teaching assistantship.

The Preparing Future Faculty Initiative

Founded in 1993, the Preparing Future Faculty (PFF) initiative has aspired to develop programs that explicitly train future faculty in the arenas of teaching, research, and service (PFF, 2005). Supported by the Pew Charitable Trust, the National Science Foundation (NSF), and private donations, the PFF Initiative recognizes that "... there is a mismatch between doctoral education and the needs of colleges and universities that employ new Ph.D.s. The traditional Ph.D. is a research degree, preparing, for example, historians, chemists, and sociologists. The degree does not prepare these highly skilled research professionals to be faculty members."

Over the last decade, PFF has engaged more than 295 institutions in developing programs for graduate students to enhance their professional preparation and better equip the future professoriate with the skills to excel in teaching at the undergraduate level. Most PFF sites offer opportunities for graduate students to attend workshops on pedagogical techniques, to experience undergraduate teaching in conjunction with a mentor, and to receive feedback on their individual teaching. For some colleges and universities, the initiation of a PFF program, even in the absence of significant funding, has nucleated a structured forum for graduate students to receive encouragement and assistance in developing teaching skills. PFF is not solely focused on issues of teaching but is more broadly engaged in the development of professional skills across the domains of teaching, research, and service. Unfortunately, the extent of PFF across the country is still limited, because it requires that an institution or department pursue the development of such a program, and for whatever reasons, there are relatively few biology-focused PFF programs. Nonetheless, PFF programs have very significantly "legitimized conversations about teaching" (Deneef, 2002), and there are many examples of enduring PFF programs that can serve as models for other institutions (PFF, 2005). Most successful PFF programs run across multiple disciplines within a college or university. For example, Duke University participated in the 1998–2000 phase 3 of the national PFF program, which focused on developing PFF programs in the math and sciences. As a result, Duke University now in 2005 has a PFF program across its multidisciplinary graduate school (http://www.gradschool.duke.edu/professional_development/preparing_future_faculty/). The Duke program accepts more than 30 PFF graduate students into the formal program each year, and more than one-half of these students are based in science and math departments. In addition, Duke University also offers a Teaching Certificate in Biology, which is more focused on discipline-specific issues (http://www.biology.duke.edu/teachcert/). Graduate students in biology are encouraged to take advantage of both opportunities. Another more recent example of a PFF program is one founded in 2004 by a group of graduate students and postdoctoral fellows at the University of California, San Francisco (UCSF) interested in increasing their opportunities for training in teaching (http://www.ucsf.edu/pff/). This program is focused on the development of future biomedical and health scientists. Given the focused biomedical nature of the institution itself, this UCSF PFF program is rooted firmly in the issues of science and more specifically future biology faculty. For those interested in learning more about initiating a PFF program at their own institution, the national organization has an online publication, *Preparing Future Faculty in the Sciences and Mathematics: A Guide for Change* (http://www.preparing-faculty.org/PFFWeb.PFF3Manual.htm; Pruitt-Logan *et al.*, 2002).

The NSF GK–12 Fellowship Program: Developing Pedagogical Skills in the K–12 Arena

Another innovative approach to integrating pedagogical training into the graduate experience does so in the context of K–12 science classrooms. Founded in 1999 by then NSF Director Rita Colwell, the NSF GK–12 Graduate Teaching Fellows Program offers graduate student scientists the opportunity to develop and hone their teaching skills while simultaneously partnering 10–15 hours per week in K–12 classrooms with teachers and students in their communities. Fundamentally structured as a training grant, GK–12 grants are awarded not to individual graduate students but to discipline-based university faculty. NSF GK–12 grants require collaboration among members of an institution's science departments and education departments and explicitly require the institution to develop pedagogy training courses to prepare participating graduate students for their teaching experiences (Figure 1).

