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DEVELOPING PEDAGOGICAL CONTENT KNOWLEDGE AS COMMUNAL PRACTICE: A CASE STUDY OF CHEMISTRY GRADUATE TEACHING ASSISTANTS

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DEVELOPING PEDAGOGICAL CONTENT KNOWLEDGE AS COMMUNAL PRACTICE: A CASE-STUDY OF CHEMISTRY GRADUATE TEACHING ASSISTANTS

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Education at the University of Kentucky

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ABSTRACT OF DISSERTATION

DEVELOPING PEDAGOGICAL CONTENT KNOWLEDGE AS COMMUNAL PRACTICE: A CASE-STUDY OF CHEMISTRY GRADUATE TEACHING ASSISTANTS

Learning does not only happen during dedicated instructional time, which also applies to learning how to teach. Teachers can reflect on their practice while working to continue to improve and develop their teaching skills. In addition to self-reflection, teachers can also learn from their colleagues to experiment with new practices and take others' teaching knowledge into their repertoire. Understanding how these two processes function can lead to developments in teacher education and professional development, specifically for initiatives that seek to promote collaboration among teachers. Post-secondary educators in particular can benefit from collaborative and reflective practices to improve their teaching, especially given that these educators do not often have rigorous teaching training. To explore how teaching practices can be influenced by interactions with one's community of educator colleagues, this work combines the recently developed refined consensus model of pedagogical content knowledge (PCK) with Wenger's communities of practice framework to explore how teaching knowledge moves throughout a community of educators. Taking an ethnographic approach that involves participant observation and in-depth immersion, a cohort of graduate teaching assistants (GTAs) in a chemistry department is studied to learn how teaching knowledge and practice are developed through experience in their cohorts of fellow GTAs. Specifically, this work compares the experiences of recitation and laboratory GTAs teaching in the same discipline and level of course: general chemistry. Observations of GTA training, weekly meetings, and instructional time are supplemented with data from semi-structured and informal interviews to determine specific features of this group's PCK and the social factors that moderate its uptake by members of the group. Analyzing the knowledge bases that contribute to PCK reveals that the structure of the specific job these GTAs perform mitigates the development of their teaching practices, specifically their content knowledge, which is a prerequisite for developing PCK and therefore limits its growth. Possibilities for connecting this research into practice are explored, as is the benefit of the new framework that this study seeks to validate.

KEYWORDS: Pedagogical Content Knowledge, Teaching Practice, Ethnography in Education, Community of Practice, Graduate Teaching Assistants, Qualitative Research.

Walker Bryan Mask

(Name of Student)

August 2nd, 2023

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1.1 The History of GTA Instruction in the U.S.

In the history of U.S. higher education, the social and political environment of the mid-20th century is often cited as a catalyst that urged many significant changes to the structures of collegiate ecosystems. Lagging behind the Soviet Union in technological innovation, the U.S. government pushed for a more educated workforce, particularly with knowledge and skills in science and engineering. Backed by federal effort and money through the National Defense Education Act, the number of students pursuing post-secondary education more than doubled in the decade following its passage (Ponte, 2016). Consequently, more students required the hiring of more instructors. However, many higher education institutions at the time were still clinging to having a faculty body made primarily of white, male, disciplinary experts. While few concessions were made based on gender and race for hires, many institutions were forced to lower their restrictive standards to accommodate their staffing needs. Post-secondary institutions relinquished their ideal instructors having earned the 'three degrees'- faculty having completed a baccalaureate, master's, and doctoral degree in their field, indicating mastery of a topical area and a commitment to the social-political institutions of higher education. Desperate for faculty, universities had to depend on M.A. and M.S. recipients, and eventually even graduates with only baccalaureate degrees to deliver instruction to the growing student body of the time. Eventually, a shift occurred that resulted in qualified Ph.D. candidates, regardless of their prior degree completion, becoming responsible for undergraduate education as graduate teaching assistants (GTAs), often under the supervision of traditional faculty.

Higher education took no time in exploiting the new population of teaching assistants, paying them far less than other instructional faculty and designating them to the 'dirty work' of higher education, classes such as laboratories and foundational composition (Zimmerman, 2020). GTAs had been present in many disciplines since the early 20th century, but it now quickly became a system that a majority of institutions relied on. A 1947 report found that 11 of 15 departments at UCLA utilized GTAs for full undergraduate instruction, and a later 1958 survey reported that at UCLA, "TAs had 'virtually the sole responsibility for instruction' in 166 sections of 25 courses, despite the 'questionable legality' of the practice" (Zimmerman, 2020, p. 114). Over four decades later, a study found of 34 research universities found that 91% of biology laboratory courses were taught solely by GTAs (Sundberg et al., 2005). For GTAs, teaching was yet another burden of their graduate studies, and to the detriment of their undergraduate students, many prioritized their teaching roles far under their own program and research requirements. This behavior could be said to be the result of socialization within the higher education environments, as many faculty held the same belief (Gardner, 2006). It may also be the result of GTAs' attitude towards this compulsory teaching role, as for many students becoming a GTA is the only way to get early funding for their graduate studies or to maintain funding later on in their program completion (Schultz et al., 2019).

During the 1960s and 1970s, GTA training and the quality of instruction in higher education started to become a focus for many universities. Before this shift, most of the training that GTAs would receive was more or less a 'trial by fire,' in which they were given materials and simply told to go teach (Zimmerman, 2020). It was also difficult to convince or find faculty that would be willing to train any GTAs, again perpetuating the attitude that undergraduate teaching is nothing more than a job that must be done. The evolution of these attitudes persists well into the first decades of the 21st century and is seen among beliefs that a teacher's role is only to transmit knowledge to their students. This belief evolves into another, one that post-secondary instructors do not need any professional teacher training (Gardner & Jones, 2011). Despite these cultural setbacks, the effort put into training GTAs to teach began to slowly improve. The first dedicated national conference focusing on TA issues even happened in 1986, but this was largely motivated by a push to improve undergraduate education and outcomes, rather than the experience of TAs themselves (Seymour, 2005).

