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Investigation of chemistry graduate teaching assistants' teacher knowledge and teacher identity

Eleni K. Zotos[1] | **Alena C. Moon**[2] | **Ginger V. Shultz**[1]

[1]University of Michigan, Ann Arbor, Michigan

[2]University of Nebraska-Lincoln, Lincoln, Nebraska

Correspondence
Ginger V. Shultz, University of Michigan, Ann Arbor, MI.
Email: gshultz@umich.edu

Abstract

Graduate students play an integral role in undergraduate chemistry education at doctoral granting institutions where they routinely serve as instructors of laboratories and supplementary discussion sessions. Simultaneously, graduate teaching assistants (GTAs) balance major research and academic responsibilities. Although GTAs have substantial instructional facetime with large numbers of undergraduate students, little is known about their conceptions of teaching or their identities as teachers. To investigate the knowledge that GTAs have regarding teaching in this unique context, their teaching identities, and how these developed, we conducted 22 interviews with graduate students from several universities at various levels in their graduate school career using a modified Teacher Beliefs Interview. Interviews were analyzed for two overarching teacher learning constructs: teacher knowledge and teacher identity. We characterized chemistry GTAs' teacher knowledge and identity and determined major influencing factors. We found that chemistry GTAs often identified as a tutor or lab manager, which hindered their self-investment in developing as teachers. The results presented herein contribute to an understanding of GTAs' teacher knowledge, teacher identity, and their teaching context, from which training can be designed to best support GTA development.

KEYWORDS
pedagogical content knowledge, science teacher education, teacher beliefs

1 | INTRODUCTION AND BACKGROUND

1.1 | Graduate teaching assistants in undergraduate STEM education

Thousands of undergraduate students at doctoral-granting institutions are instructed by graduate students who are also managing their own course and research responsibilities. STEM graduate teaching assistants' (GTAs') teaching assignments typically range from 10 to 20 hr each week, during which GTAs are expected to be instructing undergraduate students in a laboratory or discussion setting, preparing to teach assigned sections, grading student work, and hosting office hours. Laboratory and discussion sections are typically composed of 20 to 30 students, and consequently, GTAs have more facetime with undergraduate students than professors who teach large enrollment lectures (Lawrenz, Heller, Keith, & Heller, 1992). During laboratory sections lead by GTAs, undergraduate students gain fundamental hands-on experience in performing experiments and analyses, and during discussion sections, course content is reinforced or learned for the first time. Given their central role in undergraduate STEM education and because they are uniquely different from post-secondary instructors and pre-service teachers, the design, implementation, and assessment of GTA training programs are emerging foci in STEM education literature (Addy & Blanchard, 2010; Wheeler, Maeng, Chiu, & Bell, 2017).

GTAs comprise a unique population because, while they are essential contributors to undergraduate education, they work in an environment that places more focus on research than teaching (Luft, Kurdziel, Roehrig, & Turner, 2004; Shannon, Twale, & Moore, 1998; Wheeler, Maeng, & Whitworth, 2015) and where teaching is sometimes solely viewed as a means of financial support (Seymour, Melton, Wiese, & Pederson-Gallegos, 2005). Moreover, GTAs rarely have formal teaching experience and therefore rely heavily on their content knowledge to teach (Seymour et al., 2005), though it is well known that content knowledge alone is not sufficient for effective teaching (Grossman, 1990; Trumbull, 1999), and in some cases, GTAs do not have adequate content knowledge required to teach introductory courses (Bhattacharyya & Bodner, 2005). One in every three STEM GTAs will go on to become a faculty member or instructor within 6 years of receiving their PhD (Pfund et al., 2012). Teaching as a GTA commonly has a large influence on faculty members' and instructors' conceptions of teaching and learning as this experience is oftentimes their first introduction to formal teaching (Brownell & Tanner, 2012). GTA training currently takes on many different forms—weekly staff meetings throughout the semester, one-day or one-week workshops before the start of fall semester, or half- or full-semester pedagogy courses—depending on the university. In some cases, training is not provided at all (Baumgartner, 2007; French & Russell, 2002; Hammrich, 2017; Marbach-Ad et al., 2012; Nurrenbern, Mickiewicz, & Francisco, 1999).

Investigations into how GTAs experience and conceptualize their role as instructors have shown that GTAs teach using instructive (teacher-centered) teaching practices and conceptualize their role as transferring information to students (Kurdziel, Turner, Luft, & Roehrig, 2003; Luft et al., 2004; Sandi-Urena & Gatlin, 2012), neither of which align with the current national call for the implementation of evidence-based teaching practices (National Academies of

Science, Engineering, and Medicine, 2018). Kurdziel et al. (2003) conducted a study in which inquiry-based general chemistry laboratory GTAs were interviewed and observed. The authors found that GTAs did not have the instructional skills needed to facilitate inquiry and that GTAs had ill-informed conceptions about how students learn. GTAs in this study thought that students learn best when information is clearly and cleanly presented to them (Kurdziel et al., 2003). This result, along with findings from other studies that demonstrated GTAs are not prepared for their instructor role, are quite problematic for undergraduate STEM education (Kurdziel et al., 2003; Luft et al., 2004; Sandi-Urena & Gatlin, 2012).

With a national call to implement reformed-based practices in undergraduate STEM courses and to understand the research culture of doctoral programs (National Academies of Science, Engineering, and Medicine, 2018) recent studies have focused on developing and evaluating training sessions to support GTAs across STEM disciplines, especially because 70% of life and physical science classes are taught by GTAs (Addy & Blanchard, 2010; Becker et al., 2017; National Center for Educational Statistics, 2002; Zehnder, 2016). Few studies focused specifically on chemistry GTAs (Marbach-Ad et al., 2012; Mutambuki & Schwartz, 2018; Wheeler et al., 2015). Despite this work thus far, a call to improve GTA training and instruction remains (Bautista, Schussler, & Rybczynski, 2014; Bond-Robinson & Rodriques, 2006; Deacon, Hajek, & Schulz, 2017). The purpose of this study was two-fold: to investigate how chemistry GTAs conceptualize teaching and their instructional role to (a) further inform the design of GTA training to specifically address the needs of GTAs and (b) to contribute to an understanding of chemistry GTAs' teacher knowledge and teacher identity.

1.2 | Teacher beliefs and practices

Teacher behavior and actions in the classroom are influenced by teachers' knowledge and beliefs about teaching and learning (Gibbons, Villafañe, Stains, Murphy, & Raker, 2018; Harwood, Hansen, & Lotter, 2006; Lotter, Harwood, & Jose, 2007; Veal, 2004) as well as their teacher identities (Chesler & Young, 2007). Teacher knowledge and teacher beliefs are viewed as independent but strongly interconnected—beliefs refer to personal values, attitudes, and ideologies, and knowledge refers to ideas derived through formal education and experience (Calderhead, 1996; van Driel, Berry, & Meirink, 2014). Gibbons et al. (2018) conducted a large-scale survey study focused on the self-efficacy of chemistry faculty members, teacher beliefs about how teaching and learning should occur, and self-reported instructional practices. The results from this study demonstrated that chemistry faculty's teaching beliefs aligned with their practices, reinforcing the connection between teacher beliefs and instruction. The authors of this study recommended to begin teacher reform with a focus on teacher beliefs (Gibbons et al., 2018), which is lacking in chemistry GTA training designs.

