Current Issues in Education
Mary Lou Fulton Teachers College • Arizona State University
PO Box 37100, Phoenix, AZ 85069, USA

Volume 19, Issue 2 August 29, 2016 ISSN 1099-839X

Reforming Undergraduate Biology Teaching through Graduate Assistants: Identifying Bridges and Barriers to Making Change

Kathleen M. Hill
Pennsylvania State University

Miles Orchinik
Arizona State University

Abstract:
Among policy makers, there is an ongoing discussion about the need to improve undergraduate education in science and engineering. With many undergraduate students being taught by graduate teaching assistants (GTAs), it is important to explore the development of STEM knowledge for teaching by GTAs. This study follows ten GTAs as they participated in a GTA teaching program that included attending a "Scientific Teaching" course. Data collection consisted of open-ended questionnaires and concept maps. Analysis revealed that a majority of the GTAs employed more didactic, teacher-centered practices while having varied levels of development in the areas of student understanding and instructional strategies. Those GTAs with regularly scheduled opportunities to work directly with students increased their knowledge for teaching. Additionally, GTAs with lower levels of prior teaching experience and an expressed desire to improve their teaching had the highest levels of knowledge development. From this study, we suggest that GTA programs support GTAs by initiating the preparation for teaching early in the TA experience. Finally, we recommend that science departments place more emphasis on teaching by providing GTAs with additional science education coursework as well as structured opportunities to work directly with students and to practice making use of reformed teaching strategies.

Keywords: pedagogical content knowledge, undergraduate, biology education, graduate assistant, teaching assistant, GTA, GTA training

APA-Style Citation:
Hill, K. M., & Orchinik, M. (2016). Reforming undergraduate biology teaching through graduate assistants: Identifying bridges and barriers to making change. *Current Issues in Education*, *19*(2). Retrieved from http://cie.asu.edu/ojs/index.php/cieatasu/article/view/1487

Accepted: August 8th, 2016

Among policy makers there is an ongoing discussion about the need to improve undergraduate education in science and engineering (The President's Council of Advisors on Science and Technology, 2012). In a study of science majors at seven U.S. colleges and universities, students who left science majors pointed to unsupportive environments in which introductory-level classes were unstimulating and often seen as weed-out courses taught by unfriendly professors (Seymour & Hewitt, 1997). In addition, those students who complete undergraduate STEM degrees often do not possess adequate scientific knowledge and skills to meet the 21st century workforce needs (National Research Council [NRC], 2012). Many reason that by improving undergraduate education, more science and engineering students will persist in these fields and fill the ongoing shortage that exists in the United States. Additionally, improving undergraduate education in the sciences will ensure that all students in higher education become scientifically literate. That is, they will be able to reason through scientific claims that are shared in the media (e.g., genetic engineering, personalized medicine, global climate change).

One particular pathway for improving undergraduate education in the science fields is to reform teaching in undergraduate courses. Publications from the National Academy Press stated that undergraduate education should embrace (a) active learning environments, (b) fewer key concepts, and (c) cooperative learning groups (NRC, 1998; 2000; 2003; 2015). The methods discussed give undergraduates an opportunity to build deep knowledge in certain areas and allow them to participate in learning communities. The *Vision and Change* documents (American Association for the Advancement of Science [AAAS], 2009; 2015) provide recommendations intended to result in fundamental changes to the way that colleges and universities engage in teaching undergraduate biology courses. Recommended reforms include shifting away from lecture-based instruction to a focus on student-centered learning to "ensure that undergraduate biology courses are active, outcome-oriented, inquiry-driven, and relevant" (p. 29) along with providing required training to graduate students in how to teach biology (AAAS, 2009).

Graduate Teaching Assistants (GTAs), who teach undergraduates, may be the most likely to adopt more student-centered instructional methods, such as facilitating small group interactive exercises, challenging students' naïve conceptions, and capitalizing on students' interests. Many higher education institutions employ GTAs for the teaching of undergraduate STEM courses, which include lectures, recitations, and laboratory classes. Often, undergraduate students have more contact with GTAs than faculty members in large introductory courses (Rushin et al., 1997). Moreover, GTAs, like new teachers, are just learning to teach. Just like new teachers, they need a solid preparation program that ensures they build their skills and knowledge in their instructional area. According to Schussler et al. (2015), there is a lack of consistency in professional development for GTAs with many programs being limited to 10 or fewer hours and providing insufficient pedagogical information and critical feedback. The design and implementation of effective GTA programs are critical components to successfully reforming undergraduate science teaching in both the near and long term as many GTAs will become faculty at institutions of higher education.

To support student persistence in STEM fields and increase the science learning of non-majors, STEM departments can leverage GTAs in the effort to reform of undergraduate science teaching. A teacher's knowledge base ultimately effects how they teach and what students learn. This study serves as a first step in characterizing GTA's knowledge of science teaching and identifying critical supports and barriers to their knowledge development. It expressly looked at how GTAs developed their knowledge to teach science as they participated in a GTA teaching course entitled "Scientific Teaching." The development of a knowledge base for teaching science among GTAs was documented through qualitative methods to address the following research questions:

1) What are the GTAs' orientations toward teaching undergraduate biology during the "Scientific Teaching" course?
2) What are the shifts in the GTAs' knowledge of students and pedagogical knowledge during the "Scientific Teaching" course?
3) What are the barriers and bridges to building the GTAs' knowledge to teach?

PCK: A Conceptual Framework of Teacher Knowledge

In the science education literature, many studies have investigated and sought to characterize the professional knowledge to teach, often referred to as pedagogical content knowledge (PCK). Initially conceptualized by Shulman (1986; 1987), this knowledge has been described as the transformation of content knowledge and other professional knowledge domains into instruction that impacts student learning (Grossman, 1990; Wilson, Shulman, & Richert, 1987). Studies in this area have provided insights into how the knowledge to teach develops in K-12 teachers (e.g., Friedrichsen, van Driel, & Abell, 2011; Geddis, 1993; Gess-Newsome, 1999; Lee et al., 2007; van Driel, Verloop, & De Vos, 1998). While the vast majority of studies have involved elementary and secondary teachers, few studies have focused on the development of this knowledge for teachers at the postsecondary level.