By the 1990s, many opinions on GTA training had shifted, and university funds were diverted into professional training for their instructional faculty at many levels, including GTAs. This trend has not faltered. From 1992 to 2011, the number of graduate students, not just GTAs, who received teacher training and preparation during their Ph.D. programs doubled (Zimmerman, 2020). Just as universities have seen benefits from investing in GTA preparation, so have the GTAs themselves. For example, an American Chemical Society (ACS) survey of chemistry Ph.D. recipients working in both industry and academia found that over 2000 of the respondents felt very favorably toward the notion that their experience as a GTA helped them with their current career performance (ACS Committee on Professional Training, 2002). Research has also found that the development of graduate students' teaching ability can lead to improvements in their ability to conduct and communicate their research, further examples of the indirect benefits for the GTAs (Gilreath & Slater, 1994; Feldon et al., 2011). With support such as this from Ph.D. graduates, universities certainly have no incentive to remove the practice from their educational systems, especially as doing so would cause a collapse in the quality of undergraduate education they offer.

1.2 GTA Training Formats and Structures

As the push to better prepare GTAs for their teaching positions grows, so do the variety of methods used in training and the goals that academic units hope to achieve. Developing alongside this movement is an area of research dedicated to the effective training of GTAs, including research on the implementation of training and how effective training differs among academic disciplines. We know that GTAs cannot rely entirely upon the subject matter knowledge they generate during their undergraduate education, and they often need specific and targeted training to promote effective teaching (Kind, 2014). Therefore a central interest to the researchers in this field is determining how much training is needed and which format is best for ensuring that GTAs can teach effectively, or at least within the expectations of their institutions.

Over the past decades, GTA training has taken on many different formats, varying in the length of time invested, the method or delivery of information, and specific goals. An idealized system of training for those most concerned with true teaching effectiveness may be similar to a dedicated collegiate teaching and learning program, with or without a specific focus on one's discipline or subject area. This format would likely be akin to a Preparing Future Faculty program as described by Pruitt-Logan et al. (2002). A similar training curriculum may be found in teaching certificate programs, which can be used to promote complex changes in teaching behavior and beliefs such as the shift from teacher-centered to student-centered approaches and practices (Addy & Blanchard, 2010). However, these programs often take multiple semesters or even years to complete and require a substantive commitment by the student on top of their other graduate program obligations and requirements. For many GTAs, their teaching obligations come after their coursework requirements and research progress, serving mostly as a means to an end and another hurdle in the marathon that is the Ph.D. (Latulippe, 2007). These efforts, like many forms of teacher education and professional development, require buy-in from participants to be effective. Therefore, any expectation that institutions have of their GTAs to complete such a program is unrealistic due to the intensity of the commitment required.

If GTAs cannot reasonably receive training for their teaching roles that is on par with that of traditional teacher training programs, then more condensed formats must be developed and used. However, there is a balance that must be achieved between condensing the information from a traditional teacher training program and reverting to the most minimal support possible. Many GTA training programs rely on singular campus-wide workshops to train all GTAs for an academic year in as little time as possible (Luft et al., 2004). A common example of this is the Microteaching format, which is designed to focus on lesson planning and delivery through practice with other teachers, or in this case GTAs in other disciplines (Allen & Ryan, 1969). While the time efficiency of this method cannot be argued, assuming that teaching knowledge can be generalized is a fallacy to avoid. For one, these workshops tended to limit the focus to topics such as classroom management or general advice for interacting with students. While useful in some capacity, the training is not specialized enough to be any more effective than making GTAs figure out everything on their own. Microteaching is also not standardized, so just because one university covers effective teaching strategies does not mean others will, not to mention the ill-suited fit of certain disciplinary-specific teaching strategies and approaches to other disciplines.

If traditional teacher training programs and boilerplate university-wide training are two extremes, then there must exist some middle ground that training can take the form of. Departmental training typically focuses on the aspects of teaching needed to successfully fulfill the instructor role in a GTA's discipline. Ranging in length from single-day workshops to semester-long courses, departmental preparation can cover a myriad of teaching approaches, methods, and practices (Gardner & Jones, 2011). However, just because a department designs and requires this training does not mean it will be effective in preparing its GTAs. Often, these efforts are too focused on what to teach, or just what to do in the classroom, rather than how to teach (Brannon, 2014). Therefore, the primary focus of the research field regarding GTA training asks questions about how to best design GTA training to achieve different outcomes regarding their teaching. Literature on the topic shows some agreement, largely in the structure and the broad topics to be covered. From this research, we know that GTA training should include experiential learning opportunities that allow GTAs to practice developing their teaching skills (Park, 2004). Useful components of training include active learning practices, constructivist teaching approaches, peer interaction, different methods of assessment, and reflective teaching practices (Park 2004). However, a training program's success will still largely depend on the buy-in of the GTA participants. Even when a training program has been designed to efficiently expose GTAs to student-centered teaching practices and constructivist approaches, these practices may not stick in the long term (Pentecost et al, 2012; Gretton et al., 2017). Additionally, the culture of institutions or departments may not encourage approaches outside of positivist and traditional information transference (Nurrenbern et al, 1999; Volkmann & Zgagacz, 2004).

Another factor when considering the structure of GTA training and its effectiveness is the knowledge and skill of the people who lead these training sessions. In most cases, a faculty member from the same department the GTAs work for will lead the training sessions. The teaching knowledge of these individuals will vary, but we can likely assume they have accumulated expertise in training GTAs for at least their specific roles In some cases, departments may bring in academic support specialists or leaders for dedicated teaching workshops to facilitate GTA training. As with other forms of education, biases, attitudes, opinions, and behaviors may transfer from trainer to trainee, influencing future teaching practices.

