

Assessing a Professional Development for Teaching Assistants in a Project-Based Guided Inquiry General Chemistry Lab

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Abstract

The purpose of this investigation was to explore changes in teaching assistants' (TAs) content knowledge, perceptions of their role, and perceptions of the effectiveness of a professional development following professional development. The professional development was informed by the K-12 professional development and TA training literature bases as well as situated learning theory. It was designed for TAs implementing a project-based guided inquiry approach to General Chemistry laboratory instruction. The professional development was assessed using a sequential mixed methods approach. Participants included 8 graduate TAs and 5 undergraduate TAs. Data collection included TA pre-, post-, and delayed-post surveys and post- and delayed-post interviews. Data were analyzed using t-tests and systematic data analysis (Miles & Huberman, 1994). Results indicate TAs' content knowledge significantly improved following the professional development ($M=80.2\%$, $t(11) = 2.20$, $p = .025$) and was maintained over the semester. By the end of the semester, the majority of TAs perceived their roles to include facilitating student learning (61.5%) and helping students act like scientists (53.4%). TAs cited modeling, performing experiments, and discussing logistics as the most helpful professional development components. TAs with no teaching experience and low content knowledge prior to the professional development had more malleable beliefs compared to TAs with previous teaching experience. The results of this investigation suggest situated learning theory may be an effective professional development model for TAs teaching reforms-based general chemistry lab courses. Further, TA previous experience, confidence, content knowledge, and self-efficacy may influence the extent to which professional development changes TAs beliefs. Future research will focus on examining TA self-efficacy, TA practice, and TA impact on student outcomes following implementation of professional development to support a project-based guided inquiry approach to general chemistry laboratory instruction.

Keywords: inquiry, laboratory science, professional development, teacher beliefs

Laboratory instruction in undergraduate education provides students opportunities for active, “hands-on” learning (Bond-Robinson, 2000; Cho, Sohoni, & French 2010; Herrington & Nakhleh, 2003) and is a venue to help students connect concepts (Bond-Robinson & Bernard Rodrigues, 2006; Baumgartner, 2007). However, the traditional approach to laboratory experiments (e.g. cookbook, verification, expository) has been heavily criticized for not providing opportunities for students to think critically (Domin, 1999; Germann, Haskins, & Auls, 2005). The National Research Council (NRC) and the American Chemical Society have charged undergraduate science departments to implement science curricula that integrate reforms-based practices (Cooper, 2010; NRC, 2000). One such curriculum is a project-based guided inquiry (PBGI) approach to general chemistry laboratory instruction, which served as the context for the present study.

At large universities, graduate students teach undergraduate science labs or recitations sections (e.g. Cho et al., 2010; Lawrenz, Heller, Keith & Heller, 1992; Luft, Kurdziel, Roehrig, & Turner, 2004). Thus, they play an essential role in the quality of undergraduate education (e.g. Bomotti, 1994; Carroll, 1980; Kendall & Shussler, 2013) and can influence retention of students majoring in the sciences (Cho et al., 2010; Baumgartner, 2007), particularly minorities and females (Gardner & Jones, 2011). Yet, graduate teaching assistants (TAs) typically have little previous teaching experience (e.g. Hammrich, 2001; Krockover, 1980; Nurrenbern et al., 1998; Sharpe, 2000), so it is essential to support TAs as laboratory instructors. The literature primarily describes TA training programs (e.g. Birk & Kurtz, 1996; Clark & McLean, 1976; Sharpe, 2000) and only a subset of these rigorously examine the effectiveness of such programs (e.g. Roehrig, Luft, Kurdziel, & Turner, 2003). Thus, researchers have called for further empirical studies on TAs and TA programs (e.g. Hammrich, 2001; Gardner & Jones, 2011; Luft et al., 2004). Further, only a handful of studies focus on TAs teaching in reforms-based laboratories (e.g. French & Russell, 2002; Volkmann & Zgagacz, 2004).

In this study, we address this gap in the literature by developing and assessing a professional development for TAs implementing a PBGI approach for a general chemistry laboratory. Specifically we assessed the relationships between TAs’ prior experience (French & Russell, 2002), content knowledge (Rushton, Lotter, & Singer, 2011), and teaching beliefs (Addy & Blanchard, 2010) following a professional development as well as the TA’s perceptions of the professional development. The characteristics of effective K-12 professional development (e.g. Desimone, 2009; Guskey & Yoon, 2009; Loucks-Horsley & Matsumoto, 1999), characteristics of TA training (e.g. Luft et al., 2004; Roehrig et al., 2003), and situated learning (Lave & Wenger, 1991) guided the design and assessment of the professional development.

Guided Inquiry and Project-based Learning

Two instructional approaches currently used to re-design general chemistry include inquiry-based instruction and project-based learning. Scientific inquiry instruction can be defined as “an active learning process in which students answer research questions through data analysis in a manner consistent with how scientists do their work” (Maeng, Mulvey, Smetana & Bell, 2013, p 841). In a project-based instructional approach, students are given a problem with a driving question they have to solve over time by engaging in research and scientific inquiry (Blumenfeld et al., 1991).

Within an inquiry context, the degree of support provided to students determines the level of inquiry. In open inquiry, students develop their own question and procedures, and they do not know what results to expect in advance of doing the investigation. However, open inquiry has been criticized for not providing enough structure for student success (Kirshner, Sweller, & Clarck, 2006), and undergraduate professors believe incoming students may not be able to handle this type of inquiry (Brown, Abell, Demir, Schmidt, 2006). In guided inquiry, students are provided with a specific research question and develop the procedure for answering the question. Some research has been done on guided

inquiry (what they call “open inquiry”) compared to the traditional cookbook laboratory approach (what they called “guided inquiry”). These studies suggest guided inquiry (what they called “open inquiry”) improves student affect, student perception of learning, and laboratory competence (Chatterjee, Williamson, McCann & Peck, 2009; Suits, 2004). Because guided inquiry may be an effective method of laboratory instruction, a number of universities currently implement this approach into physical chemistry and organic chemistry labs (e.g. Deckert, Nestor & DiLullo, 1998; Gaddis & Schoffstall, 2009).

Another method used to restructure traditional chemistry laboratories is project-based instruction. The project-based learning approach provides students the opportunity to work collaboratively and to actively engage in an authentic problem to gain scientific knowledge (Blumenfeld et al., 1991; Hmelo-Silver, 2004). Project-based learning, like guided inquiry, has been implemented in analytical chemistry and atomic & molecular introductory chemistry courses (O’Hara, Sanborn, & Howard, 1999; Wenzel, 1995). Additionally, results from a previous study indicate project-based learning in a general chemistry class, when compared to traditional laboratory instruction, result in significant improvement in student learning outcomes (Barak & Dori, 2004).

Thus, both guided inquiry and project-based learning demonstrate promise for improving student outcomes in chemistry. However, one barrier to implementing inquiry in an introductory course is the lack of structure provided to the students. Therefore combining these two approaches into a project-based, guided inquiry (PBGI) approach has the potential to be an appropriate method of instruction for general chemistry as it simultaneously makes the experience authentic and manageable for students with little experience in engaging in “real” science.

Teaching assistants in undergraduate lab courses

One practical aspect of a PBGI approach to chemistry laboratory instruction which bears consideration is implementation. For large general chemistry laboratory courses, TAs are often the primary instructors. In fact, TAs have been described as the “first line of defense for instruction” (Nicklow, Marikunte, & Chevalier, 2007, p. 89) and the “bridge between faculty and students” (Dotger, 2011, p. 158). Laboratory TAs take on a variety of different roles and responsibilities such as grading, giving pre-lab lectures, knowing lab procedures, ensuring student safety, getting out equipment/materials, teaching lab techniques, and holding office hours (Calkins & Kelley, 2005; Cho et al., 2010; Herrington & Nakhleh, 2003; Roehrig et al., 2003). During lab, TAs are expected to know and explain the content, relate lecture concepts and abstract concepts to labs, and help improve students’ process skills (Addy & Blanchard, 2010; Bernard Rodrigues & Bond-Robinson, 2006; Cho et al., 2010; Luft et al., 2004). Teaching techniques TAs are expected to implement in laboratories include: questioning strategies, providing students feedback, helping students engage in critical thinking and analysis of data, effectively communicating content, assessing student prior knowledge and understanding, using formative assessment, being a facilitator, and understanding student misconceptions and difficulties (Addy & Blanchard, 2010; Bond-Robinson & Bernard Rodrigues, 2006; French & Russell, 2002; Hammrich, 2001; Luo, Grady, & Bellows, 2001).