Furthermore, it has been shown that professional development programs that do not consider teachers' attitudes and beliefs have been ineffective (Ryan, 2004; Stipek & Byler, 1997). Alignment of teacher beliefs and teacher practices are a focus in pre-service teacher education programs. K-12 teacher training works to surface, challenge, and develop pre-service teacher beliefs as a foundation for developing teaching practices. Similarly, effective and efficient GTA training must elicit and be informed by GTA teacher beliefs (Jones & Leagon, 2014; Lumpe, Czerniak, Haney, & Beltyukova, 2012), which have been investigated in other STEM disciplines (Addy & Blanchard, 2010; Chapman & McConnell, 2017; Gardner & Jones, 2011) but, to our knowledge, have not been investigated for chemistry GTAs.

Luft and Roehrig (2007) designed a semi-structured interview protocol, the Teacher Beliefs Interview, to investigate teacher beliefs. The Teacher Beliefs Interview was first utilized to explore and capture the teacher beliefs of secondary science teachers. Luft and Roehrig (2007) uncovered a range of beliefs, from traditional and teacher-focused to reformed and student-focused, within and across participants. The Teacher Beliefs Interview has been used in a variety of contexts, including studies of GTA teacher beliefs in geoscience and biology (Addy & Blanchard, 2010; Chapman & McConnell, 2017). Investigations of teacher beliefs are motivated by the potential to gain insight into the knowledge teachers have about teaching and learning, which correspond to the instructional practices used to instruct students (Gibbons et al., 2018; Gibbs & Powell, 2012).

The primary goal of implementing training and professional development programs is for teachers to gain knowledge of teaching and learning. Reflection has been shown to be an essential component in learning how to teach science (Adams & Krockover, 1997; Geelan, 1996). Wenger (1998) states that there is a reciprocal relationship between teacher identity—how a teacher views themselves and identifies as an educator—and teacher knowledge, and that reflecting on one's experience in teaching promotes the growth of this relationship. For example, in a study focused on new primary and secondary science teachers' identities, one participant valued the messiness of science and strove to provide students space to learn through their mistakes. However, she was hesitant and discouraged from allowing her students to engage in messy science, because she viewed part of her role as a science teacher as someone who encourages the correct answer. (Varelas, House, & Wenzel, 2005). It is therefore important to consider teacher identity alongside teacher knowledge as they influence one another. Sandi-Urena and Gatlin (2013) investigated factors that contribute to chemistry GTA identity and found that prior experiences, training, epistemological beliefs, beliefs about the nature of laboratory work, and involvement in the laboratory setting contribute to the construction of GTA identity. In another study, Lane, Hardison, Simon, and Andrews (2018) demonstrated how interest in teaching, professional development, teaching experiences, mentors, and recognition as a teacher influence GTA teaching identity within the research-focused culture of doctoral granting institutions. Other studies have suggested that departmental culture may impact GTAs' conceptions of teaching and conceptions of their role as an instructor (Luft et al., 2004). GTA teacher knowledge and teaching identity have been investigated separately, but the relationship between chemistry GTAs' teacher knowledge and teacher identity remains unexplored. In our study, we contribute to an understanding of this relationship by investigating the teacher knowledge and teacher identity of chemistry GTAs at various levels in their graduate school careers.

1.3 | Theoretical framework

In the sociocultural theory of teacher learning perspective, knowledge is shared across all entities of a community (people and artifacts) and therefore, an individual learning to teach must interact with the entities through participation in their teacher role. This theory appropriately frames our study given that it specifically places teachers within their social, physical, historical, and cultural contexts (Greeno, 1997; Vygotsky, 1978). Entities are often unique to their respective communities, and consequently, teacher expertise is linked to the circumstances to which it pertains (Kelly, 2006; Russ, Sherin, & Sherin, 2016). In other words, given the social, physical, historical, and cultural differences between universities and primary or secondary school

settings, GTAs will learn about teaching in a different way than, for example, in-service teachers. Furthermore, what is expected of an "expert GTA" may differ from what is expected of an expert in-service teacher. GTAs learn from experience through interacting with entities with which they teach: GTA peers, professors, research mentors, undergraduate students, and all tools and resources—books, worksheets, exams, lab equipment, and so on. While research on pre- and in-service science teacher learning can inform research on GTAs, the unique culture of doctoral granting institutions and the GTA role warrants investigations focused on this distinct population.

In the study presented herein, we have analyzed teacher learning through a lens described by Wenger (1998) and further developed by Kelly (2006). Kelly took a sociocultural perspective and expanded upon Wenger's four central components of social theory of learning: (a) teacher knowledge, (b) teacher identity, (c) teacher knowing, and (d) teaching practices. We focus specifically on (a) teacher knowledge and (b) teacher identity in this present study. Teacher knowledge refers to teachers' knowledge base for teaching and student learning; it encompasses pedagogical knowledge, pedagogical content knowledge, and subject matter knowledge. Teacher knowledge is derived from formal education and experience in instructional settings—either as a teacher or a student. Teacher knowledge is often unique to teachers' individual contexts, so it involves more than applying a well-developed body of knowledge. A key aspect of the sociocultural view of teacher knowledge is that teachers continuously develop their teacher knowledge as they engage in their teaching practice, and furthermore, expertise is described as "the constant and iterative engagement in constructing and reconstructing professional knowledge" (Kelly, 2006, p. 509). GTAs may draw upon their experiences as students or instructors and from GTA training to inform their initial teaching. As GTAs continue to teach and interact with the entities of their community, their teacher knowledge develops based on these experiences.

The second component, teacher identity, refers to teachers' perceptions of their role and their personal goals and desires. Teacher identity is influenced by teachers' contexts, and specific contexts may favor the construction of certain identities. Kelly (2006) described the social process of developing a teacher identity:

> Teachers' identities are neither located entirely with the individual nor entirely a product of others and the social setting. They can be regarded as the ways in which practitioners see themselves in response to the actions of others toward them; that is they are the constantly changing outcomes of the iteration between how practitioners are constructed by others, and how they construct themselves, in and away from social situations (p. 513).

Teacher identity is a social construct—it is a product of how teachers view themselves and how they are viewed by others. Teachers construct their identity by interpreting experiences with others in their community and develop their identities over time as they continue to take on instructor roles and develop more autonomy in their practice (Lave & Wenger, 1991). GTAs may initially interpret the meaning of their role through interactions with administrators, professors, or peers. As GTAs progress throughout their graduate school careers and continue to interact with members of their community, their identities may shift in varying ways. Understanding the intricacies of teachers' identities provides insight into the motivations behind how teachers think and act (Chesler & Young, 2007), and thus is an important window into understanding teacher knowledge.

The third component, teacher knowing, refers to teachers' implementation and adjustment of their knowledge base for teaching and learning. Teacher knowledge, the students present, the working practices of the school, the resources available, and previously internalized experiences can all contribute to the actions teachers take within their classroom, and the outcomes of these actions can influence future courses of action. For example, a GTA who is used to lecture-style classrooms might initially lead their discussion section with a lecture, but if the GTA notices students are not responding well, they might use a different teaching technique.

