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Pedagogical Preparation of the Science Graduate Teaching Assistant: Challenges and Implications

Abstract

Graduate teaching assistants are often left out of the science teacher education reform agenda, but these science educators are responsible for significant amounts of undergraduate instruction especially at large research universities. Within science departments specifically, a number of courses and laboratories are taught by graduate teaching assistants (GTAs). The role of GTAs in undergraduate science education, their pedagogical beliefs and instructional approaches are briefly discussed. An analysis of the structure, components, quality, and effectiveness of science GTA teacher preparation programs in the research literature is reviewed. Finally, goals for future science teacher education and sustained professional development of science GTAs are offered based on the results of the review.

Introduction

> I am put in the mind of a dinner party I attended years ago at a major northeastern university. One guest (not affiliated with the university) made it clear that he thought that the education of undergraduates was the highest priority at this particular institution. After a moment's embarrassed silence from the assembled faculty, a senior member of the psychology department smiled sadly and said, "How touching." (Trefil, 2008, p. 139).

This anecdote illustrates the disproportionate reward system that exists in many larger institutions of higher education where faculty are more often recognized for their research and much less for their teaching. Undergraduate teaching at research universities often rests solidly on the backs of graduate teaching assistants (GTAs) who teach large proportions of the introductory curriculum. In most science departments GTAs teach most (if not all) the laboratory sections and in many cases also teach components of larger lecture sections. These GTAs play critical roles in educating the next generation of professionals but often receive little or no education or professional development to prepare them for these critical roles.

Many universities are experiencing attrition rates of up to 40% of intended undergraduate science majors (Strenta, Elliot, Adair, Matier, & Scott, 1994). This trend is particularly problematic for women and people of color in science fields (Seymour, 2002). These trends in reduced student retention are accompanied by calls to improve the quality of science instruction at the undergraduate level through professional development and teacher education (Addy & Blanchard, 2009; McIntosh, 2000). But where do GTAs fit in this educational reform? This group of teachers is almost invisible in the academic machinery that drives educational programs at large universities (Park & Ramos, 2002).

The most logical point at which to implement reform in the quality of undergraduate instruction is with graduate teaching assistants (GTAs), for a couple of reasons. First, the increasing responsibility GTAs have for providing undergraduate instruction gives them a proportionately larger role over time in achieving university instructional objectives (Luo, Bellow, & Grady, 2000). These responsibilities are only increasing as student enrollment and a need for instructors in introductory post-secondary courses continues to rise (Nicklow, Marikunte, & Chevalier, 2007; Travers, 1989). Second, the experiential training GTAs receive in the classroom can be scaffolded with explicit pedagogical preparation and best-practice training prior to their faculty appointments thus breaking the reproduction of mentors with little formal pedagogical training (Addy & Blanchard, 2009).

Unfortunately, increasing the quality of science instruction through teacher education and professional development has traditionally existed in the realm of K-12 classrooms (Darling-Hammond, 2009). Because of this, teacher education has by-passed a group of instructors that have a disproportionately large role in the future of undergraduate science instruction. Nicklow and colleagues (2007) have suggested GTAs are the "first line of defense" in promoting quality instruction and student retention in the sciences. Despite the apparent appropriateness of GTAs for targeted pedagogical training, such programs are often insufficient to prepare them for effective teaching (Nyquist, Abbott, & Wulff, 1989). In addition, there is little research-based literature that focuses on the structure and components of existing science GTA training programs and their subsequent quality and efficacy.

Based on these gaps in the literature, the aim of this paper is three-fold. First, in realizing that GTA's teaching is context-based and perhaps unique, the discussion is opened by articulating the instructional role of GTAs in the science classroom by answering the following questions: What are the instructional

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roles of GTAs within science departments? What challenges do science GTAs face in defining their instructional roles? What beliefs about science teaching and learning do GTAs hold prior to training programs? These questions are addressed through a review of research on the structure, components, quality, and effectiveness of science GTA training programs. The research results are synthesized and goals are prescribed for future training and sustained professional development of science GTAs with an established professional development framework.

The Graduate Teaching Assistant Context

GTA instructional roles and challenges.

Although it varies between institutions, teaching assistants are expected to engage in numerous educational tasks including, but not limited to: lecturing, conducting review sessions, formally meeting with and advising students, designing and grading classroom assessments, proctoring and grading exams, facilitating group discussions, and providing technological support (Jacobs, 2002; Nyquist et al., 1989; Peterson, 1990). Parallel to the fact that the diversity of GTA responsibilities are increasing in undergraduate science programs, the volume of courses being taught by teaching assistants is also growing. A recent survey study by Sundberg, Armstrong, and Wichusen (2005) found that 91% of the biology labs of sampled research universities ($n = 34$) were being taught by GTAs. In studies expanded to include both the life and physical sciences, the number drops to 70%, but is still highly significant, especially when compared to other educational domains (National Center for Educational Statistics, 2000).