Many of these studies reveal the expected roles of TAs conflict with their perceived roles and practice (e.g. Addy & Blanchard, 2010; French & Russell, 2002; Luft et al., 2004). For example, the literature indicates one of the TA’s main role in lab is to help students learn content; however, in practice TAs tend to focus on helping students with procedural issues rather than content (Bond-Robinson & Bernard Rodrigues, 2006; Luft et al., 2004). In addition, Luo et al. (2001) found that TAs were split on perceiving their role as facilitator or disseminator of information.

Other studies suggest two main factors may influence TAs perceptions of their pedagogical role: prior experience (Herrington & Nakhleh, 2003; French & Russell, 2002) and beliefs (Addy &

Blanchard, 2010; Volkmann & Zagagcz, 2004). First, TAs with prior teaching experience perceived their role as facilitator compared to TAs with no teaching experience. Herrington & Nakhleh (2003) surveyed 14 TAs with previous teaching experience on their perception of characteristics of an effective TA. These TAs indicated one characteristic of an effective TA was to facilitate student learning rather than provide answers. Similarly, French and Russell (2002), surveyed 12 experienced TAs and 15 inexperienced TAs on their perceptions of their role teaching in an inquiry-based biology lab. TAs who previously taught in inquiry-based labs initially perceived their role as facilitators and helping students with the “process of science” while TAs with no inquiry-based teaching experience perceived their role as disseminator of information and focused on classroom management and teaching concepts.

Second, beliefs about teaching may influence TAs perceptions of their role, which in turn may influence their practice (Addy & Blanchard, 2010; Volkmann & Zagagcz, 2004). Addy and Blanchard (2010) observed and interviewed 8 biology lab TAs employing a traditional curriculum. Researchers used the Reformed Teaching Observation Protocol (RTOP) instrument and assessed TAs’ beliefs about teaching using the Teacher Beliefs Instrument (TBI). TAs in this study did not implement practices aligned with their beliefs, despite the differences in TAs’ understandings of their role. Overall, TA’s had the lowest RTOP scores in the domains of providing students support with communicating ideas, divergent thinking, and using student talk to dictate the direction of discussions. Volkmann & Zagagacz (2004) used a phenomenological study to explore one physics TA teaching an inquiry-based physics course for elementary education students. They found that by mid-semester the TA modified her practice, but her beliefs remained didactic. By the end of the semester, the TA’s beliefs changed to more facilitator beliefs; however, she struggled to find ways to implement these beliefs. This body of research on TAs implies TA perceptions of their role, prior experience, and beliefs may influence their instruction and that TAs must be supported through professional development.

Professional development for teaching assistants

A search of the literature identified twenty-three studies which describe and assess TA training or professional development (e.g. Hampton & Reiser, 2004; Nurrenbern, Mickiewicz, & Francisco, 1999; Nicklow et al., 2007; Sharpe, 2000). Based on this literature, TA training can be categorized into three types of programs: general university-wide orientation programs, course-specific GTA training programs, and teaching seminars. General orientation programs span multiple disciplines and focus on university policies and procedures, which science TAs find unhelpful (Luft et al., 2004). Teaching seminars are typically voluntary courses TAs take to help prepare them to become better science teachers, and many are not focused on the immediate TA teaching assignment (e.g. Baumgartner, 2007; Clark & McLean, 1979). Training programs are usually specific to subject or department area and help TAs better understand their current teaching assignment.

The existing studies on TA training vary in their rigor. The least rigorous studies provide descriptions of TA training program components, but the results are anecdotal at best (Birk & Kurtz, 1996; Clark & McLean, 1976; Hammrich, 1996; Krockover, 1980; Lawrenz et al., 1992; Nicklow et al., 2007; Sharpe, 2000). Three studies assessing TA training programs appear to be rigorous enough to warrant further discussion (Addy & Blanchard, 2010; Luft et al., 2004; Roehrig et al., 2003). In a study of TA training programs in physics, biology, and chemistry labs, Luft et al. (2004) found that TAs, faculty, and staff agreed that many of characteristics of the current training programs for TAs were not sufficient. Luft et al. (2004) recommended TA training should be aligned with characteristics of effective professional development found in the K-12 literature. Interviews of 6 TAs in an inquiry-based laboratory setting revealed TAs did not understand their role in the inquiry-based labs, and they did not implement practices aligned with inquiry-based instruction (Roehrig et al., 2003). The authors concluded that using modeling, reflection, and explicit instruction about inquiry-based practices may

improve TA teaching effectiveness. Addy & Blanchard (2010) interviewed and observed biology TAs which showed the beliefs of the TAs varied but their practice was more teacher-centered than student centered. The authors believe the conflicting results were due to the inconsistency between the traditional lab approach and the reforms-based instruction from the teaching seminar the TAs attended. Taken together, the results of these studies suggest TA professional development should include the following components: practical course details, mentoring, feedback/reflection, pedagogy, modeling, and teaching culture. The details on how each component is carried out vary slightly by department, course, and implementer; however, these components represent an overall consensus from the literature about what should be included in TA training. In addition, incorporating components of effective K-12 professional development, specifically modeling, reflection, and explicit inquiry instruction into TA professional development may be effective. Further, the pedagogy discussed in the TA professional development should align with the course curriculum.

Comparison of TA professional development with K-12 professional development

A handful of studies call for the use of education faculty expertise and reference the educational literature in developing and assessing TAs and TA programs (Addy & Blanchard, 2010; Baumgartner, 2007; Luft et al. 2004). Researchers generally agree that there are fundamental professional development characteristics that help promote changes in teacher learning, teacher practice, and possibly student learning including: content, coherency, collective participation, best-practices, and sustained support (Desimone, 2009; Guskey & Yoon, 2009; Loucks-Horsley & Matsumoto, 1999; Luft & Hewson, in press). These characteristics are not specific to science education and span different types of professional development; thus, they may also be applicable to professional development of TAs.

Professional development focused on *content* should incorporate clear content objectives for what the teacher should know (Luft & Hewson, in press) and pedagogical content knowledge (Desimone, 2009, Guskey & Yoon, 2009, Loucks-Horsley & Matsumoto, 1999). A *coherent* professional development program addresses the context of teaching (Desimone, 2009; Luft & Hewson, in press). The professional development should be aligned with local or national standards, which in science education can be integrating reforms-based practices like the essential features of inquiry (NRC, 2000) or characteristics of scientific practices (NRC, 2012). The term *collective participation* refers to whether groups of teachers in the same school or content area are involved in the professional development (Desimone, 2009; Loucks-Horsley & Matsumoto, 1999; Luft & Hewson, in press). Collective participation provides opportunities for dialogue and collaboration between teachers of similar disciplines, which Luft & Hewson (in press) indicate help improve teacher knowledge and confidence. Professional development should also include *best-practices* for teachers (Desimone, 2009; Guskey & Yoon, 2009), which may take the form of active learning or discipline specific practices such as inquiry or problem-based learning in science education. Finally, *sustained support* describes the type of follow-up support provided to teachers after the professional development. This can be characterized as helping teachers reflect on practice, providing teachers feedback on practice (Desimone, 2009; Louckys-Horsley & Matsumoto, 1999), and offering teachers individualized support over time (Guskey & Yoon, 2009; Luft & Hewson, in press).

Analyzing the TA training literature and the K-12 professional development literature provides insight into what characteristics should be incorporated into TA professional development. Table 1 overviews the alignment between these two bodies of research. Practical course details include discussing expectations and responsibilities, providing *coherency* to the TA professional development. As these practical course details are typically discussed during weekly meetings, they also serve as a *sustained support*. Other forms of *sustained support* include modeling and mentoring. Pedagogical approaches such as micro-teaching or teaching TAs about inquiry-based instruction are *best-practices*.

