Transforming Graduate Training in STEM Education

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Introduction

The need for improved instruction in college science, technology, engineering, and math (STEM) courses is a prominent national policy issue (Brewer and Smith 2011, Olson and Riordan 2012). To address this need, instruction in many college STEM courses is being revolutionized through the adoption of student-centered evidence-based teaching practices. There is a growing body of literature on how to employ these techniques and on the benefits of using empirically validated teaching practices in college classrooms (Handelsman et al. 2004, Allen and Tanner 2005, Haak 2011). The majority of efforts in STEM education transformation are directed at faculty, while graduate student training in these practices has not kept pace. Pre-service faculty (i.e. graduate students) should receive training in pedagogy from the beginning of their education (Bouwma-Gearhart et al. 2007), just as K–12 science teachers receive professional development in both the pre-service and in-service stages of their careers. Offering graduate students more training in pedagogy and meaningful opportunities for practice throughout their graduate careers will benefit not only graduate students as they enter the workforce, but also the undergraduates and faculty at their institutions.

STEM graduate students both want and need formal training and experience in education (Nyquist 1991). Despite the perception that STEM graduate students are primarily research-motivated, they are more likely than their peers in other disciplines to express an interest in teaching, but are less likely to be given increasing responsibility and freedom in the classroom as their graduate careers progress (Nyquist 1991, Golde and Dore 2001). Although a portion of curriculum design often falls to graduate student teaching assistants (TAs) under current models, these opportunities could be more effective and meaningful with additional training, support, and mentorship in pedagogical best practices. Indeed, current training in pedagogy for TAs is often limited to seminars and workshops without opportunities for practice (Nyquist 1991, Luft et al. 2004). There have been a few notable national efforts to improve graduate training in teaching, such as the Preparing Future Faculty program and the now-defunded NSF GK–12 program. While these programs have made some progress in increasing opportunities for pedagogical training, they were not specifically designed to transform college level STEM instruction and they impact only a limited number of graduate students (DeNeef 2002, Trautmann and Krasny 2006).
The consequences of a lack of pedagogical training are well documented: graduate students and new faculty frequently report being unprepared for the responsibilities of teaching in tenure-track positions (Nyquist et al. 1999, Golde and Dore 2001, Austin 2002). At the same time, teaching experience is rapidly becoming a decisive factor in faculty job searches of all levels (Meizlish and Kaplan 2008), and an increasing number of doctoral students in the sciences are pursuing non-tenure track careers (Snyder and Dillow 2013), all of whom would be served by more structured training and practice in pedagogy. Below we describe the benefits of increasing graduate student access to pedagogy training, the current barriers to graduate students taking leadership roles in the classroom, and the mechanisms to overcome existing barriers to providing graduate students training and experience in college level education as part of broader STEM education reform. Finally, we propose a model for pedagogical training in which mentorship and support for teaching begin early in a graduate career and students gain progressive responsibility for course design and teaching throughout their training (Fig. 1).

Benefits of increasing training

Training and practice in modern teaching techniques can benefit graduate students in their graduate and post-graduate careers in several tangible ways. First, graduate students will be better prepared for the demands placed on them as faculty and educators in STEM disciplines (Boice 1991, Adams 2002). Second, the skills students gain as they learn to be better educators, such as how to communicate information effectively to a range of audiences, manage time efficiently, and lead groups with diverse perspectives and abilities, will also make them better scientists (Trautmann and Krasny 2006). Third, in a climate of increased competitiveness for academic positions, evidence that an applicant is a proven educator and has the skills to design and implement courses with active learning components gives them a distinct advantage (Adams 2002). This advantage will be particularly evident as universities experience increasing pressure to improve undergraduate STEM education, and are looking for educators to help them meet their goals (Adams 2002). Overall, graduate student training in education, and opportunities for meaningful practice prior to entering the workforce, will make future scientists into more effective educators and more competitive in academic and non-academic job markets.

Not only are there clear benefits for graduate students in receiving training in best practices in teaching and learning, but putting highly trained graduate student instructors into the classroom to implement these practices will increase the quality of undergraduate education. A survey of undergraduate perceptions of graduate TAs relative to tenure track faculty suggests that TAs relate better to undergraduates on a personal level and create a classroom atmosphere which is more personalized, engaging, and interactive (Kendall and Schussler 2012). In this same survey, however, undergraduates report that TAs were more hesitant, nervous, and uncertain in their approach to teaching. Providing graduate students with opportunities for meaningful teaching experience (Fig. 1) increases confidence in their instructional abilities and effectiveness in implementing best practices (Adams 2002). Empowering TAs through the development of their teaching skills transforms the TA experience from an obligation to an intellectually engaging activity that will benefit not only graduate students but also their undergraduate students.

Finally, increasing pedagogical training for graduate students will also benefit faculty and institutions by reducing the teaching commitments of current faculty. Many faculty members identify time constraints as the primary barrier to adopting active learning practices, despite recognizing the benefits of active
learning (Brownell and Tanner 2012). By implementing teaching collaborations between faculty and graduate students, graduate students can take on increasing responsibility and leadership for incorporating evidence-based teaching practices into current courses with the support of a more-seasoned educator (Adams 2002). Thus, co-teaching with a graduate student will reduce the teaching time-commitment on faculty, allow graduate students to gain valuable teaching experience, and ultimately increase the quality of college STEM education.