Although the impact of this relatively new program on participating graduate student scientists remains to be seen, more than 100 institutions across the country are engaging graduate students in this formal approach to gaining experience in teaching. Many research studies on the impact of using a K–12 partnership experience to train science graduate students to teach are under way across the country, and the American Institutes for Research has been conducting a formal, nationwide evaluation of the program. Although these studies are still unpublished, there is informal evidence on lessons learned about key elements of the GK–12 programs. First, the majority of GK–12 programs begin with a moderate-to-intensive preparatory experience for graduate students (NSF GK–12 Directors' Conference, personal communications). Often this preparation takes place in the summer, occurs with K–12 teachers present and sometimes in instructional roles, and serves as a crash course for graduate student scientists in science education topics such as standards, curricular materials, inquiry-based and active-learning pedagogical techniques, and issues of equity and diversity in education. Another key element found in many GK–12 training programs is a close partnership or mentorship with a practicing K–12 teacher. Successful GK–12 scientist–K–12 teacher partnerships are informally identified as the core of successful projects (NSF, 2005). Not entirely unlike a student teaching experience for future teachers, these partnership experiences for science graduate students afford them opportunities to put theory into practice, to observe a trained science educator in action, and to develop a philosophy of science teaching of their own. Finally, as mandated by the NSF, each GK–12 program must develop course work in science education pedagogy for the participating graduate students to take simultaneously with their field experiences in K–12 classrooms (NSF, 2005). These courses are to be codeveloped by faculty from both science disciplines and the College of Education. This requirement has the added value of providing an incentive for faculty from these often-isolated arenas to collaborate. Although these graduate courses in science education vary widely among programs, they provide the conceptual and scholarly grounding in science teaching that many traditional teaching assistantships and training programs lack.

The GK–12 programs across the country vary greatly in their structure (e.g., one graduate student–one teacher partnership or multiple graduate students partnering with a school faculty), focus (e.g., ocean science, elementary science, or high school biology), and history of duration. As an example, the Vanderbilt-Meharry-Tennessee State University GK–12 program (founded in 1999) has partnered specifically with middle school teachers in the local Nashville schools (http://www.vanderbilt.edu/GTF/desc.php) and has pioneered an intensive multiweek summer institute to prepare graduate students for science teaching and partnerships with teachers in K–12 classrooms. *Access Science*, the GK–12 effort at the University of Pennsylvania, partners both undergraduates and graduate students with K–12 teachers and students in local Philadelphia public schools and has pioneered a community-service learning course work approach to sustaining the GK–12 efforts for years to come (http://www.upenn.edu/ccp/programs/Access-Science/about_us.shtml). To explore the entire variety of programs across the country, one can peruse the NSF abstracts of 114 awards (NSF, 2005). Because the first GK–12 grants were awarded in 1999, the most experienced programs are in their sixth year, and many of these programs are creatively addressing the NSF's charge to institutionalize these pedagogical training experiences for graduate students. Of great interest will be the extent to which the teaching techniques that graduate students learn in the K–12 sector through their GK–12 experiences can and will transfer to their teaching at the undergraduate level as future faculty. This question will no doubt be the subject of many research efforts in science education.

Figure 1. San Francisco State University biology graduate student teaches a life science lesson to San Francisco middle school students as part of a GK–12 partnership program.

Using Graduate Student Teachers within Large-Enrollment Courses

An alternative approach to integrating pedagogical training into the graduate experience can be the use of graduate students as "peer coaches" or "small group monitors" in the context of large-enrollment courses. This approach has been successfully used in engaging undergraduates in supporting faculty using active-learning techniques, such as problem-based learning, in large-enrollment courses (Allen and White, 1999; Platt *et al.*, 2003). Using graduate students as well as undergraduates as part of such an approach could avoid the common isolation of graduate teaching assistants alone in a laboratory section. One structure would be to convene a team of graduate student coinstructors who work closely with an experienced faculty member. This approach would seem to be mutually beneficial, supporting a faculty member in attempting more innovative pedagogical approaches, while offering the graduate student a mini-course in teaching through weekly planning sessions and actual implementation in the classroom with a teaching team. The major impediment to this approach becoming more widespread is the requirement that an already innovative faculty member be willing to adapt their teaching to include training of peer coaches. On the positive side, this approach can address the continued problem of the large-enrollment university classroom, increase the number of teaching assistantships in lecture courses, and engage trainees in techniques of active learning in what is otherwise a traditionally passive lecture class.

Teaching Workshops and Orientations for Graduate Student Teaching Assistants

Increasingly, college and universities are offering at least some preparation and training for graduate teaching assistants, recognizing that the lack of training has a significant potential negative effect on undergraduate teaching and learning (Bartlett, 2003). The profile of training varies widely. University teaching assistant training can be as minimal as a half-day workshop that is offered across disciplines as disparate as English and chemistry (Rushin *et al.*, 1997). These workshops tend to emphasize general university policies on topics such as plagiarism and sexual harassment and as such contribute minimally, if at all, to the pedagogical development of graduate students (Carroll, 1980; Rushin *et al.*, 1997). Some universities go further in offering single or multiple-department workshops that can range from a half-day to a week. However, there often is little if any follow-up on these initial training experiences, and graduate students generally express dissatisfaction with the adequacy of these types of workshops in preparing them for teaching (Rushin *et al.*, 1997).