Further, these strategies should be embedded in the *content* related to the lab to provide TAs an active and authentic learning opportunity similar to what their students experience. Finally, professional development can address the *collective participation* aspect of K-12 professional development by involving faculty and encouraging TA discussions (changing the culture of TA professional development).

Table 1

Alignment of TA training components with characteristics of effective K-12 professional development

TA Training Component	Characteristics of Effective K-12 Professional Development				
	Content	Coherency	Collective participation	Best-practices	Sustained support
Practical course details		x			x
Mentoring					x
Feedback/reflection					x
Pedagogy	x			x	
Modeling	x			x	
Teaching Culture			x		

In summary, the literature provides evidence that it may be beneficial to incorporate the following into TA training: modeling pedagogy and linking instruction to content, opportunities for self-reflection of teaching, and incorporating best-practices such as learning theory and modeling reforms-based practices. Differences in TAs' and K-12 teachers' experience and training imply some additional components including explicit discussion of expectations and responsibilities, grading, mentoring, and feedback, should also be included in TA training.

Situated Learning

According to situated learning theory, learners create knowledge and become 'experts' as they meaningfully participate within a community of practice (Lave & Wenger, 1991). This community of practice includes the social, ethical, and historical norms affecting how people interact with the objects in their environment and with each other. Situated learning indicates certain characteristics of the community of practice will aid in individuals' transition from novice to expert. These include: participating in authentic learning opportunities, understanding the significance of concepts and skills, and experiencing and practicing expert language. These components can be achieved through an apprenticeship model, where an expert models, coaches, and fades support for novice members of their community of practice. The TA training that served as the context for the present investigation integrates these components, as detailed in the methods. Therefore, situated learning theory provides an appropriate theoretical perspective through which to frame this investigation.

Purpose

TAs play an important role in quality undergraduate laboratory courses and should be supported in their teaching. Previous research indicates TAs need to know and be able to explain content and use reforms-based pedagogical practice in their instruction. TAs' perception and implementation of these roles may be influenced by their prior experience and beliefs. Thus, developing an effective TA professional development model and assessing how it influences the TA is essential. However, little rigorous research assesses how TAs implement a reforms-based curriculum in large-enrollment chemistry courses (Roehrig et al., 2003; Sandi-Urena et al., 2011). Furthermore, no research has utilized a situated learning framework for TA training or has examined changes in TA's content knowledge

following professional development. The purpose of this study is to assess the components of the professional development for TAs implementing a PBGI approach in general chemistry. The research questions that informed the study were:

1. What changes, if any, in TA's content knowledge, beliefs about teaching, and their understanding of their TA role, occurred following the professional development?
2. How did the TAs perceive the professional development as supporting their ability to effectively implement the PBGI approach?
3. What suggestions do the TAs have to improve the professional development?

Methods

An explanatory sequential mixed-methods approach (Hesse-Biber, 2010) was employed to explore changes in TA's content knowledge, beliefs, perceptions of their role, and perceptions of a professional development informed by situated learning theory. Specifically, we used surveys and interviews to answer the research questions.

Participants

Participants were 8 female and 5 male TAs teaching General Chemistry lab ranging in age from 20 to 26 years old. Of the participants, 5 reported their ethnicity as Caucasian, 5 were Asian, 1 was Middle Eastern, and 2 declined to provide ethnicity data. In addition, 8 were part-time graduate student TAs and 5 were part-time undergraduate student TAs. The graduate students, all Ph.D. students in chemistry, were 1st, 2nd, or 3rd year students whose funding came from their TA assignment. The 1st year graduate students taught while concurrently taking graduate science classes. Those 2nd or 3rd year graduate students worked in a research lab and were required to TA because their advisor could not provide funding. Each graduate participant taught two sections of lab, totaling approximately 50 students (approximately 25 students per section). Undergraduate participants were 3rd or 4th year undergraduates majoring in chemistry who applied to be a TA. Only undergraduates with high GPAs and positive references from chemistry professors were accepted as TAs. Undergraduate participants only taught one section of lab. Table 2 provides demographic information including previous teaching and research experience for the 13 TAs. Pseudonyms are used throughout.

Table 2
Participant Demographics

Participant (pseudonyms)	Program	Highest Degree	Teaching experience	Research experience
Christine ⁺	3 rd year undergraduate	none	none	none
Karen	3 rd year undergraduate	none	tutoring – undergraduate students	none
Michelle	3 rd year undergraduate	none	none	faculty lab- undergraduate; summer research program
Peter	4 th year undergraduate	none	none	faculty lab- undergraduate
Andrew ⁺	4 th year undergraduate	none	tutoring – K-12 and college	faculty lab- undergraduate
Steven* ⁺	1 st year graduate	Master's	tutoring – high school students	faculty lab- undergraduate
Mike	1 st year graduate	Bachelors	tutoring – undergraduate students	summer research program
Margaret	1 st year graduate	Bachelors	TA - general chemistry lecture	faculty lab- graduate
Jessica ⁺	2 nd year graduate	Bachelors	TA - general chemistry lab	faculty lab- graduate
Seth ⁺	2 nd year graduate	Bachelors	TA - general chemistry lecture (guided inquiry); TA- general chemistry lab; TA- analytical lab	faculty lab- undergraduate and graduate
Caroline	2 nd year graduate	Bachelors	TA-general chemistry lecture, TA-general chemistry lab	faculty lab-undergraduate and graduate
Patty*	2 nd year graduate	Bachelors	TA-general chemistry lab	faculty lab- graduate; summer research program; research technician
Helen ⁺	3 rd year graduate	Bachelors	TA- general chemistry lab; TA- analytical lab	faculty lab- undergraduate and graduate

Note: *= international TA; ⁺ = interview participant

Context

The professional development was situated within the context of a PBGI-based general chemistry laboratory curriculum. In the first semester of general chemistry lab students have a 3.5 hour lab period once a week for twelve weeks. Students work with a single TA who is responsible for their section. The defined role of these TAs included: 1) interacting with students as a guide/facilitator, 2) supporting students acting as scientists, 3) maintaining safety in the lab, 4) helping students with lab technique, 5) grading student work, 6) fostering student discussions through the use of questioning, and 7) encouraging students to try multiple experimental methods to solve each problem.

In the PBGI approach, students complete four projects over the course of the semester. For each project, students are provided an overarching scientific research question within a real world context. The students work collaboratively to plan and implement their approach to the project. The TA interacts with the students on a weekly basis and assesses student work, including experimental plans, experimental summaries, presentations, and lab reports. The TA also supports the students in lab through each project. TAs use the cognitive apprenticeship model to model, coach, and scaffold the support provided to students during planning, experimenting, analyzing data, and communicating results. The TAs help guide students through the planning process and ensure students have a detailed enough (not necessarily correct) plan to be able to experiment. During experimentation time, the TA provides students with feedback on lab techniques, ensures students' safety in the lab, and encourages them to run multiple trials, write down all procedures in their lab notebook, and make sense of their data during lab. After each groups' presentation, the TA facilitates a group discussion about groups differing experiments and results. These expectations were explicitly discussed and outlined for the TAs (Methods Supplement A).

TA professional development. The TA professional development was developed to explicitly incorporate characteristics of effective TA and K-12 inquiry-based professional development (e.g. Desimone, 2006; Luft et al., 2004) within a situated learning framework (Lave & Wenger, 1991). Feedback from TAs who experienced a pilot version of the professional development and PBGI curriculum also informed the design of the professional development that served as the basis for the present investigation. TAs completed a pre-semester week-long professional development and attended weekly TA meetings incorporating these components (Table 3).