1.3 GTA Training Outcomes

Research on the outcomes of GTA training shows the benefit of experimenting with the format and content of training programs. At the minimum, training should improve undergraduate learning outcomes and performance (Wheeler er al., 2017). However, it can change a GTA's conceptual understanding of their role and the subject matter for the better (Baumgartner, 2007). GTAs can become more aware of the challenges of teaching science, and learn methods for overcoming certain barriers or difficulties (Trautmann & Kransky, 2006). Workshops or seminars can be used to provide GTAs with information about specific teaching topics on a regular schedule. While the effectiveness of non-mandatory workshops can depend on participation, they can still expose GTAs to the information that they need, moving away from a one-size-fits-all approach (Nicklow et al., 2007). When structured purposefully training can lead to gains in GTAs' understanding of equity in teaching, although equitable initiatives are sometimes in conflict with larger cultural norms in post-secondary science education (Sarju and Jones, 2022).

Department-level training is focused on the skills needed to teach their courses, rather than specifically preparing GTAs with transferrable teaching knowledge. Disciplines that use laboratory courses, such as biology, chemistry, and physics, may choose to focus their training efforts on inquiry-based learning, but this can be a difficult teaching approach for novice or non-traditionally trained teachers to effectively employ. Hammrich's (1994, 2001) studies with biology GTAs show that they can change their conceptualization of teaching as a result of effective training, noting recognizable changes to the GTAs' approach to assessment and evaluation. French and Russell's (2002) analysis of biology laboratory GTA teaching behaviors before and after training showed that the GTAs were able to include some more inquiry-based teaching approaches in their laboratory instruction.

Outside of the effects of the training, studies have also reported confounding effects from other contextual factors. Many studies capture demographic data to support their argument that their training intervention has a significant impact on GTA teaching, followed by other individual factors. However, the demographic data in these studies show that a major factor found to influence teaching effectiveness is having prior teaching experience before entering the GTA position (Adams & Krockover, 1997; Skamp, 2001). Additionally, prior teaching experience will lead to increased self-efficacy in teaching as more experience brings increased confidence in one's abilities (Prieto & Altmaier, 1994; Boman, 2013). Depending on the training structure and complexity, prior experience may even be more influential on teaching practices than the training (Kurdziel et al., 2003). If this is true more often than not, then training curricula should incorporate this when possible. Conversely, the benefits from training can also be amplified depending on how much experience a GTA has before entering their new teaching role (Marbach-Ad et al., 2012).

When a GTA does not have prior experience to rely on, they instead use their academic interactions to develop and refine their teaching. One such interaction is mentoring between GTAs, as well as mentoring between faculty and GTAs. Mentoring allows GTAs to take the perspective of others into their teaching practices. In a case study of a single physics GTA, Volkmann & Zgagacz (2004) observed that the continuous relationship between the GTA and their supervisor had a compounding influence on teaching practices as well as the development of new teacher identity. In a similar vein to mentoring, receiving feedback from a knowledgeable colleague or supervisor can also significantly influence GTAs' practices, as long as the feedback is given promptly and includes actionable advice that the GTA can use (Hampton & Reiser, 2004; Becker et al., 2017). Regular feedback, and when possible feedback from multiple sources, can additionally improve GTA uptake of suggested changes to their teaching practices (Cox & Hahn, 2011). If the professional relationship is strong, GTAs may pursue continued mentorship to further improve their teaching practice, outside of the specific context they currently teach (Young and Bippus, 2008). Coaching, an alternative to mentoring, can also be an effective scaffold for the continual development of GTA teaching practices and skills (Fennel, 2014). Though these studies exist in different contexts, as a whole it is clear that GTAs can benefit from a variety of interactions with their academic communities in addition to their training.

Through discussion on teaching and observation of each other's teaching practice, GTAs can learn from their peers (Miller et al., 2014). A physics GTA training course developed by Alicea-Muñoz et al. (2021) includes the observation of recorded teaching by past GTAs, allowing new GTAs to learn from their experienced peers even when they are not present. The process of reviewing and learning from a video recording of instruction is also common in other formats, in which GTAs review their own recorded teaching practice with other GTAs. Lang et al. (2020) conducted a reformatting of the GTA training in the chemistry department at Purdue University, and one of many important pieces of feedback they received from the GTAs was the desire for increased opportunities to observe their GTA colleagues during instruction. Similar to how GTAs gain from interactions with others, they also gain from different types of teaching experiences, whether as teachers or observers.

Although there is not full agreement on the best training methods or goals, even within one discipline, research collectively shows that GTAs are influenced by more than just their training alone. The GTAs bring their opinions, attitudes, and beliefs with them into training and teaching. These personal aspects may change because of training, but they may also change as they gain graduate school experience (Becker et al., 2017). Interactions with their graduate student peers, faculty and supervisors, their students, and even with their departments and institutions as non-human actants may all be significant influences on how a GTA develops their teaching practices. Additionally, the impact of social structures such as gender, race, and ability also have a hand to play in shaping teaching practice. For example, it is well known that international GTAs have a very different experience with their students than domestic GTAs based on cultural and linguistic barriers (Plakans, 1997; Luo et al., 2000; Bond-Robinson & Rodriques, 2006). Academic experiences, socialization, training, and individual factors all come together to influence and shape GTAs' teaching practices. Teaching practice development directly connects with the processes of training and is modified as different experiences are had. Understanding the mechanisms that influence changes in teaching practice is crucial to developing better training and preparation for GTAs, and properly understanding their true experience in this role.