The diversity and volume of responsibilities in undergraduate science instruction often results in teaching assistants having more contact with undergraduate students than do the professors (Lawrenz, Heller, Keith, & Heller, 1992). GTA's extensive interactions with university students as well as their increased instructional responsibilities contribute to the role that GTAs play in defining the quality of undergraduate science education (Commander, Hart, & Singer, 2000; O'Neal, Wright, Cook, Perorazio, & Purkiss, 2007). In addition, undergraduates often relate more readily to GTAs than professors because of similarities in age and social status and this can lead to undergraduate students seeking out GTAs for their educational needs rather than established faculty (Moore, 1991).

Given that the amount of contact that science GTAs have with undergraduate science students and the apparent role they have in defining the quality of instruction, it would seem that their pedagogical training might hold high priority in academic settings. This is not often the case. In fact, many GTAs encounter numerous hurdles to their training as science instructors. One of the most significant challenges is defining their role within the academic department that requires finding a niche in multiple communities: graduate student, academic and professional, scientist, and instructor (Austin, 2002; Muzaka, 2009). Positions in these various communities are not always well defined. While balancing the classroom responsibilities of a student, science GTAs often occupy an "ambiguous niche" (p. 355) that hovers somewhere within the intersecting identities of student, instructor, employee, and apprentice (Park, 2004).

> "(T)hey are both student and teacher, but neither fully. The problem is not necessarily that this role is contested, it is more to do with underlying tensions between responsibility and power, with the marginalized niche that GTAs occupy within departments, and with the lack of ownership of the teaching and learning process (Park & Ramos, 2002, p. 52)."

This marginalization is a by-product of not only how GTAs perceive their own roles, but how they are perceived by their own students and colleagues. Undergraduates often perceive the GTAs as existing somewhere between a role of student and teacher, where as the faculty perceive them as academic apprentices and research students (Muzaka, 2009).

Furthermore, Park and Ramos (2002) explain that the pressure that most science graduate students are under causes them to develop a researcher identity at the expense of a teacher identity. Despite the fact that many departments have mission statements with numerous teaching objectives (Buerkel-Rothfuss & Gray, 1989), at many universities and within many science departments, faculty rewards are disproportionately based on research and grant productivity, not excellence in teaching (Barrington, 2001; Jones, 1993). Research indicates that there is a hierarchical cascading effect when emphasis is placed on teaching in a university or college: if the institution values and rewards education, so will the department, the faculty, and the graduate students (Graff, 1994; Grunwald & Peterson, 2003). Trefil (2008) calls this the "invisible university" that is organized to promote research agendas. Despite educational mission statements and the increasing teaching responsibilities of GTAs, many GTAs are still encouraged to focus more on research than teaching (Shannon et al., 1998; Smith, 2001).

This reinforced focus on research leaves many GTAs receiving implicit signals that teaching is not important, while being expected to excel at it (Nyquist et al., 1989). The expectations of excellence are at times not bolstered by faculty support for teaching. Studies have found that interactions between GTAs and their faculty advisors in respect to teaching are often limited (Austin, 2002; Anderson & Swazey, 1998). Furthermore, GTAs may not initiate this mentorship out of fear of being perceived as incompetent (Seymour, 2005). The most consistent source of support for GTAs typically is from peers and fellow teaching assistants who mentor each other in proper role expectations, behavior norms, rules and procedures, and the location of available resources (Luft et al., 2004; Seymour, 2005; Staton & Darling, 1989). However, if untrained peers are teaching the novice GTAs, this can compound ineffective pedagogical practice.

Luft and colleagues (2004) have suggested that this lack of support for teaching is based on the pedagogical beliefs of faculty, who often feel teaching ability is innate and the only way for graduate students to excel is to accumulate experience. Instructional skills are often seen as a secondary consequence of obtaining a graduate degree and not something that requires explicit training (Latulippe, 2006; Shannon, Twale, & Moore, 1989). Since science instruction is viewed as technically simple it is considered that "trial and error" approaches will allow graduate students to learn all they need to know about effective science teaching (Gunn, 2007; Luft, et al., 2004; Tanner & Allen, 2006). Because of these misconceptions, science GTAs often have fewer opportunities for pedagogical training and professional development as compared to graduate students in some other educational domains (Golde & Dore, 2001). It is extremely difficult for graduate students to know how to improve their teaching, let alone to justify the need for refining their teaching skills, through explicit training programs (Nurrenbern, Mickiewicz, & Francisco, 1999; Sundberg, Armstrong, Dini, & Wichusen, 2000).