Table 3
PBGI professional development details

PD components (from TA training and K-12 PD literature)	Pre-semester week	Weekly follow-up meetings	Situated Learning characteristics
Practical course details ⁺	Student responsibilities	Waste and safety for each project, lab technique demonstrations to show students, student responsibilities	---
	Graded sample lab reports, graded TA presentations	Graded sample plans and summaries, discussed lab report grading and presentation grading for each project	Authentic learning opportunities
	Read and discussed course syllabus and TA responsibilities, Small group discussion of lab/grading scenarios and TA's response	Ensured TAs completed grading in a timely fashion and attended office hours	---
Pedagogy ⁺	Took different roles for lab projects and group work	Took different roles for lab projects and worked together to develop content-based discussion	Authentic learning opportunities
	Planned, experimented, and summarized lab projects 1 & 2, developed presentation and presented project 1	Planned, experimented, and summarized lab projects 3 & 4	Authentic learning opportunities
	Learned and read about guided inquiry	Guided inquiry workshop through university and share experience	Understand the significance of pedagogy
Modeling ⁺	Modeled how to interact with students during lab projects, modeled how to encourage discourse between students	Modeled how to use questioning to help struggling students	Cognitive apprenticeship, Experience expert language
	TAs read guided inquiry article, watched a modeled discourse circle and practiced in small groups with provided facilitation questions	Encouraged TAs to use discourse during content-based discussion and use discourse questions during student planning sessions in lab	Cognitive apprenticeship, Practice expert language
Content*	Application of content during TA completion of lab projects	TA-led content-based discussions	Understand significance of content, Practice of expert language

Note: *=component of K-12 professional development literature; ⁺ = component of TA training literature

The professional development began with a week-long session prior to the beginning of the semester, totaling 29 contact hours. First, TAs discussed course and TA expectations, then they worked in teams to complete two of the four PBGI projects. To provide TAs an *authentic learning experience*, the TAs acted as students and developed a procedure for the projects. The TAs also observed the type of *appropriate language* and interactions they should have with students as the first author modeled coaching and cognitive apprenticeship. TAs also had opportunities to practice their own facilitative language and learned the *significance* of the PBGI approach during the discourse session. Throughout the semester TAs were supported through 14 weekly meetings, totaling 35 contact hours. TAs continued to have experiences aligned with situated learning, as outlined in Table 3.

Data collection

In order to assess the professional development, participants completed surveys and interviews. Survey and interview protocols were reviewed by a panel of science education experts and chemistry content experts, who provided support for face and content validity (Haynes, Richard, & Kubany, 1995; Newman & McNeil, 1998).

Surveys. Surveys assessed changes in participants' understanding of inquiry, content knowledge, and beliefs about teaching and their perceptions about the professional development. The survey took approximately 30 minutes to complete and was administered before and after the week-long professional development (pre-survey and post-survey, respectively) and at the end of the semester (delayed post-survey). Each survey included 9 content-based questions and 4 open-ended questions related to beliefs and TA role. The pre-survey contained an additional 10 questions about the participants' demographics and prior experience including age, ethnicity, gender, prior degrees, year in program, previous research experience, previous teaching experience, and previous experience with inquiry-based teaching as a teacher and student. The post-survey contained an additional 9 open-ended questions pertaining to participant's perception and feedback about the professional development.

The content-based survey questions were chosen based upon their alignment with the project objectives. A panel of chemistry content experts evaluated these questions for their clarity, accuracy, and alignment with the objectives. Changes to these questions were made based upon the panel member's feedback. Pre-survey content-based questions responses were also analyzed to determine retention or removal of items from the survey. Questions that the majority of participants correctly answered the question and that had an item discrimination value of .2 or less were removed from the survey. Those questions with both low item discrimination and that the majority of participants did not answer correctly were retained as these questions had the potential to reveal participants' content understanding on the mid- and post-surveys.

Interviews. A subset of 6 participants were purposefully selected to complete semi-structured interviews after the week-long professional development (post-interview) and at the end of the semester (delayed post interview) based upon their program (i.e. undergraduate, 1st year graduate or returning graduate) and their background experience in teaching and research. One participant was also selected because he was an international graduate student. The approximately 30 minute interviews contained questions about their teaching beliefs, perceptions of their role, and the professional development (Methods Supplement B). Further, incorporating follow-up questions to survey responses in the interview protocol served as a member check of the participants' perceptions. The interview also focused on how the participant perceived the effectiveness of the professional development as supporting their implementation of PBGI. The post-interview contained an additional four questions following up on their answers to survey questions about their prior experience. The delayed post-interview asked six additional questions about their perceptions of the professional development.

Data Analysis

Survey and interview responses were analyzed both quantitatively and qualitatively. Quantitative data about content and inquiry were analyzed using a paired t-test. The use of these multiple data sources allowed for triangulation of data related to TA beliefs, perceptions of their role, and perceptions of the professional development. Qualitative data from open-ended survey questions and interview questions about inquiry and teacher beliefs were analyzed using systematic data analysis (Miles & Huberman, 1994).

Quantitative data analysis. The multiple choice questions assessing the participant's content were coded as correct (1) or incorrect (0). A rubric was developed for the open-ended content questions and reviewed by a panel of experts to ensure its accuracy and consistency with possible answers. Each answer to the open-ended questions was scored using the rubric. For example, when asked to give a net ionic equation for a particular reaction, a participant received 3 points for correctly writing the net ionic equation with correct states. The participant received 2 points if they did not include states or wrote the correct chemical equation (not net ionic equation). The participant received 1 point if they wrote a net ionic equation that was not the correct net ionic equation, and no points were given if the chemical formulas for any compound were incorrect. Participants received a score for the percent of correct content-based questions on the pre, mid, and post survey. The pre/post, post/delayed post, and pre/delayed post scores were analyzed using paired t-tests. The data were tested for normality and sphericity. A Greenhouse-Geisser correction was used to determine significance as the assumption of sphericity was not met.

Qualitative data analysis. Qualitative data related to participants' beliefs about teaching, TA role, and perceptions of the professional development were analyzed using systematic data analysis (Miles & Huberman, 1994). The first researcher coded the data, then a second researcher coded a subset of the data. This use of a second researcher in the data analysis process ensured the trustworthiness of the data used to support the coding schemes. First, a priori categories about teaching beliefs and TA role based upon previous TA research were identified and included categories such as "TA-as-disseminator" versus "TA-as-facilitator." A participant who discussed facilitator teaching methods included statements such as TA as a "reference guide" or TA to "facilitate inquiry." Teaching methods categorized as disseminator included TAs "answering questions" and TA "providing [students] with enough knowledge." The two researchers had 83% agreement when coding for facilitator/disseminator, and all disagreements were resolved upon discussion. Pre-determined codes about the professional development originated from the TA training literature and included the following categories: cooperative groups, completing projects as students, learning theory, modeling, discourse, content, and practical course details.

After initial categories were identified, the data set was read holistically to identify any additional categories arising inductively. A subset of the data was discussed with a second researcher to ensure codes were clear and consistent. For example, a third teacher belief category arose inductively out of the data, called facilitator-disseminator. Participants with a mixture of both responses were categorized using this third category. After coding the data, a second reading through the data across participants and across data points for each participant helped collapse or expand codes. For example, the single code for practical course details was expanded into codes about grading, safety, and predicting student problems. Data analysis was complete when the researchers agreed the qualitative data were accurately represented by the coding scheme.

Results

The purpose of this study was to assess a professional development for TAs implementing a PBGI approach to general chemistry lab informed by situated learning and existing research on TA and

K-12 professional development. First, we discuss changes in participants' content understanding. Then, we describe changes in participants' beliefs about teaching following the professional development. Participants' perceptions about the professional development and its ability to support their implementation of the PBGI curriculum are presented next. Finally, relationships between participants' content knowledge, beliefs, and prior experience are discussed.

Content Understanding

A paired t-test of the 12 participants who completed the content-based assessment across all time points (92% response rate) revealed significantly improved content understanding following the week-long professional development ($M=80.2\%$, $t(11) = 2.20$, $p = .025$) (Table 4). This content knowledge was maintained at the end of the semester. Further, first year graduate students entered the professional development with a higher average content knowledge ($M=79.4\%$) than undergraduates ($M=52.4\%$) or the returning graduate students ($M=59.1\%$). The undergraduate TAs made the most improvement after the week-long professional development (pre/post difference = 32.1%) and like the first year graduate students maintained this at the end of the semester (1.2% and 1.6% respectively). The 2nd/3rd year graduate students' content knowledge decreased by the end of the semester (-3.7%).