In an effort to extend pedagogical training for graduate students, some departments have developed an accompanying course taken by teaching assistants, in which they meet weekly as a group, often with a faculty or laboratory coordinator (Roehrig *et al.*, 2003; Luft *et al.*, 2004). In these examples of an accompanying pedagogy course, the content addressed is common among all of the teaching assistants participating, and thus the workshop affords the opportunity to discuss discipline-specific pedagogical issues. For example, common student misconceptions might be addressed; this can have a transformative effect on graduate student conceptions of teaching (Hammrich, 1996). In this course context, graduate students can also discuss upcoming laboratory exercises and related teaching strategies and in some cases engage in peer observation and feedback with fellow graduate student teachers (Roehrig *et al.*, 2003). In addition to peer observation and feedback, videotaping of teaching assistants with subsequent feedback by a teaching mentor has been shown to have a positive influence on the subsequent effectiveness of teaching assistants in undergraduate classrooms (Dalgaard, 1982).

Although the increased offering of teaching workshops, orientations, and support courses for teaching assistants is a substantial improvement, it is only the beginning. For future faculty to be adequately trained in teaching and prepared to implement modern, inquiry-based approaches to science learning, we need to begin to integrate pedagogical training into the training of future scientists as a regular practice. As such, this aspect of professional preparation needs to become part of the graduate curriculum. This will provide opportunities for scientists to go beyond learning a few general teaching strategies to begin to understand the challenges and strategies specific to their own discipline (Hammrich, 1996). Most likely, the integration of such coursework into graduate training will be best accomplished by collaboration across disciplinary and structural divides, including faculty from Colleges of Science, skilled K–12 teachers, and science educators from Colleges of Education.

Training Science Faculty to Teach—Implications for K–12 Science Education

Because teacher quality—at all levels of the educational system—is a key predictor of student success (Darling-Hammond and Barnett, 1998), the teaching abilities of science faculty in undergraduate classrooms are absolutely critical. To continue to engage young people in the excitement of science and engender in them a desire to pursue science as a career has a direct impact on the community of science itself. Yet, research shows that poor teaching abilities in college and university faculty are turning students away from science who would otherwise be assets to the scientific research enterprise (Tobias, 1990; Seymour and Hewitt, 1997; Tanner and Allen, 2004). In addition, a second influence of science faculty derives from the fact that they play an integral role in the preparation of future middle and high school science teachers enrolled at their institution. If one subscribes to the adage that "one teaches the way one was taught," then effective pedagogy becomes doubly important for this student group. In fact, evidence from a recent study on this topic suggests that high school biology teachers who have experienced reformed undergraduate courses that use more inquiry-based teaching techniques are more likely than a comparison set of teachers to 1) exhibit these pedagogical styles in their high school classrooms and 2) have students that show significantly higher levels of achievement on measures of scientific reasoning and biological concept knowledge (Adamson *et al.*, 2003).

Building a Research Literature on the Effective Pedagogical Training of Future Biology Faculty

There have been a variety of research studies over the last three decades into the training of graduate students across all university disciplines in teaching, but the research literature specifically addressing the integration of professional development in teaching for future scientists is minimal. Recent articles in the fields of geoscience and chemistry have called for more research into the effectiveness of graduate teaching assistant training programs and an analysis of discipline-specific programs to promote the pedagogical development of young scientists (Roehrig *et al.*, 2003; Luft *et al.*, 2004). Clearly, more extensive research on the effectiveness of different approaches to training science graduate students in the teaching of their disciplines is needed, especially in the area of life science education, if we are to generate both a definition of what it means to be a well-trained university science teacher and a menu of effective strategies for integrating this into the graduate experiences of future science faculty.

Have you pioneered a supporting pedagogical course for your graduate teaching assistants? How have you assessed the effectiveness of your efforts? What evidence do you have that your approaches influence the teaching skills and pedagogical stance of scientists-in-training? To what extent have individual programs developed under the umbrella of PFF or the NSF GK–12 Fellowships been successful in crafting transformative training experiences for graduate students in science teaching? *CBE–Life Sciences Education* welcomes manuscripts from faculty in the life sciences who are pioneering innovative approaches to integrating pedagogical instruction into graduate training. The quality of undergraduate science education for both future scientists and future science teachers will depend on how successful we are at developing an effective training paradigm for our great untrained profession of university science teaching.