Teaching ability is not a pre-requisite for entering into most graduate programs, especially in the sciences (Welford, 1996). Once a graduate student enters a program and is assigned a teaching assistantship, they often are partnered with science professors who have not moved beyond the novice stage of pedagogical beliefs themselves. Most science professors view education as a technically didactic process with the teacher as the content expert. Historically, instructors are assumed to have the responsibility of transmitting the body of knowledge to the student (DeHaan, 2005; Volkmann, et al., 2005).

"Why do scientists, trained to demand evidence for every aspect of their research, enter their classrooms as instructors using teaching methods that are supported only by intuition and habit?" (DeHaan, 2005, p. 264). The following possibilities exist: a) scientists are unaware of the effectiveness and frequency of research in science education, b) they trust anecdotal evidence of students who were successful in the current system more than educational research, c) they distrust the unfamiliar methodologies of science education researchers, d) they do not have the time or inclination to learn new teaching methods, e) they fear a focus on teaching will reduce their credibility as a researcher, and f) they see few institutional or departmental rewards for improved teaching.

Whether singularly or in combination, these factors can contribute to the maintenance of a cycle of pedagogical misconceptions in university science education that are passed from faculty to graduate students. As a consequence, there is little difference in knowledge of teaching effectiveness between GTAs and the professors who are mentoring them (Schmidt, 2004). This is even more apparent in international teaching assistants (ITAs) who often hold traditional concepts of learning involving memorization, acquisition of factual knowledge, and being ruled by structured procedures (Constantinides, 1986).

Amidst these conflicts and challenges, graduate teaching assistants often experience numerous tensions while attempting to establish a balance between personal time, time spent teaching, and time spent on research (Park, 2004). Park and Ramos (2002) found that frustration associated with time and responsibility management is often highly correlated with job satisfaction, research completion, timely thesis submission, and completion rates. Self-survival can become the primary concern of graduate students at the expense of bettering themselves as teachers or researchers. With their heavy workload, sizeable responsibilities, and limited autonomy, some GTAs feel like the "donkeys in the department" (Park & Ramos, 2002) whereas others frequently allude to their graduate experience as analogous to "doing time" (Freyberg & Ponarin, 1993).

Beliefs about science teaching and learning.

Despite the challenges to defining their identity as science instructors, many GTAs enter into their academic careers with beliefs about effective science teaching and learning. These belief systems begin to shape their classroom practices as well as their perspectives on science teaching and learning (Kagan, 1992). However, GTAs often have little explicit training, and are likely to define their instructional identity based on their past experience as students, fantasized views of teaching, or untested personal beliefs about teaching (Kagan, 1992). These beliefs about science teaching and learning and the instructional identities that they foster can be in stark contrast to current undergraduate science teaching standards calling for excellence in teaching.

Most studies examining GTA beliefs have found that they tend to believe that only content knowledge is needed to be an effective teacher. For example, Luft and colleagues (2004) conducted a study with 11 GTAs in science, biology, and physics. One student acknowledged the presence of educational research, but felt experience, intuition, and practice were more important than pedagogical knowledge. The importance of content knowledge in teacher preparation has also been reported by Volkmann, Abell, and Zgagacz (2005). Certainly science content knowledge is an important component of effective teaching, but it is problematic that science GTAs sometimes feel it is the only type of knowledge required to teach.

Effective science teaching is built on an array of knowledge including: content knowledge, conceptual knowledge, reflective practice, and knowledge of teaching and learning (Luft et al., 2004). Herrington and Nakhleh (2003) conducted a study in which 14 GTAs in chemistry completed a survey both before and after an undergraduate chemistry laboratory and found multiple knowledge themes. Teaching assistants compartmentalized knowledge and claimed four distinct types were necessary for effective science teaching:

knowledge about student learning, knowledge about teaching, knowledge of chemistry content, and knowledge about the specific laboratory tasks. This group of participants did not explicitly identify the need for pedagogical content knowledge.

Another important hallmark of science instruction, especially in laboratory settings (where most GTAs are teaching) is the use of scientific inquiry curricular activities (American Association for the Advancement of Science, 1993; National Research Council, 1996). Scientific inquiry allows students to develop questions, initiate investigations, and explore concepts. Adoption of K-12 science standards is becoming more common in higher education science laboratories but is far from widespread (French & Russell, 2002). Although higher education is beginning to stress inquiry, this view of teaching science conflicts with many GTA views of teaching and learning.