Lastly, teaching practices refers to teachers' engagement in the discourse, norms, and working practices of teaching both inside and outside of the classroom (e.g., assigning homework, implementing whole-group discussions, collaborating with other teachers, or sharing lecture notes). Expert teaching practices are unique to teachers' contexts as specific schools may encourage certain practices over others (Kelly, 2006). For example, sharing lecture notes is a common practice in post-secondary schools. In this study, we investigate the teacher knowledge and teacher identities of chemistry GTAs to gain insight into what and how GTAs learn about teaching within their specific contexts.

2 | RESEARCH QUESTIONS

Given the prominent call for improving STEM GTA training and the lack of insight into chemistry GTAs' conceptions of teaching from which training should be developed, the goal of this project is to investigate how chemistry GTAs conceptualize teaching and their instructional role and to contribute to an understanding of chemistry GTAs' teacher knowledge and teacher identity. Our guiding research questions are informed by the sociocultural theory of teacher learning proposed by Kelly (2006):

1. What is the nature of chemistry GTA teacher knowledge and teacher identity?
2. What factors influence the development of chemistry GTA teacher knowledge and teacher identity?

3 | METHODS

The objective of this study was to qualitatively investigate the beliefs for teaching held by chemistry graduate students to better understand their teacher knowledge and teacher identity. Specifically, we aimed to identify the nature of chemistry GTAs' teacher knowledge and teacher identity and to explore factors that have influenced the development of these constructs. The findings of the study presented herein are grounded in (a) the experiences of the chemistry graduate students and (b) our conceptual framework and can serve as the basis for empirical work aimed at testing hypotheses about the interconnected relationships between graduate student beliefs, knowledge, and identities.

3.1 | Participants and setting

We interviewed 22 chemistry doctoral students with a range of teaching experience from four research institutions. A purposeful selection process (Merriam, 2009) was used to recruit

participants with experience ranging from zero to five or more terms of teaching as a GTA. First, a subset of 15 participants were recruited and interviewed from a single Midwestern institution. Few of these participants had substantial teaching experience, and after initial analysis, it was determined that saturation was not reached. An additional seven participants with more experience were then recruited from this and three other institutions. All participants entered research-focused chemistry doctoral programs in which graduate students are primarily evaluated based on their capabilities to conduct research. In these programs, funding is provided to graduate students through teaching assistantship, research assistantship, or fellowship programs. GTAs are frequently hired to teach laboratory or supplementary discussion sections for large-enrollment courses where many GTAs are teaching the same course. The GTA training programs for 20 of our participants were structured as a short one- or two-day workshop before their first fall semester, one participant underwent a 5-day training, and one participant underwent an eight-week GTA training pedagogy course. Some faculty instructors may hold course-specific weekly staff meetings to keep GTAs on track and informed. Nine participants identified as female, one participant was an international student, 21 participants went to graduate school in the Midwestern United Sates, and one participant went to graduate school in the Western United States. All participants were recruited via email and consented to participate using an IRB reviewed consent process. IRB approval was obtained for this study and all participants were given pseudonyms to maintain confidentiality. Participant information is included in Table 1.

3.2 | Data collection

A semi-structured interview protocol was used to capture chemistry GTAs' teacher beliefs, previous experiences as a student and as a teacher, and beliefs about the nature of science (see Supplemental Information) (Hesse-Biber, 2017). The interview protocol followed closely to the Teacher Beliefs Interview (Luft & Roehrig, 2007). Questions were added to provide GTAs with opportunities to discuss factors—undergraduate experiences, any experiences teaching, and beliefs about the nature of science—that may have contributed to the development of their teacher beliefs (Sandi-Urena & Gatlin, 2013). Multiple researchers conducted 13 interviews in 2016, 4 interviews in 2017, and 5 interviews in 2018. Interviews ranged in length from 45 to 90 min and were conducted in person, via Skype, or via Google Hangouts. There were no noticeable differences in the interviews conducted by different media or at different time points. All interviews were audio recorded and transcribed verbatim.

3.3 | Data analysis

We approached our data analysis with theoretical perspectives of sociocultural theory of teacher learning. All interviews were coded through provisional coding methods (Saldaña, 2016), during which data was coded using predetermined codes derived from our theoretical framework. The application of the conceptual framework to these data was reviewed by two experts; one with expertise in teacher knowledge research and the other an experienced college level chemistry instructor. During our first round of coding with predetermined codes, we coded for evidence of two of the four categories of teacher learning as defined by Kelly (2006): teacher knowledge and teacher identity. Because the other two categories of teacher learning, teacher

TABLE 1 Participant semesters as a GTA, type of class taught as a graduate teaching assistant (GTA), length of training, and undergraduate institution

Participant	Semesters as a GTA	Type of class taught	Length of training	Undergraduate Institution
Abby	1	Discussion	1–2 days	R1
Vanessa	1	Discussion	1–2 days	R1
Bud	1	Discussion	1–2 days	R2
Calvin[a]	1	Discussion	1–2 days	R2
Mallory	1	Discussion	1–2 days	PUI
Jamie	1	Lab	1–2 days	R1
Erica	1	Lab	1–2 days	PUI
Robert	1	Lab	1–2 days	R2
Faith	2	Discussion	1–2 days	PUI
Frankie	2	Lab	1–2 days	R1
Phil	2	Lab	1–2 days	PUI
Allison	3	Discussion	1–2 days	PUI
Sol	3	Discussion	1–2 days	R2
Grace	4	Discussion + Lab	1–2 days	R1
Andrew	5+	Lab	1–2 days	PUI
Amanda	5+	Discussion + Lab	1–2 days	R1
Brian	5+	Discussion + Lab	1–2 days	PUI
Eman	5+	Discussion + Lab	1–2 days	PUI
Janice	5+	Discussion + Lab	1–2 days	R1
Jacob[b]	5+	Discussion + Lab	1–2 days	PUI
Macklin	5+	Discussion + Lab	5 days	PUI
Daphne	5+	Discussion + Lab	8 weeks	PUI

[a]International student.
[b]Western U.S. graduate school.

knowing and teaching practices, are more active than reflective in nature, they cannot be fully captured in an interview and thus were excluded from analysis. During this round of coding, the authors noted that GTAs frequently referenced challenges they faced. Thus, challenges were added to our codebook. Interviewee responses could receive multiple codes if warranted. Responses that were coded for teacher knowledge or teacher identity were then open coded, and major themes were identified inductively from this round of coding (see Figure 1 and Table 2).