Table 4

Participant Scores on Content-based Survey Questions (n=12)

	Pre (%)	Post (%)	Delayed post (%)
All (n=12)	61.9	80.2*	79.4
Undergraduates (n=4)	52.4	84.5	85.7
1 st year graduates (n=3)	79.4	77.8	79.4
2 nd /3 rd year graduates (n=5)	59.1	78.0	74.3

Note: * = significant difference ($p < .05$). No inferential statistics performed on subgroups due to sample size.

TA Beliefs about Teaching

Open-ended survey and interview responses indicated 9 of the 12 participants (75%) beliefs about teaching shifted following the professional development (Table 5). The 3 participants whose beliefs did not change maintained facilitator beliefs across the study. For the remaining participants, their beliefs were categorized as facilitator ($n=2$), disseminator ($n=1$), or facilitator-disseminator ($n=6$) prior to the professional development. Following the professional development, all participants holding facilitator beliefs shifted to facilitator-disseminator beliefs, and all participants holding either disseminator or facilitator-disseminator beliefs shifted to facilitator beliefs. By the end of the semester, 5 of the 9 participants (56%) retained their post-professional development beliefs, 1 participant shifted from facilitator-disseminator to facilitator, 2 participants reverted back from facilitator to facilitator-disseminator, and 1 participant shifted from facilitator to disseminator.

Table 5
Participant Beliefs About Teaching (n=12)

	Pre (%)	Post (%)	Delayed post (%)
Facilitator	5 (41.7)	10 (83.3)	8 (66.7)
Facilitator-Disseminator	6 (50.0)	2 (16.7)	3 (25.0)
Disseminator	1 (8.3)	0 (0.0)	1 (8.3)

Interview data supports changes evidenced in the survey data. For example, Steven indicated how his idea about TAing changed on the delayed-post interview:

Previously I think as a TA, I might just be here. [The students] have to learn what they should do from a textbook or from the lecture, and then they just do it, and I am here to answer questions....But now I know it's better for them to learn something...I think a lot of the time, if you give them the direct answer they don't understand it. They just copy your answer...but you can obviously tell that they don't understand why it is like this. (delayed post-interview).

Steven shifted from wanting to give students answers to realizing students just copy and do not learn when they are given answers.

Conversely, Seth, whose views shifted from facilitator to facilitator-disseminator following a semester of teaching, described his TAing experience using the PBGI approach:

There are times when you're like, 'I just need to flat out tell you this'. That's just going to be the easiest route for everyone. Most convenient route. No reason to drag on (delayed post-interview).

Seth believed there were instances when providing students' answers rather than facilitating discussions was most appropriate. When giving an example of when he gave students answers, he described an instance in which he instructed students on a different method to help them gather more accurate data. Seth's comment and example in which TAs needed to provide students' procedural and lab technique-related answers was representative of the other participant whose beliefs shifted from facilitator to facilitator-disseminator views across the semester.

Data revealed participants believed the purpose of laboratories was to either apply content learned in lecture or to learn content. Christine, like the majority of other undergraduate TAs, believed lab was a venue for applying content. She noted, "I think the best way for students to learn is lecture paired with hands-on experience" (delayed post-survey). Conversely, Caroline believed the purpose of lab was for learning content. She stated "I think students learn best when they have to struggle with the material first. Students will not learn if the answers are just given to them" (delayed post-survey). Caroline believed lab was a place for students to learn as they grappled with concepts, and passive learning, such as lecture, did not necessarily help students learn. Helen, a 3rd year graduate TA, also believed lab was more than just a place to apply chemistry content. When interviewed about the PBGI approach, she stated, "I feel like I'm helping them learn science as opposed to just doing science...getting them to think about why they're going, what they're doing" (delayed post interview). Consistent with the majority of the 2nd/3rd year graduate student TAs, Helen's experience helped her see the laboratory setting as a mode of learning rather than an application of science.

TA Role in PBGI General Chemistry Labs

Overall, participants' perception of their role shifted to become more aligned with the expectations of their role (Table 6). Prior to the professional development, participants described their roles as one of the following: being a guide, helping with lab techniques, and maintaining safety. After

the professional development, participants predominately perceived their role as maintaining safety in the lab. Since the majority of the professional development involved completing the projects, the emphasis on this role was expected. However, at the end of the semester, most participants described their role as a guide/facilitator in lab.

Table 6

Alignment of Participants' Perceptions of Their Role with the Expected TA Role (n=13)

Expectations	Pre (%)	Post (%)	Delayed-post (%)
Guide/facilitator for lab	9 (69.2)	4 (30.8)	8 (61.5)
Support students acting like scientists	1 (7.7)	4 (30.8)	7 (53.4)
Maintain safety	6 (46.2)	5 (38.5)	4 (30.8)
Provide lab technique feedback	2 (15.4)	1 (7.7)	1 (7.7)
Grading	1 (7.7)	1 (7.7)	1 (7.7)
Foster discussion	0 (0.0)	2 (15.4)	1 (7.7)
Encourage multiple methods	0 (0.0)	0 (0.0)	0 (0.0)
Affective*	0 (0.0)	5 (38.5)	5 (38.5)
Helping students learn content*	2 (15.4)	2 (15.4)	5 (38.5)

Note: * denotes expectation not explicit component of TA role

Guide/facilitator role. Karen described her role as “asking students questions to guide them toward their goal” (delayed post-survey). In fact, all 6 of the interviewed participants indicated that interacting with students during lab as a guide was the most enjoyable aspect of TAing. Seth’s response is representative of the TAs: “Actually being in lab, interacting with students. It’s fun watching that aha moment when they don’t understand something and you keep questioning them and there there’s that sudden click” (post interview). Seth perceived interacting with students as a facilitator rather than giving them the answers as rewarding. This positive reinforcement may explain why some participants maintained their beliefs about being a facilitator versus disseminator.

Support students as scientists. The number of participants who perceived their role as supporting students acting like scientists increased after the professional development (n=1 to n=4) and at the end of the semester (n=7), suggesting they better understood their role following the professional development. For example, after the professional development participants described their role as “more than making sure they do things right, to see that they understand important things about the project” (Patty, post survey) and “to teach the students to think scientifically” (Michelle, post-survey). Jessica, a 2nd year graduate TA, used her own experience to help students understand that experiments do not always go as planned in real scientific research. When discussing student reactions to experiments that did not work, Jessica stated:

It’s science and it’s not going to work the first time you do it...If you give them an example, I’d say ‘I’m doing research in my lab, do you think that the first time I do something it works? No, of course not. You may do it 200 times, and it still may not work. But that’s just how it goes (post-interview).

At the end of the semester, participants indicated their role was “getting students to communicate ideas well” (Mike, delayed post), “getting them to think about their process and the reasons for each step they plan to take” (Karen, delayed post), and “encourage them to think critically” (Andrew, delayed post-survey). Participants appeared to develop an in-depth understanding of the scientific practices students

should engage in during lab. This may be related to their experience interacting with students or the follow-up professional development sessions.

Grading responsibilities. Participants rarely discussed grading when asked about their role (7.7%); however, when asked about their least favorite aspect of TAing, 9 participants (69%) stated “grading lab reports.” Participants struggled with time and consistency when grading. When asked about his least favorite aspects of TAing, Andrew responded:

I guess people grade grubbing bothers me a lot for single points here and there...It’s like they’re trying to argue that their lab reports did something well when I don’t think they did it as well. It’s kind of hard because it’s the nature of a lab course. There is going to be a little bit of subjectivity in there (delayed post interview).

Andrew perceived grading was subjective, which may have been a problem for his students. Christine also voiced her concern about grading, “The part I probably disliked the most is when they give me a hard time about their grade” (delayed post interview). She then discussed how students argued with her on whether they met certain criteria in the lab report rubric. Both the time required to grade labs and the ability to consistently grade lab reports using the rubric resulted in participants’ dissatisfaction with this component of their role.

Encourage multiple methods. No TAs identified an expectation of their role as encouraging students to try multiple methods. Rather than discussing this type of divergent thinking as part of their role, 5 of the participants (38%) believed their role was to “push students in the right direction” or to help students “find the answer.” The only instance of divergent thinking was when Karen described her ideal general chemistry lab: “Students are ... *approaching the problem from various angles* and constantly asking questions and searching for the answers” (delayed post-survey, italicized for emphasis).