Volkmann, Abell, and Zgagcz (2005) developed an undergraduate physics course based on a science inquiry model. The graduate student who assisted in the course was able to experience inquiry learning first hand, but still held views that science was a body of knowledge to be transferred to students. Her views were best summed up in a quote. "What is more important-knowing or learning? To me knowing is more important; maybe to him (the professor), learning is more important" (p. 858). GTAs seem to consistently believe that the laboratory setting is for delivering content or honing student laboratory skills and not for allowing students to explore science concepts (Luft et al., 2004; Volkmann et al., 2005).

Many science educators and researchers would agree that laboratories should help students better understand the nature of science and make insights into scientific practice (Lazarowitz & Tamir, 1994). However, studies show that when undergraduates conducted inquiry labs, GTAs often felt that activities were frustrating to the student and did more to confuse them than help (Luft et al., 2004; Volkmann et al., 2005). GTAs in the Rhoehrig, Luft, Kurdzeil, & Turner (2003) study also questioned whether inquiry methods were appropriate for lower level courses where students needed to learn so much content. Many of the beliefs that GTAs had concerning the difficulties of inquiry teaching in laboratories came from their own experiences as undergraduates (Luft et al., 2004; Roehrig et al., 2003). And often, even if GTAs have beliefs more in line with reform-based practices, they have difficulty actually implementing these practices in the laboratory (Addy & Blanchard, 2009).

Research into GTA beliefs about science teaching and learning has included other factors as well. GTAs believe that teachers should be good communicators and be able to translate new and difficult information into "layman's terms" (Herrington & Nakleh, 2003). They also indicate that effective teachers should show concern for their students by being willing and available to help students when needed (Herrington & Nakleh, 2003). Assessment was seen as a way to distinguish the 'A' students from the 'F' students along a curve (Volkmann et al., 2005). Finally, GTAs in the Luft et al. (2004) study believed that student success in the class had little to do with how the course was taught, and more to do with innate student ability or prior motivation.

These studies highlight the limited conceptions that GTAs have about the way that undergraduates learn and subsequently how they should be taught science. It could also be noted that they have limited conceptions of teaching in general and, as a consequence, this limits the development of insights into what students need to learn science effectively. What most GTAs seem to hold is a conception similar to traditional teaching theories—that knowledge is tangible and the role of the instructor is to transmit knowledge. For teacher educators, the challenge is determining if GTA's beliefs and practices can be altered through professional development programs.

Science GTA Instructional Preparation

Prior to the 1960's, most universities and colleges did not acknowledge a need to educate graduate teaching assistants about their responsibilities as teachers in the academy. The first national conference on TA issues was held in 1986, and, in the years that followed, institutions of higher learning began to offer teaching assistant preparation programs in an effort to improve undergraduate education (Seymour, 2005). However, training opportunities continue to be limited and informal, especially in areas of science, technology, engineering and math (Shannon, et al., 1998). For example, Rushin et al. (1997) found that 49% of all universities they surveyed did not provide formal teacher preparation for their teaching assistants in biology and only 22% offered pre-semester teacher workshops. The steady increase in science teaching assistants' responsibilities is not being met by a subsequent increase in research into the types and effectiveness of programs to prepare science GTAs.

Although there are programs that exist to prepare science graduate teaching assistants to be more effective instructors, there is a dearth of primary research on the subject. What do programs geared toward developing the teaching skills of science GTAs look like? More importantly, how effective are these programs at changing misconceptions and beliefs about science teaching and learning of science graduate teaching assistants?

Table 1 offers a detailed summary research on GTA preparation programs and professional development prior to 2008. Programs studies were identified that specifically focused on the instructional training and preparation programs of science graduate teaching assistants in the fields of biology, chemistry, physics, or engineering. The search was limited to studies found in peer-reviewed journals that contained a research sample of GTAs within pedagogoical preparation or development programs.

Structure and components of preparation programs.

Studies have noted that high percentages of teaching assistants receive little or no pedagogical training (Luft et al., 2004; McComas & Cox-Peterson, 1999). Graduate students themselves report that their training as educators is often extremely limited during their graduate career (Gaia, Corts, Tatum, & Allen, 2003). Often GTA training programs consist of a single campus-wide workshop that is highly generalized and may not even address pedagogical techniques or methods (Luft et al., 2004; Jones, 1993). In addition, these workshops tend to limit their focus to skills such as class and time management. Although important for a beginning instructor, many of these workshops fail to address effective teaching strategies aligned with the standards of science instruction in higher education.

A few training programs have sought to supplement the traditional campus-wide or departmental workshop with additional workshops that directly address science teaching and learning. French and Russell (2002) implemented a one and a half day pre-semester workshop for 27 biology teaching assistants in which they learned about teaching philosophies and laboratory pedagogy, and observed experienced GTAs in a laboratory demonstration. Hammrich (1994) also used a structured workshop to instruct four biology GTAs on specific pedagogical techniques for biology. These training sessions were only "one-shot" programs that sought to supplement the university-sponsored workshops that focused on administrative and classroom management duties with a brief introduction to some basic teaching theory.