1.4 Study Objectives and Research Questions

Learning does not happen in a vacuum or only in formalized settings. Students learn outside of their classes, on their own through exploration, and with others. This feature also extends to learning how to teach. Teachers of all contexts can learn and develop their teaching practice outside of their formal, dedicated instances of education. Additionally, teachers will learn about more than just what they are trained on. All of these statements also extend to GTAs. Much of the research surrounding GTA training and cognition is focused on undergraduate outcomes or the evaluation of the preparation and professional development programs (Reeves et al., 2016). The objective of this study is to learn how GTAs use their experiences in academic settings to build their teaching knowledge and behaviors. By closely observing changes in GTA behavior over time, we will learn more about how GTAs develop as teachers while simultaneously developing as academic professionals. In pursuing this goal, important sub-objectives will be to explore the shared teaching knowledge of the community of the teaching assistants and how they share information, as well as how individual teaching assistants act on their knowledge while they are teaching or interacting with students. The study also aims to understand how non-teaching academic experiences, such as interactions with faculty, interactions with other graduate students, and their program obligations impact their teaching. Similar work has associated and modeled these phenomena with GTA self-efficacy in teaching (DeChenne et al., 2015), so investigating their impact on teacher knowledge and practice development is well within the interest of the field. To achieve these objectives, I conducted an ethnographic study that focuses on the GTAs of the chemistry department at the University of Kentucky, as there are features of their training and their academic roles that are advantageous for learning about how different academic experiences and interactions influence their teaching practices, behaviors, and attitudes. The particular research questions of the study are as follows:

1. What are the characteristics of the general chemistry recitation and laboratory GTAs' pedagogical content knowledge (PCK)?
2. How do recitation and laboratory GTAs interact with their communities of practice to develop their PCK?

These research questions allow for the observation and analysis of how GTAs teach and how their teaching knowledge, operationalized as pedagogical content knowledge, is shared among the group of GTAs in the same subject. Additionally, although the cohort of GTAs is not explicitly structured as a community of practice in their training and collaboration, the framework is useful for studying this group's social learning behaviors. The results of these analyses will help further research on GTA teacher knowledge development so that future GTA training can be designed with their knowledge construction processes in mind, so not only can GTA teaching be improved, but the experience of being a GTA can be improved as well. This study is also timely within the current developments in the area of chemistry education research and even GTA teacher cognition research, with studies focusing on similar research objectives and populations recently published (Hirshfield & Ramahi, 2018; Zotos et al., 2020).

CHAPTER 2. A FRAMEWORK FOR COMMUNAL TEACHING PRACTICE DEVELOPMENT

The conceptual framework for this study brings together teacher knowledge theories and situated learning theories to build a basis for investigating how GTAs develop in their teaching roles through their academic social interactions and experiences. Constructivist worldviews weave throughout the study, as the design takes the perspective that how these theories manifest in GTAs' realities are socially and uniquely constructed (Bogdan & Biklen, 1998). This unique construction leads to the existence of multiple realities, all experienced by individuals (Kivunja & Kuyini, 2017). Teacher knowledge is constructed by the GTA through training and experience, and the groups that GTAs place themselves within fall along distinctions formed by social structures and interactions. Following this epistemological perspective, the selection of theoretical frameworks supports the idea that the experiences of these GTAs constructs unique to each individual, and must be explored at this level to fully understand their lived experiences as post-secondary teachers.

2.1 Teacher Knowledge

Pedagogical content knowledge (PCK) is described by Lee Shulman as the "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding," (Shulman, 1987, p 8). PCK is a form of specialized knowledge that teachers construct during training and continued practice that they then draw upon to inform their teaching practices, both in the moment and outside of instructional instances. It reflects the difference between how a subject matter expert and a teacher of subject matter each approach the practice of conveying knowledge to others.

Shulman's initial PCK model was based on an integrative perspective, theorizing that PCK forms at the intersection of subject matter knowledge (content knowledge), pedagogical knowledge, and broad knowledge of the educational context. These sources that contribute to the PCK construct are often referred to in the literature as knowledge bases. It was well believed at the time that teachers with strong content knowledge can more easily detect students' preconceptions and misconceptions (Hashweh, 1987). Shulman argued that additional knowledge of the act of teaching is what pushes content mastery into the ability to teach that content effectively.

Shulman's work was expanded and re-contextualized into PCK models and frameworks. A shift in perspective on the action of PCK construction led some researchers to develop transformative models of PCK. In contrast to Shulman's integrative perspective, the transformative approach considers PCK as a new construct made by changing the knowledge from the various knowledge bases, rather than being produced from their intersection. The transformative model informs the work of researchers such as Grossman (1990), Gess-Newsome (1999), and Magnusson et al. (1999). Generally, PCK is a 'cognitive toolbox' that teachers can pull from to help them teach effectively and address issues that arise from the different knowledge bases. For science teachers, this manifests as the ability to represent science as inquiry, transmitting facts of science, encouraging the learning and understanding of the physical world through collaboration, promoting the investigation of solutions to problems, and helping students develop the skills to 'do science' and the knowledge to understand scientific work (Lehavi et al., 2017).

2.1.1 Recent Models of PCK

Some PCK models incorporate other kinds of knowledge into the construct to represent or investigate their impact on PCK and teaching. For example, the technological PCK or TPACK model includes teachers' ability to effectively integrate technology into their instruction (Mishra & Koehler, 2006). The TPACK model changes Shulman's model by incorporating a knowledge base concerning only technology, which also introduces the intersections of content-technology knowledge and pedagogy-technology knowledge. Hill et al. (2008) expanded the content knowledge base in their model by introducing specialized forms of mathematical content knowledge. Their content knowledge base includes knowledge of what students learn before and after their time with a particular teacher, as well as the applicability of concepts in mathematics to the students' lives. PCK also manifests at different scales, from the PCK of a discipline down to the PCK of a specific topic or concept. For example, mathematical PCK is distinct from biological science PCK, and the PCK of teaching functions would be different than the PCK of teaching proofs, although they may also share components as they are both within the same disciplinary domain. However, regardless of the interpretation or the use of a particular model, PCK is well accepted as an academic construct and is widely used as a framework for operationalizing teachers' knowledge of instruction (Loughran et al, 2014).