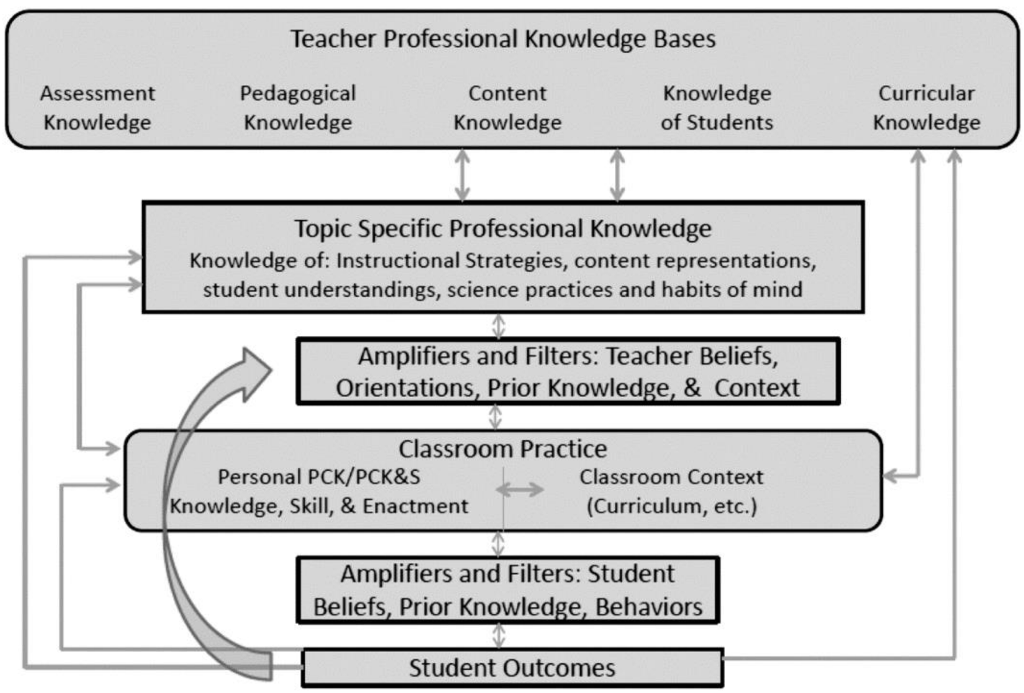


Figure 1. Model of teacher professional knowledge and skill including PCK and influences on classroom practice and student outcomes (adapted version from Berry, Friedrichsen, & Loughran, 2015).

Many different PCK models are presented in the literature, (e.g., Cochran, DeRuiter, & King, 1993; Grossman, 1990; Loughran, Mulhall, & Berry, 2004; Magnusson et al., 1999; Park & Oliver, 2008), however, a synthesized model culminated from a "PCK Summit" held in 2012, which involved a select group of science education researchers. Consensus was reached in defining PCK as "the knowledge of, and reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (Gess-Newsome, 2015, p. 36). PCK&S refers to a teacher's observed act of teaching that manifests in the classroom as a result of drawing upon PCK. The proposed model of PCK for science teaching (Gess-Newsome, 2015) includes teacher general professional knowledge bases (TPKB) and topic-specific professional knowledge (TSPK) along with as set of amplifiers/filters leading to PCK development (Figure 1). The diagrammatic depiction illustrates that PCK is influenced by teachers' professional knowledge, their beliefs and orientations toward teaching, and the context in which they teach.

Professional Knowledge Bases

Both general professional knowledge and topic-specific professional knowledge are important in PCK development. TPKB is a generic set of professional knowledge about (1) assessment, (2) pedagogy, (3) content, (4) students, and (5) curriculum. TSPK is knowledge about teaching a particular topic to students at a particular developmental level. This knowledge base would include instructional strategies, ways of representing the content, common naïve conceptions, and integration of science practices, all of which are directly related to a specific disciplinary topic (e.g., chemical equilibrium, natural selection, radiometric dating).

Amplifiers and Filters of the Teacher

The model indicates that these knowledge bases are filtered or amplified by a set of conditions unique to a teacher. As defined in the literature, teachers' orientations toward science teaching include their conceptions of teaching and preferred instructional approaches (Friedrichsen et al., 2011). Friedrichsen (2002) grouped previously identified teacher orientations into three main categories: (1) teacher-centered orientations (didactic and academic rigor), (2) orientations based upon reforms of the 1960s (process, activity-driven, and discovery), and (3) orientations based upon more recent reform efforts (conceptual change, project-based science, inquiry, and guided inquiry). The *teacher-centered* orientation category includes conceptions of teaching as the transmission of knowledge from a science expert to a novice with lecturing as the primary instructional approach. The other two categories are more *student-centered* in nature such that the conceptions of teaching revolve around students' ideas and instruction includes structured activities designed to build students' knowledge and skills.

Teaching Context

In addition, teachers experience varying conditions within the context of their teaching, which ultimately impact their teaching practices. Particularly influential elements of the teaching context include curricular resources and supplies for science teaching, allotted planning and instructional time, as well as political and cultural values of the schooling environment (Gess-Newsome, 2015). Both teachers' orientations and teaching contexts mediate the learning, acceptance, and integration of new knowledge into their classroom practice. This study explored GTA's knowledge development (TPKB) during an introductory "Scientific Teaching" course while seeking to identify the orientations and elements of the teaching contexts that served as bridges or barriers to their knowledge development.

Review of Relevant GTA Literature

In response to the recent calls for reforming undergraduate science teaching, studies indicate that widespread change has been slow with any major shifts resulting from the efforts of a select few faculty members (Hederson et al., 2011). Brownell and Tanner (2012) reported on faculty-identified barriers to pedagogical change, with the most common including insufficient training, time, and incentives. Insufficient training is consistent with faculty lacking knowledge of student-centered pedagogy (Luft et al., 2007; Yarnall et al., 2007) and maintaining beliefs that reformed teaching methods are no more effective than traditional approaches (Ebert-May et al., 2011; Handlesman et al., 2004). One strategy to address the lack of faculty training is to design and implement professional development programs for GTAs.