Content and affective roles. Some participants also perceived content and affect to be additional components of their role not explicitly discussed in the professional development. On the delayed post-survey 5 participants (38%) felt they were responsible for helping students understand content. For example, Andrew indicated his role was to “help the students understand their topics without giving them the answers straight up” (delayed post-survey). All of the participants who indicated their role was to help students with content also believed the purpose of lab was to apply content.

Five of the 6 interviewed participants also felt part of their TA role was affective in nature. Affective characteristics included “getting students to like chemistry,” “motivating students in lab,” and “helping students feel comfortable asking questions.” When asked about her favorite part of TAing, Christine said “A lot of them came into it and they really didn’t like chemistry. And some of them at the end were like ‘Oh, chemistry is okay’. And I was like, ‘Awesome!’” (delayed post-interview). Clearly she was pleased when her students shared some of that passion. Participants also felt part of their TA role was to motivate students. Andrew shared how he motivated his students:

I was always trying to remind them why things are useful....And a lot of them really went above and beyond because they were interested...even though they knew we weren’t grading them on the quality of their experiments like yield and stuff like that, they still wanted to make them fit the requirements because they knew it would be useful (delayed post-interview).

He perceived helping students see the applicability of what they were doing in lab would encourage additional laboratory experiments.

Jessica’s responses on the delayed post survey and interview reflected contradictory views about her role in lab. On the delayed post-survey, she perceived her role as affective - “making sure the students feel comfortable with what they’re doing”. However, in her delayed post-interview she stated

her role was content-related - to help students "...apply their knowledge. I think that's where, at least I found as a TA, you have to step in the most to make that sense."

In summary, interview and survey data revealed the majority of TAs understood their role included being a guide/facilitator and helping students act like scientists by encouraging scientific practices. The TAs perceived these interactions with students as the best part of their role, while the grading aspect was the least favorite aspect of their role. Some TAs also explained their role as ensuring students' safety, providing students' lab technique feedback, and fostering discussion. Only one TA perceived their role as encouraging divergent thinking, while the remaining TAs believed they should help students to one correct answer. This expectation was likely not made explicit in the professional development. Finally, TAs perceived two additional roles not part of their expected role: content-based and affective-based roles.

Relationship between content, beliefs, and prior experience

There appeared to be a relationship between participants' prior experiences, content knowledge, and teaching beliefs.

Prior experience and content knowledge. The data suggest there a relationship between participants' prior teaching experience and content knowledge existed. The 3 participants with no teaching experience had a lower initial content knowledge (M=39.7%) than those with tutoring, TAing, or co-instructor teaching experiences (M=69.1%). By the end of the semester participants with no prior teaching experience increased their content knowledge by 46% compared to those participants with teaching experience, whose content knowledge increased by 15%.

Prior experience and teaching beliefs. Participants' prior experiences as teachers and students also appeared to inform their beliefs about teaching. All 5 of the 2nd/3rd year graduate participants had previous TA experience in the traditional non-PBGI general chemistry labs. These teaching experiences in both a non-reforms-based and reforms-based chemistry curricula may have influenced their beliefs about how students learn. Helen described the differences she perceived in the course:

I felt like last year it was a lot of 'make sure your buret is straight up and down. Make sure it's permanent pink'. Versus now it's 'why would you want to add hydrochloric acid over acetic acid? What are the fundamental differences in those acids?' So getting them to think about why they're doing what they're doing versus what they're doing...It's obviously so fantastic that we're talking about the why behind science (delayed-post interview).

Her previous teaching experience informed her beliefs about the course. She valued the shift from *what* to *why* and perceived this to be beneficial to students.

In addition, results suggested more prior teaching experience corresponded to less change in TA beliefs (Table 7). Two of the 3 participants with no teaching experience held facilitator-disseminator beliefs prior to the professional development, but developed facilitator beliefs by the end of the semester. Conversely, participants with extensive teaching experience did not change their beliefs over the semester. For example, when asked how his ideas about TAing changed over the course of the semester, Seth, a 2nd year graduate participant with extensive experience teaching through inquiry responded: "not a whole lot because I already had my POGIL [process oriented guided inquiry learning] experience, and I liked that system" (delayed-post interview). He went on to explain how he had not changed his approach to interacting with students, despite the change in curriculum, because he had always taken on a more facilitative role.

Table 7

Changes in Participant Beliefs in Relation to Prior Experience (n=12).

Teaching Experience	Positive Change	No Change	Negative Change
No Teaching Experience (n=3)	2 (66%)	1 (33%)	0
Tutoring Experience (n=4)	1 (25%)	3 (75%)	0
Teaching Experience (n=5)	1 (20%)	3 (60%)	1 (20%)

Note: Positive change - from Disseminator or Facilitator-disseminator (pre survey) to Facilitator (delayed post survey); Negative change - from Facilitator (pre survey) to Disseminator or Facilitator-disseminator (delayed post survey)

Interview data also suggested TAs' prior experiences as students influenced their beliefs. Participants with negative learning experiences as students appear to translate that into their beliefs about the purpose of lab. For example, Andrew talked about his own prior experience in a chemistry course:

I hated chemistry because it just seemed stupid....Memorization is involved, solubility rules, and stuff like that. So it's hard when you're amidst all this stuff to really enjoy it. So that's why I was always trying to remind them why things are useful (delayed post-interview).

Andrew also mentioned that he experienced a guided inquiry approach in chemistry that was ineffective. He noted that during this experience the professor did not facilitate student discussion and learning. Andrew's negative experience with chemistry influenced how he interacted with students and how he perceived his role as a TA.

Content knowledge and beliefs. There also appeared to be a relationship between participants' content knowledge and their beliefs (Table 8). Participants who shifted from disseminator or facilitator-disseminator to facilitator beliefs had lower initial content knowledge than participants who developed disseminator or disseminator-facilitator beliefs or participants whose beliefs did not change. Results of the delayed-post survey indicated all participants had similar content knowledge by the end of the semester.

Table 8

Relationship Between Content Knowledge and Teaching Beliefs (n=11)

	Shift toward facilitator (n=3)	No change (n=7)	Shift toward disseminator (n=1)
Pre-survey	34.92	75.51	71.43
Delayed Post- survey	82.54	82.31	85.71

Note: For participants with complete content knowledge and beliefs data set.

For example, Christine, whose initial content score was low and whose beliefs changed from disseminator-facilitator to facilitator, talked about how her lack of content knowledge influenced her teaching. In her interview, she discussed a situation in lab in which she felt uncomfortable in lab because of the varied possibilities for experimental procedures developed by students and asked for help from a TA with more in-depth content knowledge. Christine also indicated that she initially struggled to know what questions to ask students in lab. Thus, when students proposed an approach unfamiliar, her lack of content knowledge made it difficult for Christine to ask facilitative questions. However, the

support of a fellow TA with more content knowledge appeared to boost Christine's confidence and ability to ask appropriate questions. Ultimately, these interactions with her fellow TA may have influenced her beliefs about teaching.

Professional Development Support

Survey and interview responses indicated the 13 participants perceived specific components of the professional development aided in their incorporation of the PBGI approach. The most helpful components of the professional development were: 1) completing experiments (n=8, 61.5%), 2) reviewing logistics (e.g. grading, demonstrations) (n=7, 53.8%), 3) modeling how to facilitate student discussions (n=5, 38.5%), 4) supporting documents (n= 3, 23.1%), and 5) content-based discussions (n=2, 15.4%). None of the participants perceived discussions of the learning theory that supports PBGI to be effective in supporting their instruction. Participants also provided concrete examples of how to further enhance the most helpful components and improve the less helpful components.

Doing experiments. All 8 participants (61.5%) who discussed the experiment component of the professional development perceived it as an effective, helpful component. For example, Andrew indicated, "I definitely think it was a good idea to do the labs ourselves so we can kind of anticipate the problems that the students will run into" (delayed post-survey). He realized the importance of knowing what to expect in lab and valued the experience of performing the experiments. This view was representative of other participants who discussed doing experiments. Christine found the experiment component of the professional development helpful in her affective role with the students. She stated, "I think they really appreciated it that we had taken the time to do the experiments" (post interview).