Interview transcripts were coded using the NVivo 11 Pro software. The first two authors coded a subset of interviews to ensure a common understanding of what counted as evidence of teacher knowledge and teacher identity and of each particular theme. Themes for teacher knowledge were: instructional goals, knowledge of students, classroom management, and teaching strategies. Themes for teacher identity were: role in the course, affect, personal goals, and desired student perception. Interrater reliability at the theme-level was calculated with the first author and

another chemistry education researcher who was not involved in this study. The first author provided the other researcher with a codebook that included descriptions for each theme. The other researcher independently coded 10% of the data, and then met with the first author to discuss discrepancies and to elaborate on the descriptions in the codebook. The other researcher then independently coded an additional 10% of the data. Interrater reliability was calculated with this data set using the Fuzzy kappa statistic, which is a modified Cohen's kappa that allows for multiple codes to a single unit of analysis (Kirilenko & Stepchenkova, 2016). Our Interrater reliability value (0.86, Fuzzy kappa) indicated almost perfect consistency for the application of our coding scheme (McHugh, 2012). Given that GTAs comprise a unique population and thus their development of teacher knowledge and teaching identity will be distinct from other populations of instructors, this work extends and refines sociocultural theory to encompass this new population as we generated theories of GTA teacher learning.

GTA challenges and each theme for teacher knowledge and teacher identity were further investigated for subthemes—more specific features of the participants' challenges, knowledge, and identity. All features from each interview were individually summarized and listed in a Word document. The number of transcripts in which a specific feature appeared was recorded by pairing each feature with the corresponding participant pseudonym(s). If a feature appeared in five or more interviews, it was defined as a subtheme. Subthemes are summarized in Figure 1 and Table 2.

To examine the ways in which teacher knowledge themes may be connected or influence one another, we started by identifying excerpts coded for "teaching strategies" in each individual interview. Next, we identified any information within that interview that may have informed this teaching strategy for the given participant. All teaching strategy influences were noted and the number of times a certain influence played a role in informing teaching strategies across all GTAs was identified. If there was not a clear influence for a teaching strategy, that was noted as well. A similar process was followed to determine influential factors for other teacher knowledge themes.

Our next goal was to gain insight into how GTA training influenced GTA teacher knowledge. Responses to the interview question: "How has this training influenced your teaching?" (see Supplemental Information) were investigated to determine which teacher knowledge themes were most commonly influenced by GTA training.

Finally, the relationship between challenges, teacher knowledge, and teacher identity was explored by focusing on instances where teacher identity codes overlapped with either challenges or teacher knowledge in each individual interview. For each of these instances, the given overlap between teacher knowledge and teacher identity themes was summarized and commonalities across GTAs were determined.

3.4 | Transferability and Trustworthiness

In the study presented herein, we took multiple measures to increase the trustworthiness and transferability of our results. We used purposeful maximal variation sampling—we interviewed GTAs from multiple universities and with different amounts of experience as a GTA (Merriam, 2009)—to increase the ability of the results discussed in this study to be transferrable to other settings. We have written about our methods and results using thick, rich descriptions so that the similarities between our study and other contexts can be assessed (Lincoln & Guba, 1985). Our comprehensive account of our study also lends itself to the trustworthiness of our

conclusions, given that our interpretations and analysis are clearly described. Multiple researchers collected and analyzed the data, which requires extensive collaboration and consensus making and thus serves to mitigate the possibility of researcher bias. We considered rival explanations to ensure our explanations accurately encompass the experiences of our participants, and we received feedback from experts in science education research.

3.5 | Limitations

Perhaps the most meaningful limitation emerged from the use of interviews, which prompted participants' reflections but provide no direct evidence of their teaching practices. Given results showing that teachers can overestimate the amount of reform in their teaching when self-reporting (Ebert-May et al., 2011), these results serve as a sort of upper bound of GTA's knowledge and identity. GTA teacher knowledge can be confirmed or better understood by conducting classroom observations. Additionally, we only capture one snapshot of GTAs' teacher identities through these interviews. GTA identity in practice should also be considered and could be investigated with observations. Only one of our participants was an international student, and their experiences learning to teach may be different due to unique barriers that international students face. Further research in this area is needed, as an average of 42% of chemistry doctoral students are international (American Chemical Society, 2008). Finally, graduate student training is highly contextualized and varies within and across institutions and across national boundaries. The findings presented here were all collected at major research institutions in the U.S., the majority of them in the Midwest. These institutions happened to have comparable graduate training programs, but it is recognized that interview data collected at other institutions might paint a different picture of GTAs' conceptions and reported practices. A survey methodology would be a viable approach to eliciting and controlling for variations in GTA conceptions.

4 | RESULTS

4.1 | RQ1: What is the nature of GTA teacher knowledge and teacher identity?

4.1.1 | Teacher knowledge

While analyzing the interviews, five teacher knowledge themes were identified, which encompass chemistry GTAs' knowledge base for teaching and learning in the context of research institutions. The five themes were: *instructional goals, knowledge of students, classroom management, teaching strategies, and assessment of students*. Each theme is described in detail later, and Figure 1 includes a summary of all teacher knowledge themes and subthemes and the relationship between them.

The theme *instructional goals* refer to the goals that GTAs want to accomplish within their teaching section. Instructional goals ideally should inform all teaching practice by driving lesson plan and assessment design (Harshman & Yezierski, 2015). Five instructional goals were common across all GTAs: for their students to learn the course content, to answer their students' questions, to engage their students, to demonstrate the relevance of chemistry, and for their students to learn critical thinking skills. For example, Sol said, “I'm

trying to accomplish that the students understand the material and are most prepared for the exam." Some participant responses, like Robert stated in the following, focused more on answering students' questions:

> Addressing their questions is really important, and that answering questions be a primary means of communication, as opposed to just me standing up doing a lecture, and then asking, 'All right, any questions,' in the last five minutes.

Other GTAs were more focused on engaging students and may do so by connecting course content to examples or issues outside of the course. Phil described his goal of demonstrating the relevance of chemistry:

> To say, you know, this isn't just something that we're teaching you because someone somewhere decided it was important. This is real life; people use it every day. [...] So, to be able to make that connection to what are real chemists doing with the information you're getting in class. That, I think, is powerful for students hopefully. That's definitely what was powerful for me as a student.

Most GTAs demonstrated having *knowledge of students*. It has been shown that instructors use knowledge of their students to guide their instructional decisions (Carpenter & Fennema, 1992). GTAs were most commonly aware that students are different, and some participants also noted that student learn differently. GTAs' knowledge of students—that students have different needs, interests, and goals—often influenced their instructional goals of demonstrating the relevance of chemistry to engage all students (Figure 1, Arrow D). Phil describes this in the following:

> There's going to be a small set of students in there that actually want to be chemistry majors. [...] For the ones who don't want to be chemistry majors, who want to do something else, I want them to have a better appreciation for chemistry, as being more than just a box they have to check on their way to medical school.

The majority of our chemistry GTA participants were aware that students had interests and goals outside of chemistry (e.g., going to medical school). This motivated their instructional goal of demonstrating the relevance of chemistry to engage students in the course content.

The third theme, *classroom management*, refers to the methods GTAs have used to manage, facilitate, or structure their classroom. Classroom management skills are an essential part of teaching as they are used to create and maintain an environment in which learning can occur (Emmer & Stough, 2010). The two common methods GTAs reportedly employ to manage their classroom were directing students to office hours if they need more help and organizing students in groups. Bud described a situation where he responded to a student that was struggling to understand a concept:

> I'd probably say a few more things and then move on anyway, because I felt like, if you're not getting it at the fifth one, probably I'd just say, "Come see me during office hours if this still isn't clear. We'll work through it, but we have to move on."