More in-depth professional development programs tend to promote continuous practice and reflective feedback by offering periodic sessions throughout the semester that the GTA is teaching. Both Bond-Robinson and Rodriques (2006) and Hampton and Reiser (2004) described training programs with chemistry GTAs that involved experienced science instructors or faculty members observing teaching assistant-led classes. These experienced instructors then provided feedback to GTAs to improve their teaching throughout the semester. Nurrenbern and colleagues (1999) described a similar program with GTAs meeting each week as a group to reflect on their teaching with experienced faculty. These models relied on continuous feedback as a means through which to constantly adjust GTA practice and orient it more consistently toward good instructional practice.

Teacher preparation programs for GTAs have also included more intensive apprenticeship models. Volkmann and Zgagacz (2004) conducted a case study of a single physics graduate student who worked directly with an instructor who was teaching an undergraduate course in inquiry physics teaching. This GTA had the opportunity to work closely with the professor, question and discuss her teaching strategies, and eventually enact her own curriculum. Another type of apprenticeship model for GTA training was described by Trautmann and Kransky (2006). In this model GTAs observed science teaching

Table 1: Research on Science Graduate Teaching Assistant Training Programs

Study	Baumgartner (2007)	Bond-Robinson & Rodriques (2006)	French & Russell (2002)	Hammrich (1994)	Hammrich (2001)	Hampton & Reiser (2004)
TAs/Discipline	18 Zoology & 1 Cell Biology	83 Chemistry	27 Biology	4 Biology	25 Biology	20 Computer Science & 17 Chemistry
Training Program Format	Semester long science teaching course; NSF supported GK-12 fellowship program	Semester long course in chemistry teaching	1.5 training workshop on inquiry lab teaching	Pre-semester biology specific pedagogical training	Summer semester long seminar; Various interactive activities in biology teaching	Mid-semester theory-based student & researcher feedback
Measures	Relevance of course and topics covered; Teaching conceptual understanding;	PCK gain; GTA performance variation; Factors catalyzing effective teaching	Teaching experience; in-class teaching methods; teaching-research interactions; Influence of inquiry labs on teaching/research conception	Nature of teaching conceptions	Conception of teaching, planning, assessment of student understanding, instruction effectiveness	Teaching practice; Teaching effectiveness; Student learning & motivation
Research Design	Post-survey relevance; Pre- and post-test on conceptual understanding	Periodic classroom observations	Pre- and post-interviews	Pre- and post-N.O.T. questionnaire & Interviews	Pre- and post-semi-structured interviews	Control/Mid-semester feedback groups
Results	Course was self-reported as beneficial; Conceptual understanding increased	Significant PCK gains	Report a positive influence of inquiry lab teaching on teaching/research methods	Shift in conceptualizations of student assessment, understanding, and instructional evaluation	Conceptual change in learning about learning by construction, teaching by facilitating, process planning.	Significant difference between instructional practices and effectiveness

Table 1 (continued):

Study	Nicklow et al. (2007)	Nurrenbern et al. (1999)	Roehrig et al. (2003)	Trautmann & Kransky (2006)	Volkmann & Zgagacz (2004)
TAs/Discipline	15 Civil & Environmental Engineering	43 Chemistry	6 Chemistry	27 Biology	1 Physics
Training Program Format	Semester long, student-directed weekly seminars with faculty, GTA, and professional speakers and open discussion	Semester long, weekly meetings with faculty-student discussion and teaching micro-workshops	2 day institutional training; 4-day chemistry departmental training	NSF GK-12 15hr/ wk science education outreach program	Continuous mentorship in inquiry lab teaching
Measures	Reasons for attending seminars; Relevance of topics covered; Benefit of program	Relevance of course to changing teaching habits	Conceptions of science teaching and learning	Teaching ability	Orientations to science teaching and professional identity
Research Design	Post-survey only	Control/Treatment group; Post-survey only	Pre-interviews; Continuous observations	Post-survey only	Continuous phenomenological observations & interviews
Results	Course was self-reported as beneficial to teaching behavior	Meetings were beneficial; Resistance to continuous program and social learning	Previous experience more influential than training; Instructional skills and conceptualizations were still limited;	Increase awareness of methods and challenges to science teaching	Changing teaching approaches means developing a new teaching identity

in K-12 classrooms. If trends in K-12 reform-based science teaching (such as inquiry learning) are to apply to higher education settings as well, this program presents a potentially effective mode for bridging the gap between these two educational settings.