The Topic-Specific PCK (TSPCK) model is commonly used to investigate teachers' abilities, practices, and behaviors for teaching singular concepts in a discipline (Loughran et al., 2006; Mavhunga & Rollnick, 2013). A popular choice of framework in chemistry education research, TSPCK frames studies on educators at all levels of K-20 and on different chemistry topics. For example, chemistry TSPCK studies have investigated stoichiometry (Malcolm, 2019), NMR spectroscopy (Connor & Shultz, 2018), electrochemistry (O'Brien, 2017), and thin-layer chromatography (Hale et al., 2016). While this varied collection of topics spans not only general chemistry but also organic chemistry, this is a strength of the TSPCK model as a framework for these kinds of studies. Additionally, the chemistry subject matter between these studies also shows how applicable the TSPCK model is to both conceptual and procedural chemistry knowledge, which is useful for learning in both the traditional classroom and the laboratory. A review of PCK studies in chemistry contexts found that among 89 studies, 43 used a specific PCK model to frame their study, 16 of which utilized Magnusson's (1999) model for their PCK framework, and 8 others used the TSPCK framework to guide their research design and analysis (Cirilo & Colagrande, 2021).

2.1.2 Consensus Models of PCK

While TSPCK is useful for investigating the knowledge of teaching certain concepts, it and many PCK models that came before focus more on the knowledge reservoir a teacher develops, rather than how a teacher pulls from this reserve to inform their practice. Gess-Newsome (2015) developed a PCK consensus model that combined TSPCK, professional knowledge bases, and the influences of classroom practice. The consensus model and a later variation, the refined consensus model (Carlson et al., 2019), focus on both the knowledge for teaching a topic and how teachers act on that knowledge. In this way, these models include both what is commonly referred to as 'knowledge-on-action', or what a teacher has learned about teaching, and 'knowledge-in-action', or what the teacher does during instruction (Park and Oliver 2007). This model also distinguishes the knowledge sources that are transformed into PCK by separating knowledge acquired through reflection ('personal') and knowledge gained through professional training and social learning ('canonical'). This distinction is important, as all teachers will have personal PCK, but not all teachers have canonical PCK (Smith & Banilower, 2012). In general, GTAs are likely to have minimal canonical PCK as their opportunities for professional development and the length of required training are minimal compared to that of K-12 teachers and post-secondary instructors (Hale et al., 2016). The Cirilo & Colagrande (2021) review found two studies that used a consensus model as a theoretical framework, indicating a wealth of opportunity to explore how this model applies to chemistry education research, noted additionally by Rodriguez and Towns (2019).

Like all other PCK models, the refined consensus model is built upon the different knowledge bases teachers use to construct their teacher knowledge. Shulman's integrative model of PCK existed at the intersection of the knowledge bases containing subject matter and pedagogical skills. The refined consensus model contains five knowledge bases that inform an individual's PCK, which are positioned around the perimeter of the pentagonal visualization shown in Figure 2. Content knowledge is the same as how Shulman and many others have defined it. It is the subject matter, including all concepts and topics and how they are connected within the discipline. Rodriguez and Towns, who currently explore how the refined consensus model can benefit chemistry education research, make a distinct point to include skills as well, specifically those that "reflect an understanding of and ability to engage in science practices," (2019, p. 1798). Pedagogical knowledge is the learned theories and principles of teaching in general, as well as classroom management practices. This knowledge also existed in this form in Shulman's original conceptualizations of PCK. Past models of PCK also include knowledge of assessment within pedagogical knowledge, as well as some understanding of student cognition.