Bud's quote was representative of participants who voiced utilizing office hours to deter spending class time working with an individual student. This management strategy may have been

used to mitigate the challenge of managing time during relatively short discussion and lab sessions. However, in this case, managing time occurred at the expense of students' understanding. This reflection existed in contrast to the instructional goals of answering students' questions and for students to learn the content. It is possible, that due to the constraints of teaching short discussions and laboratories once per week with certain requirements set by the professors of the course, participants were unable to accomplish their instructional goals during discussion and laboratory section but used office hours as an additional time to work toward their goals of student learning.

GTAs had varying motivations for organizing their students in groups. Some GTAs organized their students in groups to make themselves more available as questions arose, some organized their students in groups because they preferred to interact with a few students at a time, and others reported organizing students in groups so students could help each other learn content (instructional goal), given the fact that students learn in different ways (knowledge of students). Eman demonstrated using groups to support learning as follows:

> They can talk to each other about it, which also, I think helps their own learning because the more students talk to each other about chemistry, maybe they're not using the same exact wording or terminology that I'm using, so maybe they kind of hear it in a different way than from how I say it, and if you know, somebody thinks they feel comfortable enough about some topic to help another student with it, then that's probably a good evidence that they know what's going on in the classroom.

Eman showed that her classroom management strategy of organizing students in groups was motivated by her knowledge of students—that students learn differently (Figure 1, Arrow C). Eman also demonstrated the belief that allowing students to work together would support their learning of the content (Figure 1, Arrow B).

Teaching strategies refer to the techniques GTAs have reported using to convey material to students and to facilitate students' learning. The most common methods that GTAs in this study used include not giving students direct answers to their questions, using basic concepts to explain more complex concepts, and connecting material to real life or other disciplines. Allison's quote was a representative report of using the teaching strategy of guiding students to the answer, "I usually like to answer questions with more questions, which is something that I hated when I was a student, but it turns out that it really works."

Allison noted that she learned content when her instructors led her to the answer. Because she had this experience with a positive outcome (learning), she, along with many other participants, likely guided students to the answer as a way to accomplish the instructional goal of students learning content (Figure 1, Arrow A). Another way GTAs worked toward accomplishing student learning was through using more basic concepts to build students' understanding of more complex concepts. Vanessa described an example of when she scaffolded content for a student:

> I've had one girl in office hours and she really really didn't understand why a carboxylate anion is negatively charged. So it's going back and just breaking that down to, okay so, just breaking it down and trying to put it in simpler and simpler terms. So, looking at oxygen on its own, and its valence electrons, and okay so now if we were to form bonds, now how does that affect the valence electrons in the shell of the atom?

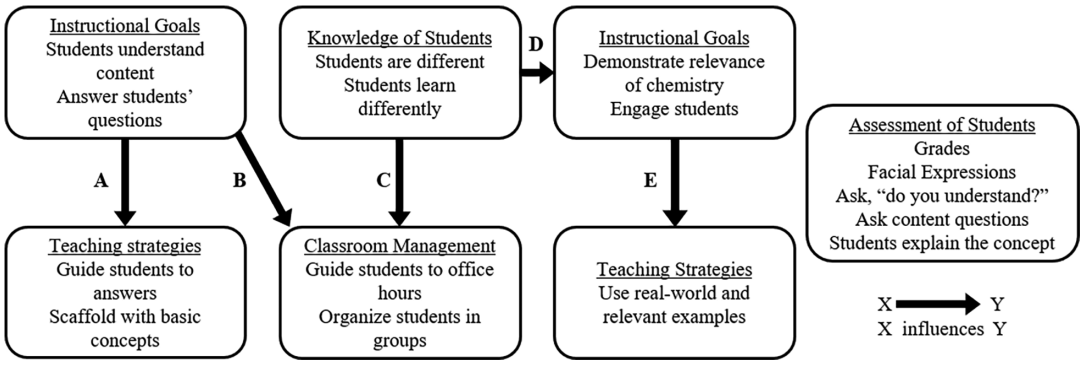

FIGURE 1 The characterization of and relationship between chemistry graduate teaching assistant (GTA) teacher knowledge components

Vanessa noted that when her student was struggling with understanding the charge of a molecule, she guided the student though recalling properties of individual parts of the molecule (the valence electrons on one oxygen atom in the molecule), and used this basic understanding to build the students' understanding of the carboxylate anion. The final teaching strategy of connecting material to real life or other disciplines was closely tied to the instructional goal of demonstrating the relevance of chemistry—connecting course material to real life is a way to demonstrate the relevance of chemistry (Figure 1, Arrow E).

The final teacher knowledge theme, *assessment of students*, refers to the ways that GTAs determined if their teaching was effective or if students were learning. Four common methods of assessment were reported by GTAs in this study: examining their facial expressions, checking students' grades, asking rhetorical questions like, "do you understand?", and determining if students could explain the concept themselves. For example, Erica demonstrated how she assessed student understanding by facial expressions by saying, "I think, I mean you can sometimes just see it in their eyes, like "yeah, I got it."" Erica's quote was representative of participants who assess students' understanding using nonverbal communication. Other participants focused on grades as a form of assessment, and some, like Brian, required verbal communication:

> Really, trying to explain it back, like, "okay, tell me what's going on here, explain what is happening." And if they could explain it back to me in a way that was correct and sounded like they understood it, that was really, you know, what I looked at.

Notably, participants' assessment of students did not appear to be related to other teacher knowledge themes in our data.

Chemistry GTA teacher knowledge unveiled in this study creates an understanding of what types of knowledge GTAs have regarding teaching and learning. In addition to characterizing GTAs' teacher knowledge, we found that GTAs' knowledge of students influenced their instructional goals and their classroom management, and GTAs' instructional goals influenced their classroom management and teaching strategies. The characterization of and relationship between chemistry GTA teacher knowledge components are shown in Figure 1. With this understanding of chemistry GTA teacher knowledge, we are better able to design chemistry GTA training to build upon this knowledge and to support GTAs in maximizing their service to students.

4.1.2 | Teacher identity

Teacher identity is defined as the ways teachers view themselves and their roles as instructors and encompasses their personal goals and desires related to their teaching and professional development (Kelly, 2006). Teacher identity is a product of both how teachers view themselves and how they perceive to be viewed by others and is important to investigate as it influences teacher knowledge development (Kelly, 2006). Four themes regarding GTA teacher identity were identified: *role in the course, affect, personal goals, and desired student perception*. Teacher identity themes are described later, and Table 2 includes a summary of all teacher identity themes and subthemes.

Role in the course refers to the ways that participants viewed the purpose of their teaching role within the course they taught. This is a naturally social construct as GTA duties are defined and communicated by the chemistry department or course instructor for whom they teach. Participants in this study viewed their role as a link between students and the professor. They acknowledged that professors are more knowledgeable, but GTAs are more accessible. Additionally, participants that have taught laboratory courses often viewed themselves as lab managers, as is consistent with another study focused on chemistry GTA identity (Sandi-Urena & Gatlin, 2013). Bud describes his view of his role in the course:

> It's just a supplement to the main lecture. You should... whoever the professor is, is way smarter than me at this subject, hopefully, probably. You should focus on them and believe whatever they say, and then when you're confused, it's my job to try to help you not be as confused and say, "Okay, she goes over this really fast, here's a little slower explanation for why this is."