Reviewing logistics. The majority (n=7, 53.8%) of participants also found reviewing course logistics helpful. As representative of all logistics-related responses, when asked about the most helpful component, Michelle stated "practicing grading" (delayed post-survey). Participants also noted discussions about time management in lab, practicing demonstrations, knowing what problems students may run into, and making sure all TAs were on the same page for student and TA expectations were also helpful logistical components of the professional development.

Modeling. Of the 13 participants, 6 (46.1%) indicated modeling was another component of the professional development that was helpful. In fact, all of the participants interviewed agreed that modeling was one of the most helpful components of the professional development. Jessica described her experience during professional development:

Our head TA will mimic being one of us and she'll go around and interact with use like we should be doing with our students. That's always really helpful to kind of get a feel for how we should be interacting with them and what kinds of questions we can pose to them when they ask us. You know, instead of directly telling them the answer, which is so tempting often times, to sort of learn how to guide them to it, rather than just explicitly telling them how to do something. I felt like that really helped prepare us (post interview).

Jessica perceived the modeling helped her envision how to use questions to facilitate student discussions. She clearly understood how easily she could take a disseminator approach when interacting with students, but because facilitating questioning was modeled for her she knew what it should look like when implemented in a laboratory setting.

While modeling was considered a very helpful component of the professional development, some participants indicated they would have liked even more practice on how to interact with students. Christine explained, "I'm not easily able to sometimes come up with the right questions to ask them....I feel like I still could have needed practice because I'm still getting used to doing that" (post interview).

Supporting documents. Participants held mixed views on the effectiveness of supporting documents in facilitating their implementation of the PBGI curriculum. Only 3 (23.1%) of participants

perceived the supporting documents (e.g. syllabus, TA expectations document, weekly reminder emails) were helpful. Steven indicated the “emails from the instructors and our head TA that explain things very well” were useful to him (delayed post-survey). Steven found these written documents particularly useful because, as an international TA, it was easier for him to understand written English than spoken English. Andrew had a different perspective. He perceived, “There were too many separate supporting documents. I got confused going from the syllabus to the lab expectations to the lab report detailed to the rubrics, etc” (delayed post-survey).

Content-based discussions. Similar to the participants’ mixed perspectives of the effectiveness of the supporting documents, only 2 (15.4%) of participants perceived the TA-led content-based discussions to be helpful, while others indicated they were not. Christine explained why she felt these discussions were helpful, noting “It definitely was really good to help review the material because I think it just made me more comfortable in terms of my own class” (post interview). These views were also mirrored by Andrew. Conversely, Seth explained that the content-based discussions “became a little too reiterative” and that his content knowledge was such that he did not need the reinforcement of these discussions (delayed post interview). Helen perceived the content-based discussions to be a good idea that was ineffectively implemented. She noted:

I think the idea [of content-based discussions] is fantastic, I think how it has been implemented has not been as fantastic. It’s been kind of a bullet point lecture of content we kind of know....There was just minimal discussion with the TAs” (delayed post interview).

Helen understood the value of the content-based discussions; however, she felt the lecture-type approach of this component was not effective.

Participants indicated that the content-based discussions would have been more effective if they integrated both content and logistics. For example, Seth suggested instead of focusing on how everything works, focus on where students are going to have challenges, using TAs with previous experience as experts to lead these discussions. Similarly, Helen suggested using scenarios into the content-based discussions. In her interview, she provided an example of the format she envisioned this taking:

Say you have three different things: The group that’s already finished and just twiddling their thumbs, how do you encourage them to dive deeper? You have a group that’s really stuck on this, they can’t get their iron to stabilize. How do you help them? And then a group that has no idea what they’re supposed to be doing. Because there is a spectrum of the students you’ll be about to help and you’re already kind of practiced and know what to say to them so you don’t have to think on your feet as much (delayed-post interview).

While some of the TA-led content-based discussions included discussion of different scenarios, she would have liked this to be an expectation across the board. She firmly believed that TAs needed to see a clear relationship between the professional development and teaching in lab and perceived this type of discussion would support participants’ having an understanding of how they might approach different lab situations.

Learning theory. Finally, none of the participants perceived the learning theory component of the professional development to be effective. Many indicated this component was too abstract and not of interest to them. Jessica best explained this perspective:

I felt like we spent maybe too much time going through the educational theory behind guided inquiry. I understand why it’s important to know that. But I’m not interested in going into academia. So I didn’t feel like it was maybe pertinent to my course or career trajectory (post interview).

Her career interests did not align with her role as a TA, so while she understood the value of the theory she did not find it practical to her. Helen noted that since participants did not have an option in what they were implementing, discussing whether guided inquiry is an effective teaching method was not important. She suggested that to improve this component of the professional development,

Instead of looking through a lens of guided inquiry as a theory and as a knowledge base, [look at] how it's relevant to our students... We're going to be doing [inquiry] whether my ideology on education and teaching strategy is different from yours. In reality we're applying guided inquiry. So through a more focused situational lens and less abstract. But the format in terms of groups and then bringing it together as a whole, I think that was effective (delayed-post interview).

Overall, participants found the practical components of the professional development including performing the experiments, modeling what interactions should look like in lab, and discussing logistical aspects to be the most helpful. Participants indicated the supporting documents, content-based discussions, and learning theory were among the least useful components of the professional development. They suggested more opportunities to practice interacting with students and using questions would be useful and that modifying the learning theory and content-based discussion components to include scenario-type discussions would improve the quality of the professional development.

Discussion

The purpose of this investigation was to explore changes in TAs' understanding of their role, content knowledge, and teaching beliefs following a professional development experience designed to support a PBGI approach to general chemistry laboratory instruction. The results of this investigation suggest professional development informed by situated learning theory and guided by key characteristics of K-12 and TA professional development may be particularly effective in changing the beliefs of TAs who lack prior teaching experience and have low initial content knowledge.

TA Role

Many studies suggest TAs expected roles conflict with their perceived roles and practice (e.g. Addy & Blanchard, 2010; French & Russell, 2002; Luft et al., 2004). Luo et al. (2001) found that TAs were split on perceiving their role as facilitator or disseminator of information. Addy & Blanchard (2010) reported that overall, graduate TA's had the lowest RTOP scores on providing students support with communicating ideas, divergent thinking, and using student talk to dictate the direction of discussions, roles consistent with a facilitative role. The authors believe the low scores in these areas are a result of the traditional curriculum of the biology course. In the present study, approximately 70% of TAs initially and appropriately perceived their role in lab as facilitative and approximately 60% of the TAs retained this perspective of their role by the end of the semester. Interestingly, immediately following the professional development, only 30% of TAs indicated their role was facilitative. It is possible this decrease was due to the emphasis on logistics and completing the experiments as students during the week-long professional development and that the rebound was due to the TAs actual enculturation in the lab setting and their experience interacting with students in facilitative ways during the semester.

The literature also indicates one of the TA's main role in lab is to help students learn content; however, in practice TAs tend to focus on helping students with procedural issues rather than content (Bond-Robinson & Bernard Rodriques, 2006; Luft et al., 2004). The results of our study conflict with these findings as the TAs in the present study perceived their role as guide/facilitator and helping students act like scientists rather than content and procedural. By the end of the semester, only 31% of the TAs in the present study indicated that their role was to teach content, and only 8% perceived their role as providing lab technique feedback. Sixty-two percent of TAs viewed their role as guide/facilitator,

and 53% of the TAs perceived their role was to support students acting like scientists by the end of the semester. This implies that the professional development and follow up support for TAs in the PBGI approach may have helped align perceived and expected roles.

The TA literature only discusses the use of graduate students as laboratory instructors (e.g. Cho, et al., 2010; Lawrenz et al., 1992; Luft et al., 2004); however, this study examined both graduate and undergraduate TAs in general chemistry labs. Undergraduate students are typically Peer-Led Team Leaders (PLTL) in science lecture courses (e.g. Tien, Roth, & Kampmeier, 2002), and no research to our knowledge examines the role of undergraduates as instructors of lab courses. The present study provides valuable insight into the potential expansion of undergraduates as successful TAs for laboratory courses.