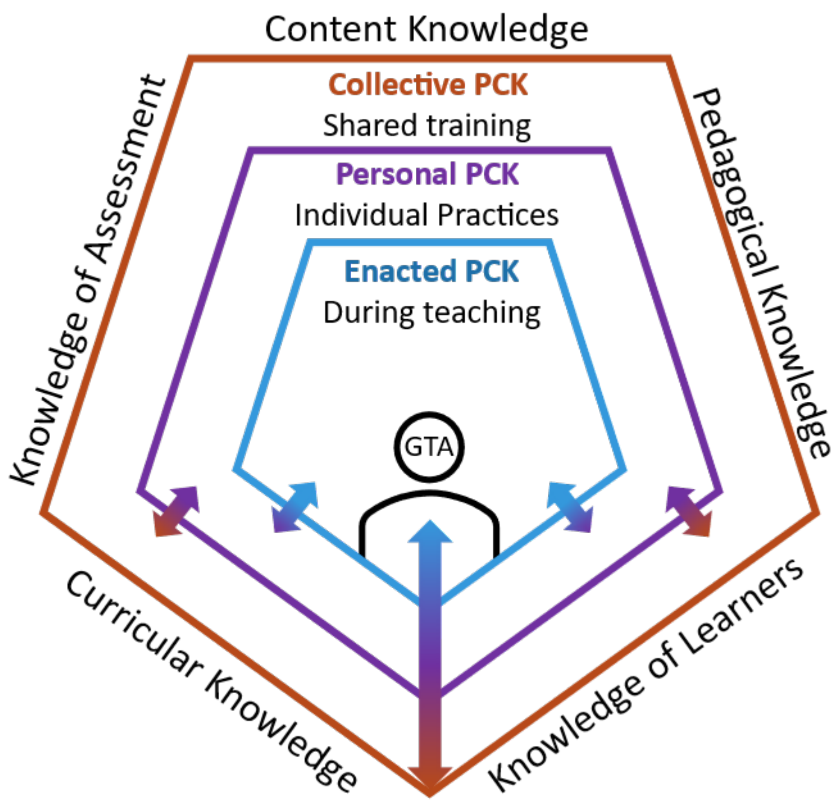


Figure 2.1 The Refined Consensus Model of PCK

The knowledge of learners is the understanding of students' cognitive development, characteristics, and approaches to learning. These all influence how students are going to interact with their teachers, the information they receive, and the knowledge they construct. It also includes an understanding of the differences that exist between students in these areas, which is drawn upon to inform culturally responsive practices (Gay, 2002). Curricular knowledge is the knowledge of the specific goals of what is being taught at the level above individual lessons. This represents an understanding of scope and sequence, learning outcomes, and performance expectations. Finally, assessment knowledge is the knowledge of designing formative and summative assessments, and how to act on data gained from assessments. These knowledge bases are similar to those used in other models of PCK in that they can be fluid in their magnitude or usage depending on the educational context. It is important to note that similar to that of Rodriguez and Towns (2019), the model visualization Figure 2 is not conceptually to-scale. In other words, the knowledge bases may not be equal for any individual teacher, even though they are shown this way for simpler visualization.

The refined consensus model focuses on the knowledge sources that teachers draw from to build their own PCK, which is unique to them based on their individual experiences and specific constructed knowledge (Rodriguez & Towns, 2019). This personal PCK is applied during teaching into enacted PCK, which is influenced by students and their learning. Enacted PCK exists whenever a teacher in engaging in instructional practice. The personal PCK exists within a certain educational context, defined by the learning environment, time, and social-cultural-political characteristics. The context, personal PCK, and enacted PCK all exist within a collective PCK of all similar teachers. These different forms of PCK are shown as nested pentagons in Figure 2.1, representing the idea that the enacted form of PCK is drawn from the personal PCK, and the personal PCK is drawn from the collective PCK. For example, a high school teacher has received their specific teacher training during their degree built upon research-backed pedagogy (collective PCK), they draw from the subjects and setting they teach to influence their personal teaching preference (personal PCK) and channel this into teaching specific students and specific content (enacted PCK). The application of deeper context refines the collective PCK into enacted PCK, and a teachers' training into practice. These influences can also be considered in the other direction. Enacted practices and behaviors may over time become an integral part of a teacher's personal PCK, and when sharing knowledge with other teachers, aspects of personal PCK may be shared and become a part of the collective PCK. In Figure 2.1, these influences are represented with the bi-directional arrows between the forms of PCK. No matter the direction of the knowledge transformation and influence, the teacher knowledge in this model is dynamic, changing based on the context. The transformations between each form of PCK, how they happen, and what exactly is taken from one form into another all need further investigation.

This study uses both the refined consensus model and the TSPCK model to investigate GTAs' personal PCK over time, how it draws from and gives back to collective PCK, and how it is transformed into enacted PCK for specific concepts and teaching moments. Specifically, the refined consensus model is used to scaffold the research design and methods, while the TSPCK is used to probe into GTAs' practices and knowledge for specific lessons and concepts. A key addition to the refined consensus model that this proposed study investigates is the impact external experiences have on a GTA's personal PCK. These experiences include interactions with their students and peers, individual characteristics such as race, gender, and nationality, and individual and shared attitudes and beliefs towards teaching in general and towards teaching chemistry.

2.2 Communities of Practice

A known phenomenon in novice teaching contexts is the impact that socialization and situated learning have on new teachers' growth in their profession (Cuddapah & Clayton, 2011). Situated learning is a theory concerning how people learn through social interactions, both actionable knowledge that they consciously act upon and non-surface level influences on their behaviors and attitudes (Lave and Wenger, 1991). Within social constructionism, learning done by an individual is possible through community, or social interactions, and contributes to an individual's unique experience and constructed knowledge (Cobb, 1994). A common form of situated learning is the community of practice (CoP), a social learning community defined by Wenger as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (2014, p. 1). In education, a CoP helps novice teachers learn from more experienced teachers, also then enabling the novices to mentor future new teachers. This evolution of roles within the community is a key feature of CoP as a learning ecosystem. Research has been conducted into how CoP can be used to assist with GTA training (Myers, 1998; Gretton et al., 2017; Hakkola et al., 2020), but it mostly focuses on how a CoP framework can be enforced onto a group of GTAs as an intervention to investigate its effects on their teaching. In contrast, this study uses the CoP framework to understand how GTAs interact with and learn from each other, as well as grow into knowledge authorities in their roles within their academic community.

The research focused on CoPs contains conflict around what kind of groups are 'true' CoPs. A CoP develops around shared practices, yet Wenger's (1998) definition is a group that specifically comes together around a shared practice with the intent of learning from each other, rather than any group that has a shared practice. Three characteristics are required, per Wenger's definition, for a community to become a CoP: domain, community, and practice. The domain is the shared activity of interest to the members of a group. Commitment to the domain is what distinguishes members of the CoP from those on the outside. For teachers, the domain is the activity of teaching, which can be further specified as the teaching of a certain discipline, level, or curriculum. The community is the group that is bound by the shared activity and how the activity occurs, such as meetings or discussions. Practice is the shared repertoire of "experiences, stories, tools, [and] ways of addressing recurring problems" that the members of a community partake in (Wenger & Trayner, 2015, p. 2).

These components are considered the foundational characteristics needed to form a proper CoP. Not every group with a shared activity is a CoP, and some groups that could be CoPs are hindered by the lack of a shared motivation to improve their practice, a disequilibrium of the social networks of its members, or lacking diverse perspectives and thoughts within the community (Li et al., 2009). Some communities may also cease to exist when they lose members without gaining newcomers. An important feature of CoPs for the setting and context of this study is the relationships developed between the novices, or newcomers to the practice, and the experts, who act as knowledge authorities within the CoP due to their experience in the community and engaging in the practice. By engaging with the CoP, gaining experience in the practice, and contributing to the construction of shared group knowledge, novices move from peripheral participation into positions of experts (Lave & Wenger, 1991).