REFERENCES

Adamson, S. L., Banks, D., Burtch, M., Cox, F., Judson, E., Turley, J., Benford, R., and Lawson, A. (2003). Reformed undergraduate instruction and its subsequent impact on secondary school practice and student achievement. J. Res. Sci. Teach. *40*, 939–957.

Allen, D. E., and White, H. B. (1999). A few steps ahead on the same path. J. Coll. Sci. Teach. *28*, 299–302.

Barrus, J. L., Armstrong, T. R., Renfrew, M. M., and Garrard, V. G. (1974). Preparing teaching assistants. J. Coll. Sci. Teach. *3*, 350–352.

Bartlett, T. (2003). The first thing about teaching. Chron. High. Educ. *50*, A10–A11.

Carroll, J. G. (1980). Effects of training programs for university teaching assistants: a review of empirical research. J. High. Educ. *51*, 167–183.

Clark, D. J., and McLean, K. (1979). Teacher training for teaching assistants. Am. Biol. Teach. *41*, 140–144.

Dalgaard, K. A. (1982). Some effects of training on teaching effectiveness of un-trained university teaching assistants. Res. High. Educ. *13*, 321–341.

Darling-Hammond, L., and Barnett, B. (1998). Investing in teaching. Educ. Week, May 27.

DeNeef, L. (2002). The Preparing Future Faculty Program: What Difference Does it Make? http://aacu-edu.org/pff/PFFpublications/what_difference/index.cfm. (accessed 19 January 2006).

Druger, M. (1997). Preparing the next generation of college science teachers. J. Coll. Sci. Teach. *26*, 424–427.

Golde, C. M., and Dore, T. M. (2001). At cross purposes: what the experiences of doctoral students reveal about doctoral education, Philadelphia, PA: Pew Charitable Trusts. www.phd-survey.org (accessed 19 January 2006).

Hammrich, P. L. (1996). The impact of teaching assistants' conceptions on college science teaching. J. Grad. Teach. Assist. Dev. *3*, 109–117.

Lawrence, F., Heller, P., Keith, R., and Heller, K. (1992). Training the teaching assistant. J. Coll. Sci. Teach. *22*, 106–109.

Luft, J. A., Kurdziel, J. P., Roehrig, G. H., and Turner, J. (2004). Growing a garden without water: graduate teaching assistants in introductory laboratories at a doctoral/research university. J. Res. Sci. Teach. *41*, 211–233.

National Research Council (1996). National Science Education Standards, Washington, DC: National Academy Press. http://www.nap.edu/books/0309053269/html/ (accessed 19 January 2006).

National Research Council, Committee on Undergraduate Science Education (1997). Science Teaching Reconsidered: A Handbook, Washington, DC: National Academy Press.

National Science Foundation (2005). GK–12 Fellowship Program. http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5472 (accessed 19 January 2006).

Platt, T., Barber, E., Yoshinaka, A., and Roth, V. (2003). An innovative selection and training program for problem-based learning (PBL) workshop leaders in biochemistry. Biochem. Mol. Biol. Educ. *31*, 132–136.

Preparing Future Faculty (2005). PFF Web. http://www.preparing-faculty.org/ (accessed 19 January 2006).

Pruitt-Logan, A., Gaff, J. G., and Jentoft, J. E. (2002). Preparing Future Faculty in the Sciences and Mathematics: A Guide for Change. Washington, DC: Association of American Colleges and Universities.

Roehrig, G. H., Luft, J. A., Kurdziel, J., and Turner, J. (2003). Graduate teaching assistants and inquiry-based instruction: implications for graduate teaching assistant training. J. Chem. Educ. *80*, 1206–1210.

Rushin, J. W., De Saix, J., Lumsden, A., Streubel, D. P., Summers, G., and Berson, C. (1997). Graduate teaching assistant training: a basis for improvement of college biology teaching and faculty development? Am. Biol. Teach. *59*, 86–90.

Seymour, E., and Hewitt, N. M. (1997). Talking about Leaving: Why Undergraduates Leave the Sciences, Boulder, CO: Westview Press.

Siebert, E. D., and McIntosh, W. J. (2001). College pathways to the science education standards, Arlington, VA: NSTA Press.

Tanner, K., and Allen, D. (2004). Learning styles and the problem of instructional selection—engaging all students in science courses. Cell Biol. Educ. *3*, 197–201.

Tobias, S. (1990). They're Not Dumb, They're Different: Stalking the Second Tier, Tucson, AZ, Research Corporation.

Travers, P. L. (1989). Better training for teaching assistants. Coll. Teach. *37*, 147–149.