Many participants, like Bud, view their role as a GTA to supplement the lecture course and as a result, focused on helping students with understanding content that has been taught by the course professor. Laboratory GTAs reported viewing their role as primarily a lab manager, as demonstrated by a quote from Robert, “I don't think that my main role as a lab [GTA] is to be a teacher. That's sort of a secondary role to being a laboratory overseer.”

How participants viewed their role in the course they taught may have influenced the way they interacted with students and participated in their teaching role. For example, a chemistry lab GTA may have been discouraged from going beyond the prescribed lab protocol to explain underlying concepts that related to their lab—which would help their students' learning—due to viewing their role as limited to a lab manager.

The second teacher identity theme, *affect*, refers to the feelings participants had about their GTA role. One subtheme was identified: participants felt unprepared for their teaching role. Amanda describes this feeling as follows:

> I was terrified the first day I walked in here and had to teach. [...] I felt good, but at the same time I felt like I was super unprepared because I never had any formal training. No one told me of things that I could do or ways to model teaching, or that there is like six million different ways to teach the same thing. I didn't even know... I had no clue.

Feeling unprepared as a chemistry GTA could be a result of many different factors (e.g., lack of experience, lack of training, and so on), but it undoubtedly impacts teaching, as demonstrated by Amanda's quote.

TABLE 2 Summary of graduate teaching assistant (GTA) teacher identity themes and subthemes

Teacher identity theme	Teacher identity subthemes
Role in the course	A link between students and the professor; supplemental; a lab manager
Affect	Feeling unprepared to teach
Personal goals	To gain a better understanding of the material; to gain experience as a teacher
Student perception	An informal, approachable resource

Personal goals refers to the goals that GTAs had for themselves as related to their teaching role. The most common personal goals were to gain experience teaching and to gain a better understanding of the material, consistent with the goals reported by graduate students in a study by Seymour et al. (2005). In the following quote, Faith described her goals of learning the content and gaining experience as an instructor:

> Two things. I want to be better at the subject of organic chemistry. So the basics are really important. Um, so, you know I taught [organic chemistry I] for an entire year, now I'm teaching [organic chemistry II] this summer, so I get to re-learn all of that content which is great. I think that will be really helpful. But then, I would heavily consider being a faculty member one day, a lecturing faculty, but I don't know yet, so I think teaching is a really nice way to discover whether or not I have a passion for that.

This theme, *personal goals*, provides insight into motivations for teaching—in addition to financial support (Seymour et al., 2005)—held by participants in this study.

The fourth theme for teacher identity, *desired student perception*, refers to the ways participants hoped to be perceived by their students. Participants strove to be perceived as an approachable resource for students. Allison described this as follows:

> I try to make it very clear that when I'm in class, I'm really open, that they can ask questions, they can email me, they can come to office hours. I don't want anyone to feel uncomfortable, so if they're struggling with something, they can ask me.

The ways that participants aimed to be perceived by their students may have influenced their instructional decisions. For example, a GTA that wants to be perceived as approachable will likely act in a friendly manner. Participants' desired student perception may have been influenced by how they view their role in the course—a GTA that viewed themselves as a link between the professor and the students may have found that the best way to take on this role is to be approachable to students.

Participants' teacher identity (summarized in Table 2) uncovered in this study provides insight into how chemistry GTAs conceptualize their role. While participants vocalized having the personal goal of gaining experience as an instructor, they did not view themselves as instructors, but rather has a link between professors and students or as a lab manager. Participants wanted students to view them as approachable resources and hoped to gain a better understanding of chemistry content through teaching. GTAs often noted feeling unprepared to teach and having to learn to teach on the spot. This understanding can inform the design of GTA training to support the development of chemistry GTA teacher identities.

4.2 | RQ2: What factors influence the development of GTA teacher knowledge and teacher identity?

To investigate Research Question 2, we further investigated interview excerpts to explore the factors that influence the development of GTA teacher knowledge and teacher identity. We first identified that the challenges related to the instructor role influence GTAs' teacher knowledge. GTAs in this study stated that they struggled when content explanations that they learned as undergraduates were inconsistent with how the current instructor is teaching the course, with understanding the content enough to teach it, with managing many different roles as an instructor, and with managing time. Mallory described her struggle with managing time while trying to cover material and respond to students' questions:

> There's definitely a big time-management part of teaching. I only have 50 min to get through all of this material, and there are some students whose questions I'm not going to be able to answer fairly, compared to the rest of the students there. There's some students who walk in and they're very confused about everything, and I can't take the time to sit down and talk it out with them, because I have 29 other students who all have questions.

As Mallory described, the lack of time in class prevented participants from covering content and answering students' questions. To mitigate time constraints, participants guided students to office hours and organized students in groups (classroom management). Amanda described this in the following when asked why she organized her students in groups:

> I taught you something, I know you can teach your neighbor it and if you can't figure it out, come ask me. [...] Which I found out is actually a teaching philosophy-type thing, which I didn't know until a while later. There were days when I was thoroughly exhausted from teaching lab and just needed to sit down for like a half hour.

By grouping students and sending students to office hours when needed, participants were also accomplishing their instructional goals of answering students' questions and for students to understand content. In addition to managing time, participants faced challenges centered around understanding course content. Calvin, an international graduate student, described his struggle with teaching a concept he had learned through different representations:

> There are certain technicalities of representation. [...] I'll give an example if you allow me. If you have a lone [pair on a] nitrogen atom that's conjugated to a double bond, they do here sp^2 hybridized. [...] My teachers followed more like, the British literature. British UK books and Indian books. They talk about more like, you cannot call it exactly sp^2 because some resonating structures will represent sp^2, some would represent sp^3.

Like Calvin, many participants voiced challenges with teaching content in a such a way that was different form how the content was taught and explained to them while they were students. This challenge that participants faced and the challenge of understanding content enough to teach it are especially problematic given that GTAs are expected to be able to effectively communicate content and understand student misconceptions and challenges (Gardner & Jones,

2010). Insufficient content knowledge may prevent participants from leading students to answers or scaffolding content (teaching strategies) (Connor & Shultz, 2018; Grossman, 1990; Hale, Lutter, & Shultz, 2016). Furthermore, experiencing this challenge may negatively affect student learning in laboratory and discussion sections.

In addition, participants drew upon their experiences as students to inform their teaching strategies, similar to GTAs in other studies (Bond-Robinson & Rodriques, 2006; Kurdziel et al., 2003). This is consistent with sociocultural theory of teacher learning—GTAs are learning from their social experiences with others, namely, interactions with previous instructors, to inform their teaching. For example, in a quote included in an earlier section, Allison states that as a student, she found it helpful when her teachers did not answer her questions directly but rather responded with more questions to guide Allison to the answer. Allison reported using this teaching strategy with her students. In some cases, this apprenticeship of observation (Lortie, 1975) method of learning to teach can be problematic because as a student, one is unaware of the goals of certain teaching strategies (Grossman, 1990). Students are only privy to their own personal experiences in the classroom and may wrongly assume that their experience is representative of their classmates' experiences.