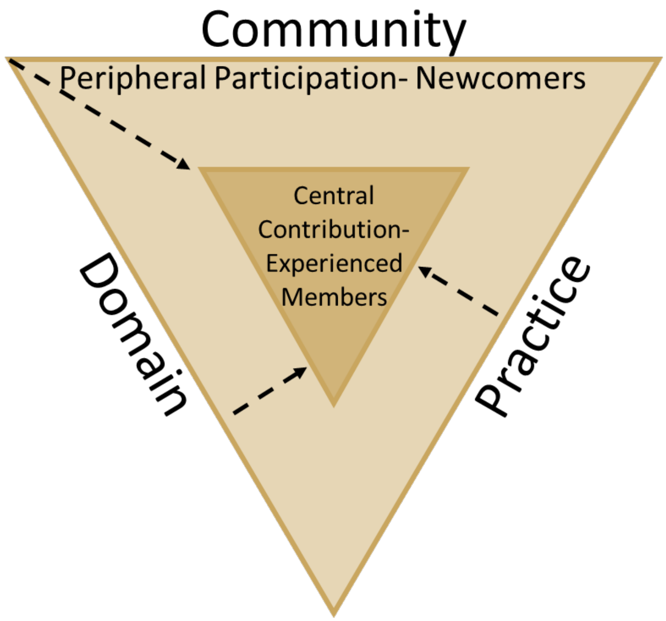


Figure 2.2 The Community of Practice Model

Wenger, McDermott, and Snyder (2002) introduced many significant changes to the concept of the CoP. For one, the three dimensions from Wenger (1998) were changed into the previously discussed domain, community, and practice. Additionally, specific roles within the CoP were introduced. A leader within the group is someone responsible for group recruitment and providing resources for group activities. In support and working in tandem with the leader is the facilitator, who is responsible for assisting with the daily activities and function of the group. Many studies on CoPs connect the success or failure of a CoP to the abilities of the facilitator (Pereles, 2002). These positions are not mutually exclusive, and in smaller groups, one person may play both roles, while in larger groups there may be many multiple facilitators.

Wenger (1998) conceptualized 14 abstract indicators of a CoP, which can be categorized into three main dimensions: mutual engagement, shared repertoire, or joint enterprise (Li et al., 2009). These domains focused less on the novice-authority relationship and more on the actions and factors that bound a CoP. Mutual engagement is the collection of interactions that produce a shared understanding of a problem. Some of the indicators of mutual engagement include shared actions, the ease of conversation and use of jargon, easy involvement in discussions and problems of interest, understanding who belongs, the ways of displaying membership and group identity, and a shared discourse reflecting a specific perspective. There is an overlap between shared repertoire and mutual engagement, notably, the indicators relating to information transmittance and communication. However, a group having specific tools, representations, and artifacts, shared stories, jokes, lore, and insider understandings of the social structures, and the ability to assess what is appropriate for the group's actions are all shared repertoire indicators as well. Lastly, there are two indicators of joint enterprise: having shared ways of doing things together (in common with mutual engagement) and knowing the value of others in the groups and the contributions to the group knowledge and practice, which is an indicator that is shared by all three dimensions. While abstract and viable to be present in various magnitudes for different groups, practices, and contexts, these indicators are a useful toolkit for classifying the actions and characteristics of groups that may be CoPs.

A variety of activities develop the practice around which a CoP is based. Wenger-Trayner, E., & Wenger-Trayner, B. (2015) describe some of these activities within the context of the interactions between members of the group. For example, help-seeking behaviors involve members asking for information or assistance with problem-solving from other members in the group, typically those with experience or those that are known to be knowledgeable about the problem at hand. A group may also provide support in pursuing a new action within the shared practice. In this scenario, a member of the group chooses to elicit the opinions of their group members about a proposed idea. This also can present itself as synergistic collaborations between members, who choose to combine knowledge or actions to produce something greater than the sum of its parts or to simply help each other with the shared practice. Other activities that promote CoP development include shared knowledge documentation, mapping out knowledge to identify gaps, and the sharing and reuse of group resources.

2.3 A New Framework for PCK Development

This study uses the theory of communities of practice to analyze how GTAs share information to develop their teaching practice. It is important to note that the design does not assume that all GTAs participate in the CoP to improve their teaching abilities, rather some GTAs may choose to promote the development of shared knowledge simply to make their job easier. However, the shared practice can still be defined to serve both groups of GTAs. Whatever the motivation, the study design does rest on the assumption that GTAs learn from each other within a community of practice at two levels: within the community of those teaching the same course, and the community of all GTAs. The question becomes a focus on how these GTAs assimilate into these communities, develop their teaching practice as a result of participation, and contribute to the shared teaching practice development, especially as these communities' internal composition changes as frequently as each semester.