Many colleges and universities offer training for GTAs, but programs have historically been limited in scope, covering only general topics. Studies of GTA programs indicated a lack of mechanisms for developing important pedagogical and discipline-specific knowledge required for effective teaching practice (Luft et al., 2007; Hardre, 2012; Honeycutt et al., 2010). In addition, GTAs have reported little to no feedback from supervisory faculty (DeChenne, Enochs, & Needham, 2012; Prieto, 2001). However, some colleges and universities are making efforts to provide more focused GTA programs. The literature includes reports of GTA programs being extended to include various components, such as pre-semester multi-day workshops, teaching seminars, laboratory preparation meetings with instructional support, observations of GTAs' teaching, lesson study, and formal courses in science teaching for GTAs (Addy & Blanchard, 2010; Dotger, 2011; Gormally et al., 2011; Honeycutt et al., 2010; Lockwood et al., 2014). In recent review of GTA programs across the U.S. and Canada, Schussler et al. (2015) indicated that "many institutions or individual faculty or staff members at those institutions are rising to the challenge of providing formal PD opportunities to these key teachers of gateway and introductory biology courses" (2015, p. 10).

Some GTA programs include one or more formal science teaching courses. The literature provides recommendations for courses designed specifically for GTAs, such as modeling reformed teaching strategies (Marbach-Ad et al., 2010; 2012), embedding cooperative learning techniques (Wyse et al., 2014), challenging the teacher-centered beliefs of student learning (Addy & Blanchard, 2010), writing research-based teaching philosophy statements (Schussler et al., 2011), and including participation of faculty in the course studies (Dotger, 2011). Based upon these recommendations, an introductory "Scientific Teaching" course was designed and implemented as a primary component of a biology GTA training program.

Method

This study is based on a cohort of GTAs who participated in a "Scientific Teaching" course held during a spring semester at a large research institution. Quantitative and qualitative data were collected at the beginning and end of the course and used in the designed mixed methods study (Creswell & Plano Clark, 2010).

Study Setting

In working toward a broader goal of improving undergraduate science teaching and learning at a large research institution, faculty and administrators requested that a course be designed and implemented to support GTAs in teaching undergraduate biology courses. The "Scientific Teaching" 1-credit course was designed to support GTA learning in targeted areas in science education through a series of small group projects and selected readings. Ten class meetings were held weekly over a 12-week period with each class session lasting for a one-hour period. Emphasis each week was the practical application of the topics to teaching science in a large research university setting (Table 1).

The course was designed based upon recommendations from prior research, which aligned with developing knowledge and orientations for building effective PCK. Since teachers build their knowledge when they are engaged in practice (Cochran-Smith & Lytle, 1999), all of the GTAs in the course were active teaching assistants. Throughout the class sessions, the instructor modeled innovative instructional strategies, and engaged the GTAs to challenge their teacher-centered beliefs. In addition, the GTAs wrote a research-based rationale to support their instruction (Schussler et al., 2011). The course was specifically focused on building GTA's knowledge in the areas of instructional strategies and (2) student understanding.

Table 1
Target Topics Covered in the "Scientific Teaching" Course

Week	Target Topics	Specific Discussion Elements and Activities	Target Knowledge Base (TPKB)
1	Constructivism, concept maps	Created concept map of "science education", discussed how students learn	Students
2	Goals of undergraduate science education, inquiry	Discussed goals of undergraduate biology education, small group evaluation of labs	Curriculum, students
3	Conceptual change	Drew models of how students learn, paired and whole group discussions	Students, pedagogy
4	Conceptual change	Discussed status of ideas and naïve conceptions (photosynthesis, evolution) for undergraduate students	Students
5	Active learning and 5E lesson plan	Discussion of active learning and examined different strategies, co-constructed 5E lesson plan for specific topic in biology	Students, pedagogy
6	5E Lesson Plans	Small group presentations of 5E lesson plans, peer-review of lesson plans using rubric	Curriculum, students, pedagogy
7	Confronting realities of active learning	Group evaluation and discussion of videos of active learning environments	Assessment, students, pedagogy
8	Formative assessment	Small group discussions of opportunities for ongoing assessment using classroom scenarios and instructional decisions based upon student responses	Assessment, students, pedagogy
9	Student motivation	Discussed model of self-determination theory, small groups developed a lab using the elements the model	Students, pedagogy, assessment
10	Summative assessment	Small and whole group evaluation and discussion of multiple-choice questions and assignment rubrics using revised Bloom's taxonomy, small groups developed multiple-choice questions and rubrics for 5E lesson	Assessment

Participants

The participants in the study included a purposeful sample of ten GTAs in the biology department of a large research institution located in the southwestern region of the United States. The GTAs participated in the course as they were actively serving as GTAs in large, upper-division undergraduate biology courses. The names of the GTAs were replaced by pseudonyms for the purpose of protecting their anonymity. The sample included six female biology GTAs and four male GTAs. All GTAs were doctoral-level graduate students, however, they came from varied fields of biology that ranged from ecology to cellular and molecular biology. The participants also differed in their extents and levels of teaching experience (Table 2). Three of the GTAs had previous experience teaching at the secondary level. Given the small sample size (n = 10), the findings of this study are not considered to be representative of a large population of graduate assistants.

Data Collection

Data were collected at the beginning and end of the "Scientific Teaching" course using concept maps and open-ended questionnaires. Concept maps are graphical representations used for organizing knowledge and depicting relationships among concepts (Novak & Cañas, 2006). Concept maps have been used as an assessment tool in educational research (Gess-Newsome & Lederman, 1993; Morine-Dershimer, 1993). More recently, Hay, Kinchin, and Lygo-Baker (2008) discussed using concept maps to make understandings visible including prior knowledge, the learning of new concepts, and the links between existing and new knowledge structures. Although claims have been made that concept maps may reflect internal cognitive structures, it has not been established that the constructed diagrams are literal depictions of knowledge stored in the memory (Baxter & Lederman, 1999). In this study, the use of concept maps is limited to identifying any change in knowledge during a semester-long "Scientific Teaching" course.