**Barriers to increasing training**

The greatest barrier to increased graduate training is the concern that the time spent learning and practicing pedagogical skills will distract from research and prolong PhD programs. Graduate students frequently receive mixed messages about the value of time spent teaching and studying pedagogy relative to time spent conducting research and publishing their findings. In official discourse, STEM departments embrace teaching as well as research as central to their mission, while in practice, departments at both teaching and research institutions prioritize research at the expense of teaching (Austin 2002, Nyquist 2002). In response, many students feel that they should not devote the time to developing and practicing pedagogical skills and that they lack support and encouragement from peers and mentors (Nyquist 2002).

Yet there is limited empirical evidence supporting the notion that developing pedagogical skills as a graduate student will indeed distract from research and prolong PhD programs (Hoff and Welch 2006). A study did find that students funded as TAs had longer completion times than their peers on fellowships or research assistantships (Ehrenberg and Mavros 1995). However, students enrolled in programs that included strong support for pedagogy and professional development (e.g. the NSF GK12 program) had completion times and attrition rates comparable to peers who did not. These students were more active in independent research and had better time management skills (Gamse et al. 2010). Recent research even suggests that teaching improves research design skills, including the ability to generate testable hypotheses and design valid experiments (Feldon et al. 2011). Additionally, graduate students who taught reported higher satisfaction with their graduate experience and greater motivation to finish their PhD (Trautmann and Krasny 2006). When it comes to graduate training, not all teaching experiences are created equal, and time spent teaching can hinder students if managed poorly, or accelerate progress if structured well. Thus, improving graduate training in teaching can transform the obligation of TAing, into a meaningful experience for graduate students.

In addition to concerns about distracting graduate students from research and longer completion times, increasing graduate training in teaching may encounter barriers at the broader departmental and institutional level. Employing graduate students as instructors can be more expensive than hiring non-tenure track instructors, because of the additional cost of tuition and fees. Increasing pedagogy training and mentorship for graduate students can also require upfront time investments and support from faculty (Fig.1). This requires motivated faculty members who are interested in learning new education techniques and taking the lead on transforming courses and mentoring graduate students. Departments or institutions that can afford the additional costs are able to support more graduate students, provide them with better training, improve the quality of undergraduate education, and diversify course offerings. Because the majority of changes we propose can be applied with little monetary investment and varying degrees of faculty effort, our proposed model could be implemented in a broad range of STEM departments.
A model to enhance graduate training opportunities in STEM education

We propose a model for pedagogical training in which mentorship and support for teaching begin at the start of a graduate career, and students gain progressive responsibility for course design and teaching throughout their training (Fig.). In this model, graduate students progress from learning pedagogical techniques (learn), to gaining active learning and classroom management experience as a graduate teaching assistant (assist), to more collaborative teaching including responsibility for curriculum development (collaborate), and finally to assuming a lead instructor (instruct) role where they can develop a full range of course development skills (Fig.). Our model for graduate pedagogy training is similar to successful training programs designed for postdoctoral scientists (Pfund et al. 2009). Through this proposed model, graduate students have the opportunity to lead their first course in a setting where mentoring, support, and resources are available, rather than as a new faculty member without the appropriate skill sets.

The model presented here, which we are currently implementing in the Department of Ecology and Evolutionary Biology at the University of Colorado at Boulder, is designed to augment the graduate training structures already in place at most universities within the United States, and can be implemented incrementally and to varying extents. In addition to teaching assistantships which are currently offered at most universities, we also promote pedagogical instruction for graduate students, and various types of teaching experiences that allow graduate students to gain skills in course development, lesson planning and current best education practices (Fig.). Our model emphasizes the importance of providing graduate students with collaborative teaching and lead instructor opportunities so that students can acquire and practice these skillsets prior to entering the workforce. Graduate students begin by taking a science education seminar with an implementation requirement. In this seminar, graduate students read and discuss science education literature on a range of topics, including but not limited to active learning, assessments, and metacognition. In the second semester of the seminar, the graduate students learn about case studies and partner with a faculty instructor to implement the case study in an undergraduate course. Students receive feedback from the seminar participants and instructor as well as their faculty-teaching partner. After this seminar, a select number of graduate students then have the opportunity to design and implement their own course as the instructor of record. This structure is beneficial to both the faculty instructor and the graduate student, and to a department in need of undergraduate specialty courses. More importantly, it creates a precedent of teaching with active learning techniques thereby promoting STEM education reform.

Our proposed graduate training model will address the need for STEM education reform in several ways. Providing graduate students with formal pedagogical training and mentored teaching practice will benefit undergraduate STEM students, increasing the quality of the instruction they receive. Further, increased classroom time and support for graduate students will reduce the teaching requirements of current faculty, serve as pre-service training for future faculty, and help prepare graduate students for success in a variety of future careers, including non-academic positions. Our model expands existing graduate student teaching responsibilities, supplements current training structures with increased opportunities for practicing evidence-based education techniques, and enhances training and mentorship through courses and faculty partnerships. By directing these efforts towards graduate students, who often lack this type of guidance and support, we believe our model will address an area of need, benefit faculty, students and institutions, and improve nation-wide college STEM education.
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Literature cited

Fig 1. STEM graduate training should follow a logical progression of increasing knowledge that corresponds with increasing responsibility and ownership of educational materials. In this way, as a graduate student matures they also gain experience necessary for college-level instruction. Although many institutions employ graduate teaching assistants, very few have established collaborative and progressive education training.