Because many GTAs receive their only instructional training during graduate school orientation, we analyzed interviews to determine how participants' training influenced their teacher knowledge. We looked at interview responses to the question: "How has this training influenced your teaching?" and determined the teacher knowledge components that were influenced by GTA training. Eleven out of 22 (50%) of the participants in this study reported that GTA training influenced some aspect of their classroom management. Four out of 22 (18%) of the participants reported that GTA training influenced their teaching strategies. Two out of 22 (9%) of participants reported that GTA training influenced the ways they assessed their students, and 5/22 (23%) of GTAs in this study reported that GTA training had no influence on their teaching.

Teacher knowledge has also been shown to be influenced by teacher identity (Wenger, 1998). To investigate this relationship, we looked at each individual interview for instances where an excerpt was coded as a teacher identity component and either teacher knowledge or challenge. The results from this analysis demonstrated a relationship between GTAs' affect and challenges faced by GTAs. Many GTAs noted feeling frustrated or stressed when trying to teach with little preparation. For example, Allison discusses how she struggles with time management (challenge) and feels bad when she does not have time to cover some content (affect):

> The hardest part for me is that I want to make sure everyone is understanding something, but sometimes we don't have enough time in discussion to go through everything as thoroughly as the students would like, because we have to cover three lectures or the material in only an hour and still give them a quiz on it too, so sometimes it's hard to manage time to cover everything. I don't want to not talk about something that they get quizzed on, because I would feel really bad that I... I think that the managing and the pace of going through material and stuff is something that I struggle with.

This relationship is consistent with the affect-challenge-skill relationship previously reported (Inkinen et al., 2014). In this study, the authors described the affective component of situations with high or low challenge and high or low skills. Situations in which challenge is high but skills are low—akin to teaching as a graduate student—are linked to an active and unpleasant core affect, as demonstrated in this study.

Another factor that influences the development of the teacher knowledge–teacher identity relationship for GTAs is the minimization of the GTA role. As noted earlier, many GTAs in this study viewed their role as supplementary to the lecture and to serve only as a link between the students and the professor. Brian, for example, had been teaching for over five semesters when we interviewed him. As an undergraduate, Brian found he learned well from a lecture model and appreciated that his professors were available to help, so as a GTA, Brian lectured in his classes and tried to be accessible to his students. When he started teaching as a GTA, Brian was nervous about finding the best way to convey information to his students. When teaching lab sections, Brian gave short lectures on lab procedures and safety concerns, then walked around and watched students as they completed the lab. His instructional goals were for students to remember the big ideas, to make sure lab ran smoothly and students were safe, and for everyone to finish on time. When we asked Brian why these are his goals, he said:

> So I guess we didn't really have much training on how to teach. We weren't, we weren't really expected to teach much, like we weren't expected to go out there and really influence them and help them out with these new concepts and explain everything to them. [...] So mostly, especially in my early years, I didn't really feel comfortable like trying to expand or, like, do a bunch of like new stuff or come up or give them a lot of information. [...] Mostly a lot of the things we were expected to do, we were supposed to just kind of help them do the lab and once they're done, they could come to office hours and ask questions, but that's like the goal is to help them get the labs done efficiently.

Because of a lack of social interaction around pedagogy and a departmental culture where GTAs are not necessarily valued as instructors and are not expected to teach, Brian did not perceive his role to be a teacher. Brian's actual perception of his role—as someone to help students finish labs efficiently—discouraged him from explaining and expanding on concepts to support his students' learning. At best, he would answer his students' questions, but did not focus on actually teaching material to his students. When he did teach students about procedures and safety concerns, he used the method he experienced as a student (lecturing). Other GTAs voiced similar perceptions of their role; Vanessa said she is "just another wheel in a larger system," Janice noted, "my role was a self-paced babysitting job," and Jamie comments, "if I were to teach this subject as a whole, I'd need more time, but that's not my job... I am just a lab instructor."

As another example, Grace was a fourth-year graduate student when we interviewed her. As an undergraduate student, she enjoyed doing practice problems and was anxious about her grades but had supportive professors. As a GTA, Grace does not encourage the "must get a good grade" mentality, because she believes it promotes anxiety (like she experienced), and she believes students do not conceptually understand material if they are focused on getting the correct answer. As a result, she views her role as someone to help students work through practice problems. In the semester that we interviewed Grace, she was a GTA for a computational chemistry lab. She mentioned that while students are working on assignments in her lab, she walked around and did her best to help guide students to completing the lab, rather than telling students exactly what to do. However, in order to do this effectively and to anticipate students' questions, Grace tried to complete the lab assignments ahead of time. When asked about constraints that prevent her from teaching the way she would like, Grace responds:

> There are definitely time constraints because we're expected to do research, and that's supposed to be our primary focus. [...] I like to try to do the labs beforehand, so I can really understand exactly what they have to do, but I don't always have time. I don't really like teaching that much, especially in this context, because I don't have time and I feel like it's not prioritized. We're not supposed to prioritize it, and so therefore I feel like I'm not the best that I could be.

Later in the interview, Grace notes that if she is not able to complete labs ahead of time, she will work it out with the student, but she states, "I don't know exactly the best way to lead somebody in the right direction if I also don't know what the final answer's supposed to be. [...] It's also the process that you have to [understand] which I don't. That's the part I don't always fully understand in this computational class."

Brian and Grace voice many of the issues we are communicating in this paper. Brian notes that he did not receive much pedagogy training and was not expected to teach. Grace notes that she was expected to focus on research and was not able to prepare for labs as much as she would like. The institutional organization of discussion and laboratory sections—supplemental to lectures—contributes to the view of the GTA role as being supplemental, which hinders the development of GTAs' identities as instructors. Because the culture of chemistry doctoral programs discourages prioritizing teaching (especially when compared with research and course responsibilities), it is implied that an expert graduate student is one who is successful at research and takes on a researcher identity. As a result, chemistry GTAs do not prioritize teaching (Lane et al., 2018), rarely identify as instructors, and thus rarely focus on improving their teaching practice.

As shown earlier, there are many factors that influence or hinder the development of GTA teacher knowledge. Chemistry GTA participants drew on previous experiences to inform their teaching, experienced challenges that triggered a negative effect, and are discouraged from spending time improving their teaching and taking on an instructor identity. The results from Research Question 2 demonstrated the specific ways in which these factors serve as influences and inform how influencers can be leveraged in GTA training to promote GTA movement toward student-centered teacher knowledge, discussed further in the section to follow.