Table 2
Participant Quantities and Types of Prior Teaching Experience

Name*	Gender	Prior K-12 teaching (years)	Prior GTA experience (semesters)
Bruce	M	0	over 9
Ellen	F	0	over 9
Judith	F	1	8
Scott	M	3	6
Danielle	F	0	4
Patrick	M	0	4
Rose	F	0	3
Annie	F	0	2
Joe	M	1**	2
Laura	F	0	1

* pseudonym ** experience in K-12 after-school program

Table 3
GTA Interview Questions and Associated Target Information

Target Information	**Interview Question**
Amount and nature of prior teaching experience	1. How many semesters have you taught at the undergraduate level?
	2. How many years have you taught at the K-12 level?
Orientation toward being a GTA and Supports/barriers to developing as a GTA	3. Why are you a TA?
	4. What were your primary responsibilities as a TA? Please describe in detail.
	5. What were some additional responsibilities as a TA? Please describe in detail.
	6. Did you have an opportunity(ies) to work directly with students in the course? If yes, how often did this occur during the semester? Please describe the interaction(s) in detail.

Administered at the end of the "Scientific Teaching" course, an open-ended questionnaire was designed to collect demographic information and information about the GTAs' orientation toward teaching. We specifically sought to capture information about the types and amounts of the GTAs' previous teaching experience, their reasons for being a GTA, a detailed description of their responsibilities as a GTA during the semester, and detailed descriptions of their direct interactions with students. Many of the questions posed were extremely general to allow the GTAs to report the information they deemed to be important (Table 3).

Procedure

Concept maps. The change in GTAs' TPKB, in the areas of knowledge of student understanding and knowledge of instructional strategies, was operationalized as the change in concept map scores. The GTAs created concept maps during the first and last class sessions of the teaching course. To effectively construct concept maps, the GTAs received approximately 20 minutes of training immediately prior to their constructing the concept maps on both occasions. The training included instruction about the components, organizational structure, and process of building concept maps. Following the training, the GTAs were asked to create concept maps for the general topic of "science education".

Steps were taken to quantify the concept map data. Traditional methods of scoring concept maps were explored, however, this did not provide fruitful results. An alternative scoring method employed by Weizman et al. (2008) assigned scores ranging from 0 to 3 for each TPKB domain. The nodes and links were examined against a list of a priori indicators to assess the knowledge level evidenced in the concept maps. Scores were assigned for each TPKB domain using a scoring rubric (Figure 2).

Score	0	1	2	3
Level of explanation of component of TPKB	The topic is not present.	The topic was just mentioned.	The topic was partly elaborated.	The topic was clear and explained.

Figure 2. Scoring system for pre- and post-concept maps presented in Weizman et al., 2008.

Table 4
List of Indicators for the Targeted TPKB

Indicators of Knowledge of Students	Indicators of Pedagogical Knowledge
• Knowledge of common student naïve conceptions • Connected to students' lives (authenticity) • Typical student trajectories of understanding (learning progressions) • Knowledge of student understanding through assessment	• Consider students' ideas and experiences • Include multiple representations and learning experiences • Cooperative learning • Instructional design is student-centered (5E, active learning, inquiry) • Motivating environment

A similar approach was used for this study. A list of indicators was generated based upon the goals of the "Scientific Teaching" course for the two TPKB: knowledge of student understanding and knowledge of instructional strategies (Table 4). Rather than assigning a general score for each domain, the scoring rubric was used to assign a score for each indicator. An average score for each domain was calculated using the indicator scores. After the concept maps were scored, the differences in the average TPKB domain scores were calculated between the pre- and post-concept maps for each GTA.

Open-ended questionnaire. The GTAs' responses to the open-ended questionnaire served as the source of qualitative data, which pertained to the amplifiers and filters that influence their teaching practice – their orientations toward teaching and the context of their teaching experiences. The questionnaire was completed during the last class meeting. Open coding of the GTAs' responses was conducted to identify themes regarding their reported interactions with students during the course. This process followed Bogdan and Biklen (2006). The emergent themes were used to classify each GTA in terms of their orientation towards teaching into one of two broad categories: *teacher-centered* or *student-centered*. Given that the open-ended questions were general in nature, information gathered from the questionnaire regarding the GTAs' orientations toward teaching and specific instructional practices may be limited.

Results

Question 1: What Were the GTAs' Orientations toward Teaching Biology during the "Scientific Teaching" Course?

The questionnaire responses describing the GTAs' interactions with students were coded, and emergent themes were used to classify the GTAs' orientation toward teaching. Based upon the emergent themes derived from the reported interactions with students, the GTAs were classified in one of two broad categories: *teacher-centered* or *student-centered*. Six of the GTAs' were classified as having a teacher-centered orientation while four were classified as having a student-centered orientation toward teaching.

Annie illustrates a typical student-centered orientation. She served as a GTA during the 2011-2012 academic year and had no prior experience as a graduate teaching assistant. Although Annie did not have direct interactions with students as a GTA in the spring, her response described the nature of her interactions with students as a GTA during the fall semester prior to the teaching course. Annie described these interactions as follows:

> I worked with the students directly every week during recitation. At first I was primarily lecturing and taking questions from students. Later in the semester, I had them work in groups to solve problems; I would walk around to the groups and ask them questions about the problems, and take questions from them. I would also pick individuals or groups to explain how to solve the problems to the class.

Annie's orientation toward teaching emphasized instruction that supported students to construct their knowledge in collaboration with their peers. Her role was to facilitate student learning through questioning and having students articulate their explanations. Scott, Joe, and Judith reported having similar interactions with students and thus also held student-centered orientations toward teaching.