Another model is the use of graduate courses that are specifically designed to enhance the teaching of GTAs. Topics have included pedagogical approaches to inquiry, constructivism, discussion, questioning strategies, learning styles, assessment, classroom technology, and student motivation (Baumgartner, 2007; Hammrich, 2001). Other topics included designing teaching philosophies, conceptual change models of teaching, and common science misconceptions (Hammrich, 2001). Many of these courses have also required GTAs to design lessons and present them before students (or another audience) with feedback (Schussler et al., 2008; Roehrig et al., 2003). Several of the courses included broader aspects of professional development for graduate students such as career planning, research agendas, and student life (Nicklow, et al., 2007; Roehrig et al., 2003).

The benefits of the aforementioned programs are not limited to the longevity of their administration. By having a separate course focusing on the development of teaching skills, GTAs are better able to set aside time to focus on that aspect of their academic roles. In addition, these more extensive programs are better equipped to battle misconceptions GTAs might have about science teaching and learning and also more persistently scaffold concepts about science pedagogy. However, GTA training programs are not just about quantity, but must also be assessed for quality of teacher preparation.

Quality and effectiveness of preparation programs.

Characteristics of science.

Training programs have been shown to be successful in helping GTAs realize that science content is not the only important aspect of science knowledge important for student success. Following participation in a training program, many GTAs reported that they tried to teach their students the importance of the processes of science (Trautmann & Krasky, 2006; French & Russell, 2002). Additionally, GTAs reported that learning and teaching science as a process allowed them to gain a deeper understanding of science that translated into their own research agendas (French & Russell, 2002; Nurrenbern et al., 1999).

There are further complications when it comes to helping GTAs understand the deeper philosophical rationale for effective science instruction. Science content standards stress the idea that science knowledge is socially constructed (Matthews, 1997). Hammrich (2001) found that GTAs self-reported a better understanding of student construction of knowledge following instruction and it translated to their classroom practice. However, in Volkmann and Zgagacz's (2004) case study, it is apparent that the GTAs had difficulty integrating a social constructivist approach with the more traditional positivist perspective that is traditionally promoted in most sciences.

Conceptions of science teaching.

One of the most beneficial aspects of the GTA professional development programs described in the studies was the questioning GTAs had about their own traditional teaching practices (Schussler et al., 2008). Most of the GTAs held beliefs that the most beneficial form of teaching was transmitting knowledge to students in simple or meaningful "chunks." However, the new pedagogies that were taught were accepted by GTAs and they self-reported a change in their overall conception of teaching (Hammrich, 2001, 1994).

Inquiry techniques have been taught or modeled in professional development sessions in order to promote inquiry in GTA labs. Research on professional development programs suggests that GTAs perceive that they have the ability to enact inquiry labs following training as well as have increased confidence (Baumgartner, 2007; Trautmann & Kransky, 2006). GTAs that had more classroom experience implemented inquiry instruction more than inexperienced teachers (French & Russell, 2002).

When it came to actually practicing inquiry-based instruction in the classroom many GTAs appeared to experience difficulty. GTAs claimed that this mode of instruction was inappropriate, frustrating, and too difficult for young undergraduates (Schussler et al., 2008; Roehrig et al., 2003). The response to these perceptions was to change inquiry labs back into more traditional "cookbook" type labs and reduce the opportunity for students to cooperate and interact in innovative ways (Roehrig et al., 2003; Nurrenbern et al., 1999). Reasons for changing labs back into non-inquiry forms included: a) GTAs wanting students to have a better experience, b) GTA perceptions that students cannot do inquiry for themselves, and c) GTA concerns that student frustration would lead to poor teacher evaluations (Roehrig et al., 2003).

These studies showed that GTAs were receptive to challenges in their traditional concepts of teaching, but these ideas were difficult to translate into classroom practice. Inquiry based laboratory instruction provided a good example of a reform-based instructional strategy that GTAs seemed to appreciate, but often did not implement in the laboratory. This is similar to K-12 science instructors who also report challenges to implementing inquiry instruction (Eick & Reed, 2002). Perhaps if given more time and apprenticeship to practice new teaching skills, GTAs would develop confidence in inquiry-based teaching.

Conceptions of student learning.

Studies report that initially, GTAs held ill-formed conceptions about student learning. In addition, many GTAs felt that learning was a passive process and that information was transmitted from teacher to student. Both before, and frequently after, professional development, GTAs felt that student learning was determined largely by the effort or motivation of the student and their ability to appropriately follow instructions (Volkmann & Zgagacz, 2004; Roehrig et al., 2003). Following professional development, students expressed interest in active learning strategies, but, as noted with inquiry instruction, GTAs had difficulty actually implementing the strategies (Nurrenbern et al., 1999). Additionally, one challenge that resurfaced in some of the teacher preparation programs was GTAs did not anticipate student misconceptions and were not able to design their instruction from those points (Bond-Robinson & Rodriques, 2006; Hammrich, 2001).