TA Beliefs about Teaching

A plethora of literature indicates teacher beliefs, particularly those of experienced teachers, are difficult to change (i.e. Cronin-Jones & Shaw, 1992; Luft, 2001; Pajares, 1992; Yerrick, Parke, & Nugent, 1997) even with preservice teacher preparation or professional development. In addition, such changes are often difficult to maintain over time without positive reinforcement from the sociocultural context (Haney & McArthur, 2002; Jones & Carter, 2007). However, in the present study, 75% of TAs beliefs changed immediately following the professional development and 56% retained these beliefs between the end of the professional development and end of the semester.

Further, most science teachers enter teaching with behaviorist epistemologies (Jones & Carter, 2007). Similarly, many studies on TA beliefs agree that TAs believe there is one right answer in science and thus their role is to tell students information (e.g. Gardner & Jones, 2011; Luft, et al., 2004; Luo et al., 2001; Nurrenbern, 1999, Volkmann & Zagagz, 2004). The findings of the present study add to the beliefs literature: 58% participants entered the study with beliefs aligned with a more behaviorist than constructivist perspective (disseminator or facilitator-disseminator). Following the professional development, all of these participants' beliefs shifted toward a more constructivist epistemology. Further, 3 of the participants who entered the study with constructivist (facilitator) beliefs retained these throughout the investigation.

There are a number of possible reasons as to why our TAs beliefs changed and these changes were retained as compared to previous studies. First, our results suggest TAs with certain characteristics may be more receptive to changing their beliefs. These characteristics include a lack of prior teaching experience and low content knowledge. Previous research suggests TAs with prior teaching experience express facilitator beliefs (French & Russell, 2002; Herrington & Nakhleh, 2003); however, the findings of our study conflict with these. In the present study, we found TAs with more experience held beliefs aligned with more disseminator-type instruction, and these beliefs were more resistant to change. Similar to our results in which TAs with less teaching experience expressed more malleable beliefs, Luft (2001) also found that novice secondary science teachers more easily change their beliefs than experienced teachers following professional development. Our findings extend those of Luft (2001) from preservice science teachers to science TAs.

A number of studies also indicate prior experience as a student is an important mediator in the development of science teacher's beliefs (e.g. Eick & Reed, 2002, Laplante, 1997; Southerland & Gess-Newsome, 1999), but with teaching experience, they rely more on these experiences as a reference as to what good teaching looks like (Skamp, 2001). Similar to these findings, in the present study, some TAs referred to previous experiences as students and in teaching in a traditional laboratory setting as formative in their perspective on whether PBGI could be successful. However, engaging in the professional development and actually teaching through the PBGI approach appeared to change these participants' negative perspectives.

Content knowledge also appeared to moderate the ease with which TA beliefs were modified through professional development. Similar to the TAs with less teaching experience, those TAs with low initial content knowledge had more malleable beliefs, and these beliefs became more congruent with constructivist (facilitator) epistemologies. To our knowledge, no studies on TAs in undergraduate science courses examine TA content knowledge. The relationship between content knowledge and beliefs is a novel result, which may be one reason for conflicting beliefs and practices found in other studies of TAs (Luft, et al., 2004; Luo et al., 2001; Nurrenbern; 1999, Volkmann & Zagagz, 2004).

TAs' confidence in teaching may be a mediating factor between experience, content, and beliefs. One reason TAs in the present study more readily changed their beliefs than those teachers in previous investigations is that many TAs thought their students found their instruction positive and described their interactions with students as they acted as facilitators as "rewarding." This positive reinforcement of their instruction from students during the semester may have increased participants' self-efficacy and may have explained why some participants maintained their beliefs (Bandura, 1986). Additionally, TAs with little content knowledge and teaching experience may not feel confident in the laboratory setting. However, with support, in the form of professional development with sustained support, their confidence improved, and they may have appreciated a facilitative approach to teaching more than participants who begin with greater content knowledge and teaching experience and thus confidence. Further, the support of peers with greater content knowledge and more teaching experience may improve the confidence of TAs with little content knowledge and teaching experience, thus changing their beliefs.

Finally, it is possible that the sociocultural context of the professional development, course, and Chemistry department combined in supporting these TAs in changing their beliefs and retaining these changes throughout the semester. Luft & Hewson (in press) also suggest that culture can be more influential on teacher change than professional development.

Situated Professional Development for TAs

The situated nature of the professional development may further explain the changes in TA's beliefs. Situated learning theory suggests that learning situated both within social and authentic contexts is most effective. The professional development program in this study provided numerous opportunities for social support as the TAs learned to integrate a PBGI approach in the authentic context of a general chemistry lab. In the present study, TAs indicated doing experiments, reviewing logistics, and modeling were most important components of the professional development that facilitated their implementation of the PBGI approach to general chemistry lab instruction. These components relate to the authentic experience (doing experiments) and opportunities to experience and practice language (modeling) aspects of a situated learning model (Lave & Wenger, 1991). The TAs did not see the significance of the learning theory component of the professional development, which indicates it may not have been situated within an authentic context. Understanding the components that should be emphasized in TA professional development to support a PBGI approach provides useful information that adds to this body of literature. Further research will determine whether the situated approach to the TA professional development described in the present study results in TAs' implementation of PBGI in ways that align with the goals of the professional development and course.

Further, using situated learning theory as a framework for assessing TA professional development provides new information for the TA literature and professional development literature. Many studies assessing TA training utilize pedagogical content knowledge (PCK) to frame the research (e.g. Bond Robinson & Bernard-Rodrigues, 2006; Hammrich, 2000). Because the laboratory curriculum was fixed in the present study, TAs were unable to choose their instructional materials. The TAs' role in the PBGI approach was based upon their interactions with students, thus PCK was not an appropriate

model. By using a situated learning framework, this study provides valuable insight about the TAs' perceptions of their instruction.

Implications and Future Research

One primary factor which can be a barrier to TA understanding and practice are their beliefs. Beliefs are influenced by external factors such as faculty perception. One component of TA training which continues to present itself in the literature is the *culture* surrounding TA training. Luft & Hewson (in press) also suggest culture can be more influential on teacher change than professional development. In order for TA training to be effective, the graduate school culture must emphasize and value teaching, which is typically not the case since faculty do not value teaching or training in teaching (Shannon, Twale & Moore, 1998). A poignant quote from a TA indicates their understanding of how faculty members perceive their importance: "TAs are important because they allow the research agenda to move forward" (Luft et al., 2004, p. 222). By shifting the culture around TA training to emphasize the importance of TAs, more effort may be put in to providing quality TA training. TAs may also feel less overwhelmed with their multiple roles and responsibilities and be able to focus on teaching. This more global change may influence TAs' beliefs and practice about teaching to take on a more student-centered focus.

Only two studies on TAs in science laboratory courses focus on their affective role (Herrington & Nakhleh, 2003; Sandi-Urena et al., 2011). These studies indicated important affective TA roles included respect for students, being helpful, approachable, caring, enthusiastic, motivating, and encouraging. The affective role, while not an explicit expectation, was one the TAs perceived as important. Thus, further research should focus on the TA affective role and how it may influence their beliefs and practice. Despite the shift in beliefs from behaviorist to constructivist, none of the TAs encouraged divergent thinking. They still appeared to hold the belief that there is one right answer, or one appropriate method for solving scientific questions. Future research should focus on further examining the dichotomy between constructivist epistemologies and convergent thinking in post-secondary science teaching.

There are clearly many ideas about how to make TA training most effective. Based on the results of the present study, we suggest professional development for TAs of large-enrollment courses designed to support reforms-based instruction such as PBGI include the following: 1) having TAs complete experiments as students, 2) modeling and opportunities to practice facilitative interactions, 3) practicing grading and discussing practical laboratory issues (i.e. safety, TA expectations, lab agenda), 4) encouraging the affective role, 5) pairing TAs with differing content knowledge and teaching experience during professional development to foster a community of practice.

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