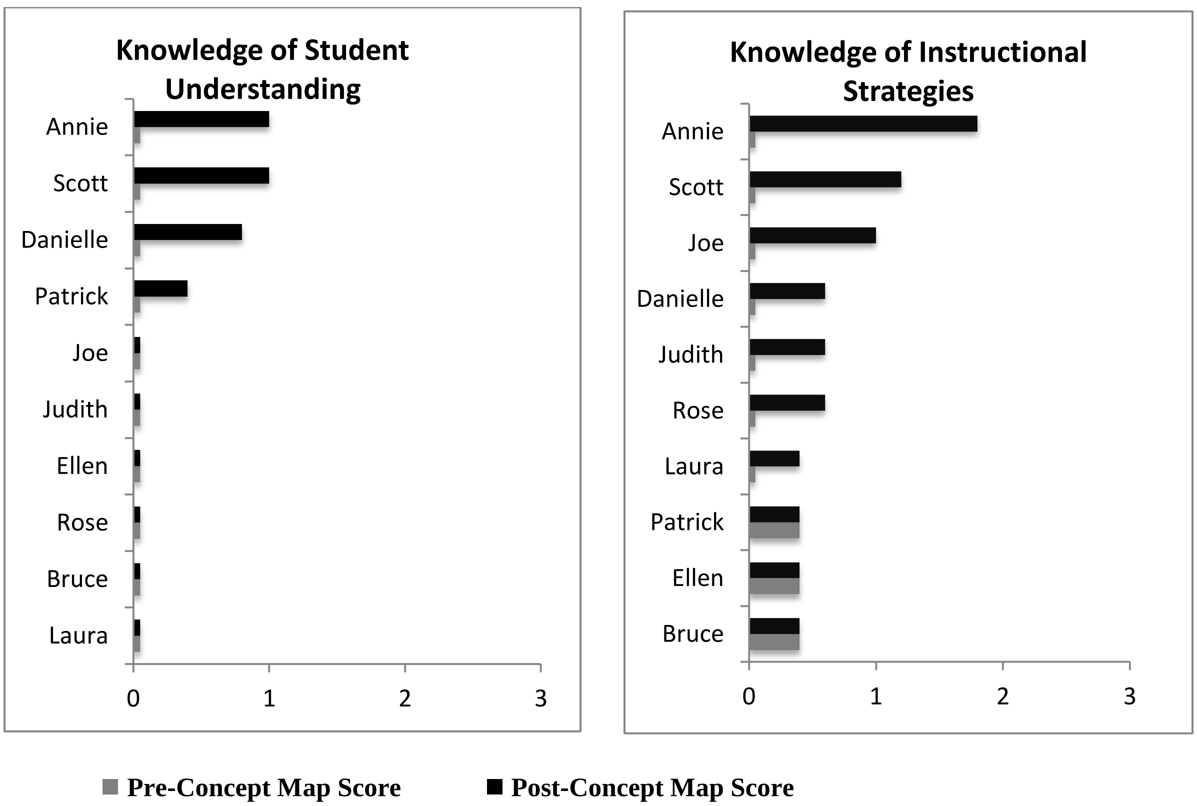
Bruce was classified as having a teacher-centered orientation toward teaching biology, and was typical of this group. His interactions primarily involved lecturing to students. Bruce reported having over nine semesters of experience as a graduate teaching experience. As a GTA, he was provided with the opportunity to work directly with students in lecture and in the laboratory setting. Bruce described his interactions with students as follows:

> I interact with students in the lecture as well as the lab that meets two times a week. The lecture interaction involved me presenting lecture material as well as facilitating small group discussions. The laboratory section allowed me to work with students on a 1 on 1 basis as well as assist the lead lab TA. I lectured roughly 50% of the time and was present in lab 50% of the time.

Bruce's orientation toward teaching emphasized the transmission model of teaching in which knowledge from a science expert is delivered to a novice via lecture. Danielle, Rose, Laura, Patrick, and Ellen reported having similar interactions with students and thus also held teacher-centered orientations toward teaching.

Question 2: What Are the Shifts in the GTAs' Knowledge of Students and Pedagogical Knowledge during the "Scientific Teaching" Course?

The "Scientific Teaching" course was designed to build the GTAs' TPKB within two knowledge bases, (1) knowledge of students and (2) pedagogical knowledge, with an emphasis on their general knowledge of student understanding and knowledge of instructional strategies. The scores from the pre- and post-concept maps were used to identify shifts in GTAs' knowledge of student understanding and knowledge of instructional strategies. Score results for the two targeted knowledge bases are presented in Figures 3a and 3b.



Figures 3a and 3b. Pre- and post-concept map scores for knowledge of student understanding and knowledge of instructional strategies along with score differences.

The pre-concept maps revealed that none of the GTAs related student understanding to the general topic of "science education". At the conclusion of the teaching course, four of the ten GTAs represented indicators of student understanding on the post-concept map. The six remaining GTAs did not mention student understanding on the post-concept map. Overall, the GTAs had little to no positive shifts in the knowledge domain of student understanding during the teaching course.

On the pre-concept map, seven of the GTAs did not mention instructional strategies, while three of the GTAs included one or more indicators of instructional strategies. At the end of the teaching course, all of the GTAs included some indicators of instructional strategies. The three GTAs that included indicators on the pre-concept map also included the same level of indicators on the post-concept map, indicating that they had no shift in this particular area. However, seven of the GTAs had some level of positive shift in the knowledge domain of instructional strategies.

The calculated score differences for both knowledge domains were averaged to generate an overall average score (Table 5). Following the "Scientific Teaching" course, two of the GTAs had positive shifts in their TPKB (average differences greater than 1.0), however, eight of the GTAs had little to no shift.

Table 5
Changes in TPKB Indicated by Difference between pre- and post-Concept Map Scores and Overall Score Averages

Name	Average Concept Map Scores		
	Post - Pre Difference Student Understanding	Post - Pre Difference Instructional Strategies	Avg. Post –Pre Differences
Annie	1	1.8	1.4
Scott	1	1.2	1.1
Danielle	0.8	0.6	0.7
Joe	0	1	0.5
Judith	0	0.6	0.3
Rose	0	0.6	0.3
Patrick	0.4	0	0.2
Laura	0	0.4	0.2
Bruce	0	0	0
Ellen	0	0	0

Question 3: What Were the Bridges and Barriers to Building the GTAs' Knowledge to Teach?

To address this research question, the amplifiers/filters to the GTAs' PCK were examined by merging the qualitative data and quantitative data along with demographic information. The GTAs' orientations toward teaching were compared to the overall average shift in TPKB. In addition, demographic data were included in the analysis, which illuminated bridges and barriers to building the GTAs' professional teaching knowledge. On the open-ended questionnaire, the GTAs reported their number of semesters of previous experience as a GTA and their reasons for being a GTA. They also described their teaching context by reporting the GTA roles assigned to them by their faculty mentors.

The GTAs differed in their overall TPKB gains as well as their orientations toward teaching and reasons for being a graduate teaching assistant. The individual overall TPKB gains are presented in Table 6 with the GTAs grouped by teaching orientation and purpose for being a GTA. Half of participants reported being a GTA to gain experience teaching at the undergraduate level while the other half reported being a teaching assistant primarily for funding purposes. Four of the GTAs were determined to have a student-centered orientation toward teaching, with three participants being among those that had the greatest positive shifts in TPKB.