It was difficult for GTAs to significantly alter their views on student learning. One of the avenues where this was expressed frequently was the need for GTAs to give students the "correct" answer to problems. GTAs would acknowledge that students could approach problems from different perspectives (Nurrenbern et al., 1999) but had difficulty allowing students to work through investigations on their own and in one case researchers observed GTAs taking projects from students' hands to run the experiment for them (Rhoehrig et al., 2003). One teaching assistant summed up the problem nicely by saying that she acknowledged that inquiry could lead to viable explanations, but she preferred to give students "correct" information (Volkmann & Zgagacz, 2004).

Assessment.

Volkmann and Zgagacz (2004) reported that GTAs in their study recognized that formative assessments were beneficial when they determine how well a student could apply a concept in class. However, after professional development, many GTAs still relied on student quizzes and tests to determine student understanding and evaluate their success as educators (Hammrich, 2001). Research addressing teacher assistant training of assessment is extremely limited.

Implications for GTA Training Programs

The role that graduate teaching assistants play in undergraduate science education is increasing both in the number of courses taught and the respective responsibilities of the GTAs. This means that GTAs play an increasingly larger role in determining the quality of science instruction at many colleges and universities. GTAs may have difficulty defining their role as a science instructor due to the numerous socialization challenges they experience as graduate students, researchers, and young professionals. As a result, understanding GTA professional development programs is a crucial element for promoting quality undergraduate instruction.

Researchers have argued that in order to demonstrate positive effects on student performance, instructors need to maintain persistent professional development in their education (Yoon, Duncan, Lee, Scarloss, and Shapley, 2007). In a recent study, Darling-Hammond et al. (2009), reviewed research results from over the past decade and set fourth four principles of effective professional development: a) intensive, ongoing, and connected to practice, b) focus on student learning and address the teaching of specific curriculum content, c) align with school improvement priorities and goals, and d) build strong working relationships among teachers. These principles refer specifically to instructors at the K-12 level, but offer a useful framework for reforming and restructuring graduate student teacher education.

Instructional training should be intensive, ongoing, and connected to practice.

We know from decades of research on preservice teacher education that learning to teach is a complex process that takes time (Abell & Lederman, 2007). The one-shot training programs that many universities offer fall short of meaningfully preparing academics for a lifetime of teaching. Although, several of the reviewed GTA programs could be called intensive, very few of them can be said to be ongoing. Until teaching is prioritized as a beneficial skill as well as a useful commitment of time, it is likely that ongoing teacher development will be difficult for many GTAs to maintain.

Some suggestions on how to create long-term appropriate teacher orientations is to encourage GTA self-reflective practice through avenues such as journaling or self-videotaping (Austin, 2002; Park, 2004). Another means to address this issue is to create partnerships with science education departments so that GTAs can have access to peers in the field of education as well as get a chance to see the effectiveness of reform-based teaching in practice (e.g. McComas & Cox-Peterson, 1999). Meetings that include time for GTAs to reflect on their teaching as well as to voice concerns about teaching and learning would also be beneficial.

However, these goals are worthless if teaching assistants are not willing or motivated to attend sessions designed to develop teaching skills. While negotiating a diversity of roles, graduate students often become frustrated with the numerous demands placed upon them. This leads to an attitude of self-preservation that is reflected in the priorities graduate students set on time. Teacher development is often not high on this priority list. Connecting GTA educational preparation directly to practice might also circumvent some of the perceived time management issues presented by extended training courses. Workshops and courses can be directly tied to practice through self-reflection and mentorship with faculty who have experience in reform-based science teaching. However, questions remain. How can GTA professional development programs be designed that are ongoing yet still sensitive to the numerous time and energy demands placed on graduate students? What can be learned from professional developments programs at the K-12 and university level that can be translated to the context of GTAs? How can teacher training for GTAs be included in their employment as faculty to maintain the quality of their teaching?

Instructional training should be focused on student learning and address the teaching of specific curriculum content.

One of the primary goals of GTA training programs should be to alter student misconceptions about science teaching and learning as well as provide them with effective pedagogical tools to implement quality science instruction. One of the largest misconceptions indicated by GTAs in the previous review is a traditional conception of student learning in which undergraduates become receptacles of knowledge. This view is in contrast to a constructivist view of education currently promoted in much of the science education reform. Future research should address the questions of conceptual change in GTAs specifically in light of student-centered classroom practice.