5 | DISCUSSION AND IMPLICATIONS

Chemistry graduate students are expected to teach multiple lab or discussion sections beginning in their first semester of graduate school with very little training or preparation while also balancing academic and research responsibilities. GTAs are in a position where they can influence undergraduate students' learning and interest in STEM disciplines (Gardner & Jones, 2011), where GTAs are routinely employed to teach discussion and laboratory sections. Some chemistry departments do not hold GTA trainings at all, and of those who do, the trainings are often overgeneralized, short, and focused on classroom management or logistics of their position (Gardner & Jones, 2011; Luft et al., 2004; Park & Ramos, 2002). Without pedagogical training, there is an implicit assumption that content knowledge is enough to teach a subject (Grossman, 1990), which is a belief that GTAs hold (Luft et al., 2004). However, content knowledge is only one piece of a larger skill set required for effective teaching (Connor & Shultz, 2018; Grossman, 1990; Hale et al., 2016; Trumbull, 1999). There is a prominent call to improve GTA training in order to better prepare graduate students for their instructor roles (Bautista

et al., 2014; Bond-Robinson, 2005; Deacon et al., 2017). We assert that a prerequisite to developing a training structure for GTAs is to understand the ways GTAs currently participate in their instructor role and how this is influenced by the context in which GTAs teach.

Through this study we contribute to this understanding; we determined the nature of chemistry GTA teacher knowledge and teacher identity (Kelly, 2006) and the factors that influence the development of GTA teacher knowledge and teacher identity. Interestingly and in contrast to other studies of GTAs, participants did not describe GTA peers and graduate school mentors as major influences on their teacher knowledge (Luft et al., 2004; Seymour et al., 2005). While further research on this finding is needed, it is perhaps due to the lack of collaboration and social interaction centered around teaching—we might imagine that this would not be true if we were investigating influences on graduate students' research knowledge (Austin, 2002). Kelly (2006) echoes the argument that the potential for constructing teacher knowledge is increased when teachers engage in collaborations involving problem solving, sharing ideas and perspectives, creativity, and innovation (Wells, 2000). As such, our first and most central recommendation is to allow for these collaborative spaces to exist between GTAs by extending GTA training past orientation and well into graduate students' first year of teaching (Gardner & Jones, 2011; Marbach-Ad et al., 2012; Nurrenbern et al., 1999). Our remaining recommendations for training would ideally be situated within a prolonged collaborative space.

Sociocultural theories of teacher learning assert that teachers draw on existing knowledge to inform their teaching, and teachers continuously develop this existing knowledge base as they engage in teaching in their own particular circumstances (Kelly, 2006; Schön, 1987). In the project presented herein, we characterized our participants' knowledge base for teaching and learning. Figure 1 displays this and relationship between chemistry GTA teacher knowledge components. GTA teacher knowledge unveiled here can serve as a foundation for chemistry GTA training. Within a prolonged training, GTAs can be exposed to high-leverage practices that relate to GTAs' current knowledge for teaching (Ball & Forzani, 2011). For example, GTAs in our study report that they know students are different—they have different goals, interests, and learning styles. Chemistry GTA training could leverage this knowledge in explaining that students learn in different ways and teaching in different ways is important in supporting their learning.

Similarly, the connections evident in our participants' knowledge bases for teaching and learning can be leveraged in GTA training. For instance, GTAs in this study reported instructional goals (students learn content, answer students' questions, demonstrate relevance of chemistry, and engage students) which influenced their choices of teaching strategies (lead students to answers, scaffold content, incorporate relevant examples of chemistry). This relationship between instructional goals and teaching strategies could be leveraged in GTA training by informing GTAs of the instructional goals of their teaching sections and exposing GTAs to teaching strategies that help achieve those goals—one should not be discussed without the other. Engaging GTAs in the practice of identifying specific achievable goals, methods to accomplish their goals, and methods to assess whether their goals were achieved should be a focus of GTA training.

The challenges that chemistry GTAs face provide insight into the complexity of the GTA teaching practice (Loughran, 2014). With the exception of the challenge regarding inconsistent explanations of content, the challenges identified by GTAs in this study echo the literature on science teacher learning (Davis, Petish, & Smithey, 2006; Loughran, 2014; Sarason, 1990), and are unsurprising given that chemistry GTAs rarely receive support for teaching

(Luft et al., 2004). Researchers have found that discussing challenges increased teachers' confidence in risk taking, enhanced students' and teachers' scientific literacy, and helped to develop teacher's knowledge of their profession (Smith, 2011). Thus, first-year chemistry departmental GTA training should include a discussion of anticipated challenges associated with the GTA role, and this discussion should continue throughout the semester and evolve as incoming GTAs experience their own challenges. Within a semester-long training, opportunities for GTAs to discuss their challenges and reflect on their practice with the support of more experienced GTAs or other instructional faculty and staff provides a space for GTAs to develop their identities as instructors and their teacher knowledge (Kelly, 2006; Wenger, 1998).

GTAs in this study and others use their previous experiences as students and instructors to inform how they teach (Bond-Robinson & Rodriques, 2006; Kurdziel et al., 2003). Similarly, pre-service science teachers have reportedly struggled with moving past what they have experienced and have found to be successful (Richardson, 1996), and a great challenge for teacher education programs is to encourage teachers to see beyond their experiences as students (Sarason, 1990). It is thought that this challenge originates from the resistant core beliefs of teaching that are held by learning, new, and experienced teachers, including GTAs (Pajares, 1992). Thus, in chemistry GTA training, teaching beliefs should be surfaced, challenged, and developed, as they are in K-12 teacher training programs (Bullock, 2011).

A semester-long departmental GTA training run by faculty or staff may also alter the research-focused culture of STEM departments perceived by GTAs. As noted in the study presented herein, GTAs rarely view themselves as teachers, but more so as tutors in discussions or as managers in laboratories. This opinion is likely due to how professors and research mentors interact with GTAs (Lane et al., 2018)—social interactions and recognition by others has repeatedly been shown to be a strong influencing factor on identities in STEM (Carlone & Johnson, 2007). Chemistry GTAs play a crucial role in undergraduate STEM education and are in a position to greatly influence the interest and retention of undergraduate students. However, in order to fulfill this role, GTAs must do more than tutor or manage labs—they must focus on supporting students' learning of chemistry. GTAs work in environments that prioritize research over teaching (Lane et al., 2018; Luft et al., 2004; Shannon et al., 1998), so they do just that. Lane et al. (2018) describe this doctoral culture as a blizzard that graduate students need to navigate through in order to develop their teacher identities. In an environment that places more focus and value on teaching, the blizzard may calm, and GTAs may be more encouraged to place more focus and value on their GTA role (Grunwald & Peterson, 2003).

In summary, a semester- or year-long chemistry GTA training that includes collaborative spaces focused on (a) discussing experienced challenges, (b) confronting beliefs, (c) reflecting on teaching, (d) aligning of GTA goals, teaching strategies, and assessments, and (e) that builds upon GTAs' previous experiences and current knowledge may be a viable option to support graduate students in their roles as instructors which will thus help the thousands of undergraduate students taught by GTAs. However, the GTA training structure will crumble without enthusiastic, committed facilitators. In accordance to sociocultural theory of teacher learning, GTAs learn to focus on research and neglect their teaching role if that is the culture of their department (Kelly, 2006). In order to improve participation in instruction, GTAs must learn to prioritize teaching, which requires a shift in departmental culture.

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ORCID

Alena C. Moon https://orcid.org/0000-0003-0379-294X
Ginger V. Shultz https://orcid.org/0000-0002-7285-748X

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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