Table 6
Overall TPKB Gains with GTAs Grouped by Their Reported Purpose for Being a GTA and Teaching Orientation

Orientation	Purpose of Being a GTA	
	GTA for Experience	GTA for Funding
Student-Centered Orientation	Annie (TPKB gain = 1.4) Scott (TPKB gain = 1.1) Joe (TPKB gain = 0.5)	Judith (TPKB gain = 0.3)
Teacher-Centered Orientation	Danielle (TPKB gain = 0.7) Rose (TPKB gain = 0.3)	Laura (TPKB gain = 0.2) Patrick (TPKB gain = 0.2) Ellen (TPKB gain = 0) Bruce (TPKB gain = 0)

Note. TPKB gains are based on differences of GTAs' average concept map scores; shown in ().

GTAs for undergraduate teaching experience: Annie, Scott, Joe, Danielle, and Rose. Five of the ten GTAs – Annie, Scott, Joe, Danielle, and Rose – reported being a GTA to gain teaching experience and/or improve their teaching practice. On average, the GTAs in this group had less than four semesters of undergraduate teaching experience, but varied in their gains in TPKB. In comparing the overall score differences, Scott and Annie had greater shifts in their TPKB than all of the other GTAs. Joe and Danielle had moderate gains, and Rose's concept map scores indicated minimal gains.

Orientations toward teaching. This group of GTAs had varying orientations toward teaching. Three of these five GTAs reported having interactions with students consistent with the student-centered orientation toward teaching: Scott, Annie, and Joe. However, Rose and Danielle were classified as having a teacher-centered orientation as they reported employing didactic methods of teaching.

Teaching context. This group of GTAs had vastly different roles assigned by their faculty mentors, which influenced the nature of their interactions with students. Scott and Annie were assigned roles that allowed them to have frequent direct interaction with students independent of their faculty mentor. Scott and Annie had regularly scheduled weekly meetings with students during recitation. The GTA roles assigned to Joe and Danielle by their mentor faculty provided opportunities for them to work directly with students, however, these interactions were irregular and unstructured. Although the meetings were not regularly scheduled, Joe and Danielle met with the students independent of their faculty mentors for exam review sessions. Rose was extremely restricted in her interactions with students as she served as an assistant during faculty-led lectures. Her primary role was to answer questions posed by students during small group work.

GTAs for graduate degree funding: Judith, Patrick, Bruce, Ellen, and Laura. Five of the ten GTAs – Judith, Patrick, Bruce, Ellen, and Laura – reported being a GTA for funding purposes without making mention of gaining teaching experience. Three of these GTAs reported a desire to be funded as a research assistant rather than a GTA. On average, the GTAs in this group had more than six semesters of undergraduate teaching experience and had similar gains in TPKB. In comparing the overall score differences, the GTAs in this group had little to no shifts in their TPKB.

Orientations toward teaching. Based upon their reported interactions with students, four of the five GTAs in this group were classified as having a didactic orientation toward teaching.

Bruce, Ellen, Patrick, and Laura all reported interactions with students that were consistent with a didactic orientation. In contrast, Judith was classified as having a student-centered orientation toward teaching. She indicated that her faculty mentor directed her to engage in teaching practices aligned with a student-centered approach, however, Judith expressed that she found this approach to teaching to be very difficult for her.

Teaching context. Similar to the previous group, these GTAs were assigned vastly different roles by their faculty mentors, which influenced the nature of their interactions with students. Bruce, Ellen, and Judith were provided with regular opportunities to work directly with students independent of their faculty mentor (e.g., course lab sessions, recitations). However, Patrick and Laura were extremely restricted in their interactions with students. Patrick was assigned to deliver a single lecture to the class along with answering student questions during office hours. Laura occasionally answered student questions at the end of faculty-led lectures, however, her primary function was to grade assignments and tests.

Discussion

This study was conducted to identify shifts in TPKB for ten GTAs during a “Scientific Teaching” course and examine the influence of the GTAs’ teaching orientations and teaching contexts as amplifiers and filters of their knowledge development. Concept map scores indicated that the GTAs increased their knowledge in the area of instructional strategies more than in the area of student understanding. Consistent with the concern-based theory of teachers, the GTAs focused primarily on the instructional tasks of the teacher and the student, and did not transition to thinking about student understanding during the course (Fuller, 1969; Fuller & Bown, 1975). The “Scientific Teaching” course provided to the GTAs was limited to the ten contact hours with the instructor and fellow GTAs. As a minimum of 80 hours of professional development are needed before changes are found in teacher practices, the “Scientific Teaching” course was not sufficient to produce significant changes in the GTAs’ teaching practices (Supovitz & Turner, 2000).

The orientations and teaching context that serve as amplifiers and filters to the GTAs building their PCK were also investigated in the study. GTAs’ self-reported interactions with students revealed varied orientations toward teaching; however, the GTAs with the highest gains in TPKB held student-centered orientations. The teaching contexts of the GTAs were dictated by the roles assigned by the course faculty members, and the GTAs’ primary responsibilities varied widely such that they had different levels and frequencies of interactions with students. (e.g., regular weekly recitations, irregular and limited number of lectures coupled with weekly offices hours, and assignment and exam graders). The GTAs having regularly scheduled direct interactions with students, independent of the mentor professor, had the highest gains in TPKB. These settings provided GTAs with consistent opportunities to implement reformed teaching practices and receive feedback from students. Those GTAs with restricted interactions with students had limited TPKB development. This is consistent with educational research reporting that teachers build their knowledge when they are engaged in practice (Cochran-Smith & Lytle, 1999).

Prior experience as a GTA also influenced their knowledge development. On average, the GTAs with the largest increase in their TPKB had lower levels of experience whereas those with higher levels of experience made little to no gains. In addition, the GTAs’ motivation for being a teaching assistant was a factor. Those GTAs with the desire to develop their teaching practices had larger increases in their TPKB than those who elected to be a GTA for funding purposes.