The recommendation of teaching of specific curriculum content is one suggestion that is perhaps most beneficial to GTAs. Many of them are experts in their field of choice and bring much content knowledge to the table. Training programs can foster GTA's understanding of the content by scaffolding pedagogical content knowledge on top of what teaching assistants already know. What does research say about student learning in higher education settings that translates to GTA training? How can GTAs high content knowledge base be used to underscore a productive scaffolding of pedagogical content knowledge?

Instructional training should align with college or university improvement priorities and goals.

This problem is particularly troublesome, because graduate teaching assistants are often unaware of college and university educational goals. Even if they do receive information in workshops or training programs, they might not then know how to translate these educational objectives into specific curriculum activities that yield effective student learning. Moreover, if university or departmental educational objectives are not made clear to GTAs, how can they be expected to translate this to effective instruction? How can universities and departments effectively communicate to GTAs about instructional goals and objectives? How can teaching quality that seeks to achieve these objectives be assured? How is teaching quality evaluated with GTAs?

Instructional training should build strong working relationships among colleagues.

Training programs should be supportive environments where students can come together informally as colleagues and support one another to alleviate some of the general tensions of graduate school day-to-day life. When planning programs, awareness of graduate student time demands is critical. Time spent in training is likely to be more effective if it can be an arena were GTAs can air their grievances about their classroom experiences and receive an appropriate level of empathy and constructive advice. In promoting effective science teaching, trainers should not forget that classroom management issues and the general stress of teaching cannot be ignored.

Motivating GTAs to attend teacher-training sessions can be a difficult task when graduate students see few institutional or departmental rewards for improved teaching. With the little emphasis science departments place on teaching and teacher training it is easy to see how the perceived priority to attend pedagogical training sessions is often low and sometimes neglected altogether. At large research universities, this prioritization is unlikely to change in the near future. In order to create a culture of teaching at a college or university, a top-down approach is a critical component for placing value on undergraduate education. Teaching beliefs and values are reflected in the behaviors of the institution, the department, and the faculty and these ideals are reproduced in graduate students.

An arena for change is likely to occur at the departmental level, where a few individuals can have a large effect on the department culture. At this level, creating a culture of teaching should include an increased validation of departmental teaching objectives, a tangible commitment of resources to the development of teachers, and a training program that is intellectually rigorous.

At the level of the faculty, creating a culture of teaching should include formalizing the mentorship opportunities. One of the most critical goals of faculty should be a validation of teaching as an important objective of an academic apprenticeship. Effective science teaching should not reduce one's credibility as a researcher, but only add to a more rigorous understanding of the nature of science and scientific inquiry. Although these are formidable challenges, once they have been addressed training programs can be implemented in an environment that is conducive to graduate student conceptual change.

Further research is needed to examine how teacher identity develops for GTAs. We need to know more about how to effectively alter GTAs beliefs that teaching is about simply transferring knowledge. We need to know if there are differences in GTAs beliefs about teaching by gender, ethnicity/culture, or content domain. Furthermore, we need long-term studies that span the graduate student to professor continuum to understand how beliefs and priorities related to teaching evolve over time. The studies cited in this manuscript merely scratch the surface of the important work that is required. University teaching is far too important to leave unattended in the hands of graduate students who may or may not put teaching as a priority.

In addition to potential impacts on students, GTAs can also have a significant influence on science faculty instruction by exemplifying good teaching practices (Milner-Bolotin, 2001) and reducing the teaching load of full-time faculty (Park, 2004). Whether these are factors that significantly impact the quality of university science instruction has yet to be empirically assessed. Nonetheless, the increased responsibilities of GTAs has likely provided science faculty with more time and opportunity to focus on their research agendas. Do all TAs have the same demands put on them, enjoy the same departmental status, and receive the same level of support? Is the position of teaching assistants understood by the undergraduate community in a clear manner? How are instructional roles of GTAs defined by themselves and the departmental/university environment? How do GTAs manage the tensions presented by research, teaching, and administrative duties?

Conclusion

Research and professional development in teacher education have done a disservice to the quality of undergraduate science education by ignoring the unique contextual situation of the graduate teaching assistant. Research exists that analyzes the unique challenges and constraints that GTAs face while obtaining their degree, but initiatives need to focus on translating these contexts to design of teacher education programs. Until a more targeted approach to the professional development of GTAs is undertaken, the quality of undergraduate science education will continue to suffer and GTAs themselves will continue to be a marginalized teacher group. Effective teacher education programs must seek to empower GTAs to gain confidence and take ownership in their teaching abilities so that they can develop into faculty with a healthy respect and deep understanding of science teaching and learning.

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