Conclusions

This exploratory study sought to characterize GTA's changes in knowledge of science teaching in the context of a "Scientific Teaching" course and identifying critical supports and barriers to their knowledge development. Programs would better support GTAs by providing longer and more sustained teacher professional development that is initiated early in TA experience. To facilitate GTAs moving from thinking about what students are doing to how students are learning, departments could ensure that assigned GTA-roles provide regular and structured opportunities, which optimize working directly with students and encourage practice of innovative teaching strategies. Building a community of faculty and graduate students that values teaching would support the GTAs in seeking to improve their teaching practices. As part of a community that values teaching, the GTA program would serve to promote GTA assignments as opportunities for developing teaching skills and diminish the view of the position as simply being a source of funding.

To further understand bridges and barriers to building successful GTA programs, future studies should investigate the GTA training programs in biology across multiple institutions to further define the amounts and types of professional development needed by GTAs that is specific to science teaching and learning, the assigned roles of GTAs, and the context and culture of teaching community in which GTAs function. While GTAs may increase their knowledge of reformed science teaching through a formal course or training sessions, the translation of knowledge in to teaching practice. Additional research should focus on the impact of sustained professional development and instructional coaching on GTAs' knowledge for teaching as well as changes in their teaching practices. This work would be bolstered by direct observations of GTAs' teaching practices rather than self-reported approaches to teaching.

For institutions working to make reforms to undergraduate biology teaching through graduate assistant training, the findings of this study offer important information to consider in designing GTA programs for undergraduate science teaching. As such, we suggest that biology faculty and graduate students across institutions work together toward developing more meaningful programs, which may lead to certification in teaching in higher education, that build GTAs' professional knowledge bases for implementing reform-based strategies as well as provide regular opportunities for GTAs to practice engaging with students in a supportive environment.

References

American Association for the Advancement of Science. (2009). *Vision and change in undergraduate biology education: Preliminary reports of conversations*. Retrieved from http://visionandchange.org/files/2010/03/VC-Prelimary-Reports-from-Conversations1.pdf

American Association for the Advancement of Science. (2015). *Vision and change in undergraduate biology education: Chronicling change, inspiring the future*. Retrieved from http://visionandchange.org/files/2015/07/VISchange2015_webFin.pdf

Addy, T. M., & Blanchard, M. R. (2010). The problem with reform from the bottom up: Instructional practices and teacher beliefs of graduate teaching assistants following a reform minded university teacher certificate programme. *International Journal of Science Education, 32*(8), 1045-1071.

Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 147-162). Boston, MA: Kluwer Academic Publishers.

Berry, A., Friedrichsen, P., & Loughran, J. (Eds.). (2015). *Re-examining Pedagogical Content Knowledge in Science Education*. New York, NY: Routledge.

Bogdan, R. C., & Biklen, S. K. (2006). *Qualitative research for education: An introduction to theory and methods*. Needham Heights, MA: Allyn & Bacon.

Brownell, S. E., & Tanner K. D. (2012). Barriers to faculty pedagogical change: lack of training, time, incentives, and…tensions with professional identity? *CBE-Life Sciences Education*, *11*(4), 339-346.

Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical content knowing: An integrative model for teacher preparation. *Journal of Teacher Education*, *44*(4), 263-272.

Cochran-Smith, M., & Lytle, S. L. (1999). The teacher research movement: A decade later. *Educational Researcher, 28*(7*)*, 15-25.

Creswell, J. W., & Plano Clark, V. L. (2010). *Designing and conducting mixed methods research.* Thousand Oaks, CA: SAGE.

DeChenne S. E., Enochs L. G., & Needham, M. (2012). Science, technology, engineering, and mathematics graduate teaching assistants teaching self-efficacy. *Journal of the Scholarship of Teaching and Learning*, *12*(4), 102-123.

Dotger, S. (2011). Exploring and developing graduate teaching assistants' pedagogies via lesson study. *Teaching in Higher Education*, *16*(2), 157-169.

Ebert-May, D., Derting, T. L., Hodder, J., Momsen, J. L., Long, T. M., & Jardeleza, S. E. (2011). What we say is not what we do: Effective evaluation of faculty professional development programs. *BioScience*, *61*(7), 550-558.

Friedrichsen, P. (2002). *A substantive-level theory of highly-regarded secondary biology teachers' science teaching orientations* (Unpublished doctoral dissertation). The Pennsylvania State University, University Park, PA.

Friedrichsen, P., van Driel, J. H., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education*, *95*(2), 358-376.

Fuller, F. F. (1969). Concerns of teachers: A developmental characterization. *American Educational Research Journal*, *6*, 207-226.

Fuller, F. F., & Bown, O.H. (1975). Becoming a teacher. In K. Ryan (Ed.), *Teacher education*. 74th Yearbook of the National Society of Education (pp. 25–52). Chicago, IL: University of Chicago Press.

Geddis, A. N. (1993). Transforming subject-matter knowledge: The role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education*, *15*(6), 673-683.

Gess-Newsome, J., & Lederman, N. G. (1993). Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment. *Science Education*, *77*(1), 25-45.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3-17). Boston, MA: Kluwer Academic Publishers.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK Summit. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.). *Re-examining pedagogical content knowledge in science education*. (pp. 28-42). New York, NY: Routledge.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York, NY: Teachers College Press.

Hardré, P. L., & Burris, A. O. (2012). What contributes to teaching assistant development: differential responses to key design features. *Instructional Science*, *40*(1), 93-118.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S. M., & Wood, W. B. (2004). Scientific teaching. *Science*, *304*(5670), 521-522.

Hay, D. B., Kinchin, I., & Lygo-Baker, S. (2008). Making learning visible: The role of concept mapping in higher education. *Studies in Higher Education*, *33*(3), 295-311.

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, *48*(8), 952-984.

Honeycutt, B. T., Ferzli, M., Morant, T., & Egan Warren, S. (2010). An interdisciplinary approach to graduate TA training: A reflection of best practice. In L. L. B. Border (Ed.), *Context and content in the preparation of future faculty* (pp. 138-152). Stillwater, OK: New Forums Press.

Lee, E., Brown, M. N., Luft, J. A., & Roehrig, G. H. (2007). Assessing beginning secondary science teachers' PCK: Pilot year results. *School Science and Mathematics*, *107*(2), 52-60.

Lockwood, S. A., Miller, A. J., & Cromie, M. M. (2014). Preparing future biology faculty: an advanced professional development program for graduate students. *The American Biology Teacher*, *76*(1), 17-21.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, *41*(4), 370-391.

Luft, J. A., Kurdziel, J. P., Roehrig, G. H., & Turner, J. (2007). Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching*, *41*(3), 211-233.

Marbach-Ad, G., Schaefer, K. L., Kumi, B. C., Friedman, L. A., Thompson, K. V., & Doyle, M. P. (2012). Development and evaluation of a prep course for chemistry graduate teaching assistants at a research university. *Journal of Chemical Education*, *89*(7), 865-872.

Marbach-Ad, G., Shields, P. A., Kent, B. W., Higgins, B., & Thompson, K. V. (2010). A prep course for teaching assistants: Building a community. In L. L. B. Border (Ed.), *Context and content in the preparation of future faculty* (pp. 44-58). Stillwater, OK: New Forums Press.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95-132). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Morine-Dershimer, G. (1993). Tracing conceptual change in preservice teachers. *Teaching and Teacher Education*, *9*(1), 15-26.

National Research Council. (1999). *Transforming undergraduate education in science, mathematics, engineering, and technology*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog/6453/transforming-undergraduate-education-in-science-mathematics-engineering-and-technology

National Research Council. (2000). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog/9853/how-people-learn-brain-mind-experience-and-school-expanded-edition

National Research Council. (2003). *Evaluating and improving undergraduate education in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog/10024/evaluating-and-improving-undergraduate-teaching-in-science-technology-engineering-and-mathematics

National Research Council. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. Washington, DC: The National Academies Press. Retrieved from

National Research Council. (2015). *Reaching students: What research says about effective instruction in undergraduate science and engineering*. Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog/18687/reaching-students-what-research-says-about-effective-instruction-in-undergraduate

Novak J. D., & Cañas, A. J. (2006). *The theory underlying concept maps and how to construct them.* Florida Institute for Human and Machine Cognition: Pensacola, FL. Retrieved from http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*(3), 261-284.

Prieto, L. R. (2001). The supervision of teaching assistants: theory, evidence, and practice. In: Prieto, L. R. & Meyers, S.A. (Eds.) *The Teaching Assistant Training Handbook*, (pp. 103-129). Stillwater, OK: New Forums Press.

Rushin, J. W., De Saix, J., Lumsden, A., Streubel, D. P., Summers, G., & Bernson, C. (1997). Graduate teaching assistant training: A basis for improvement of college biology teaching and faculty development? *American Biology Teacher, 59*(2), 86-90.

Schussler, E. E., Rowland, F. E., Distel, C. A., Bauman, J. M., Keppler, M. L., Kawarasaki, Y., McCarthy, M. R., Gover, A., & Salem, H. (2011). Promoting the development of graduate students' teaching philosophy statements. *Journal of College Science Teaching*, *40*(3), 32-35.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving. Why undergraduates leave the sciences*. Boulder, CO: Westview Press.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1 – 21.

Supovitz, J. A., & Turner, H. M. (2000).The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching*, *37*(2), 963-980.

The President's Council of Advisors on Science Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Retrieved from https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-executive-report-final_2-13-12.pdf

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673-695.

Weizman, A., Covitt, B. A., Koehler, M. J., Lundeberg, M. A., Oslund, J. A., Low, M. R., Eberhardt, J., & Urban-Lurain, M. (2008). Measuring teachers' learning from a problem-based learning approach to professional development in science education. *The Interdisciplinary Journal of Problem-based Learning*, *2*(2), 29-60.

Wilson, S. M., Shulman, L. S., & Richert, A. (1987). 150 different ways of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 104–124). London, UK: Cassell.

Wyse, S. A., Long, T. M., & Ebert-May, D. (2014). Teaching assistant professional development in biology: Designed for and driven by multidimensional data. *CBE-Life Sciences Education*, *13*(2), 212-223.

Yarnall, L., Toyama, Y., Gong, B., Ayers, C., & Ostrander, J. (2007). Adapting scenario-based curriculum materials to community college technical courses. *Community College Journal of Research and Practice*, *31*(7), 583-601.

Author Notes

Kathleen M. Hill
Associate Director and Assistant Professor of Science Education
Center for Science and the Schools
Pennsylvania State University
kathyhill@psu.edu

Kathleen Hill is the Associate Director of the Center for Science and The Schools at Penn State. Her professional activities focus on teacher professional development at both the K-12 and higher education levels. Her research studies focus on investigating teachers' pedagogical and content knowledge development as they engage in the practice of teaching.

Miles Orchinik
Associate Professor
School of Life Sciences
Arizona State University
m.orchinik@asu.edu

Miles Orchinik is a neuroscientist in the School of Life Sciences at Arizona State University who studies how stress alters behavior, brain function, and the endocrine system. He is also interested in science education research, particularly in how undergraduates learn core concepts, and which teaching methods are most effective at promoting learning.

Current Issues in Education

Mary Lou Fulton Teachers College • Arizona State University
PO Box 37100, Phoenix, AZ 85069, USA

Volume 19, Issue 2 | August 24, 2016 | ISSN 1099-839X

SOME RIGHTS RESERVED Readers are free to copy, display, and distribute this article, as long as the work is attributed to the author(s) and *Current Issues in Education (CIE)*, it is distributed for non-commercial purposes only, and no alteration or transformation is made in the work. More details of this Creative Commons license are available at http://creativecommons.org/licenses/by-nc-sa/3.0/. All other uses must be approved by the author(s) or *CIE*. Requests to reprint *CIE* articles in other journals should be addressed to the author. Reprints should credit *CIE* as the original publisher and include the URL of the *CIE* publication. *CIE* is published by the Mary Lou Fulton Teachers College at Arizona State University.

Editorial Team

Executive Editor
Constantin Schreiber

Assistant Executive Editor
Anna Montana Cirell

Authentications Editor
Tray J. Geiger

Layout Editor
Constantin Schreiber

Copy Editor
Lucinda Watson

Section Editors
Earl Aguilera
Evelyn Concepcion Baca
James Cunningham
Darlene Michelle Gonzales
Laura Beth Kelly
Tomé Martinez
Priyanka Parekh
Niels Piepgrass
Bethany Richmond
Olivia Stewart
Joseph Sweet
Lori Talarico

Faculty Advisors
Dr. Gustavo E. Fischman
Dr. Jeanne M. Powers