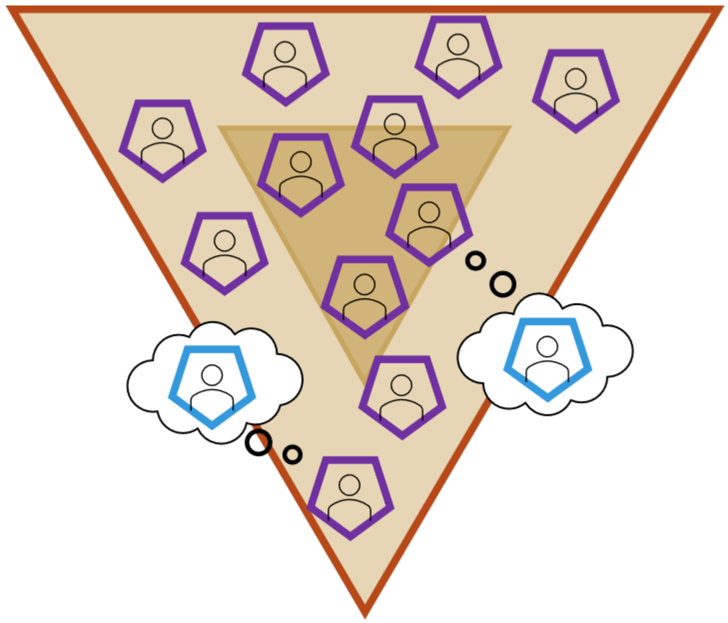


Figure 2.3 Illustration of the CDPCK model

Combining the PCK framework with Wenger's communities of practice results in a new framework I call the "community-developed PCK" model (CDPCK). An illustration of the CDPCK model is shown in Figure 2.3. In CDPCK, each member of a group of teacher colleagues (GTAs in this case) possesses their personal PCK, the set of their preferred teaching practices, which is represented as the individual purple pentagons with figures in the illustration. While engaged with the group, they reflect on their enacted practices, included as the blue pentagons in the illustration. As with the refined consensus model, the teachers' current reflection on their enacted PCK is contextualized by specific teaching moments, students, learning environments, and approaches. All members of the group reflect on their practice regardless of their status in the group, whether they are novices or experienced members. The total shared teaching knowledge of the group is defined by the collective PCK, shown in Figure 2.3 as a red outline surrounding the entire community of practice. This boundary also works to limit the activity of the practice, as developing teaching knowledge cannot extend beyond the collective PCK. Instead, the boundary may be expanded as the members work together to advance their knowledge. As a separate evolution of PCK from previous work in this field, CDPCK serves to capture and facilitate the reflection on and sharing of enacted teaching practices among teachers, leading to new developments in the collective teaching practice while simultaneously moving newcomers toward central contribution. Knowledge of the shared development of teaching practices also travels from the collective to its members, as would be common in other communities of practice.

The refined consensus model of PCK and the communities of practice framework combine into the CDPCK model to inform the research design for this study on GTA PCK development, specifically focusing on what GTAs draw from their academic experiences to construct their teaching knowledge and practices. The community of the GTAs acts as a CoP around not only the shared practice of teaching chemistry but also the shared practice of being graduate students who teach chemistry. The collective PCK in the refined consensus model not only comes from the training that the GTAs receive but also the knowledge they obtain from their colleagues, both current GTAs and students in the same program who are no longer GTAs. Investigating the characteristics of this CoP, and how GTAs use it to develop personal PCK, is the central use of these theoretical frameworks in this study. Additionally, this study also aims to validate this framework to show that it is viable for studying and exploring social learning of teaching practices so that it may be applied to other teaching and learning contexts.

CHAPTER 3. RESEARCH DESIGN AND METHODOLOGY

3.1 Research Design

This study's central objectives are to investigate how chemistry GTAs take their academic experiences and use them to shape their personal PCK, as well as understand PCK development as shared practice in a community of GTAs. The refined consensus model and previous work focused on it describes the process of moving teaching knowledge as PCK between different realms, specifically through the application of greater context. Collective PCK becomes personal PCK when we consider a specific teacher's context and personal PCK becomes enacted PCK when we consider a specific teaching moment, context, or environment. This study aims to describe movement in the other direction to fully explore how community interactions and personal experiences develop PCK. As each individual GTA's experience is unique given their different backgrounds and experiences, a qualitative approach will be most effective for gathering data and understanding the different ways that GTAs will develop their PCK. This study is designed as an ethnographic case study of GTAs from a single department that all teach the same level course in the chemistry courses sequence to explore the CDPCK model. By focusing on this one group, the participants can be studied closely to generate richer data than if other groups were considered simultaneously.

The case study design is used to investigate a phenomenon in context and in the setting where it occurs. Case studies are commonly used in research on teachers, including GTAs of many different disciplines (Gardner & Jones, 2011). Cases may be difficult to distinguish from the context in which they preside, and as such case studies can be used to "investigate a contemporary phenomenon in real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2003, 13). For this study, the group of GTAs constitutes a case out of all possible groups or communities of educators who work together and engage regularly. However, the group as an entity is not particularly the unit of data collection. While case studies can be layered to investigate complex phenomena, to do so requires data collection at the lowest level unit of analysis that is possible- in this case individual GTAs (Patton, 2002). The benefits of a case-study approach manifest in the data collection and the study's credibility because case studies provide a holistic interpretation and remain grounded within social contexts. Additionally, they usually do not include any experimental procedures or manipulated social settings, which ensures that the generated data truly captures people's lives as natural phenomena (Suryani, 2008). The study's design blends ethnography into a case study, utilizing a design commonly known as the ethnographic case study. These study designs employ ethnographic methods to construct arguments about sociocultural phenomena (Schwandt & Gates, 2018). Whereas an ethnography of GTAs may also collect data on their experiences outside of their teaching duties, such as coursework, research, and departmental events, this study chooses to focus only on the experiences related to their teaching roles. This smaller context is a common characteristic of ethnographic case studies (Fusch et al., 2017), so this research design does not sacrifice the level of immersion that ethnographic work demands. The design also pulls from what Baxter and Jack (2008) refer to as the "Single Case with Embedded Units" design, in which a large case is examined via sub-units. In this setting, the large case is the entire cohort of general chemistry GTAs, while the sub-units are the two communities formed based on GTA role (recitation vs laboratory). This structure allows for the analysis of data and understanding of the central phenomenon within the sub-units, between the sub-units by analyzing characteristics, and among the sub-units via comparison of similar characteristics.

PCK is both an internal and external construct and manifests as both action and knowledge. Therefore, PCK is too complex to feasibly rely on one singular approach, such as an assessment of content or pedagogical knowledge (Carlson, 1990). We might assume that instructional observations would reveal a more insightful look into PCK development. However, these observations alone are also not sufficient enough, given the internal thought processes behind PCK. We must also ask teachers directly about their PCK to gain their internal perspective (Baxter & Lederman, 1999), either in the moment when possible or through stimulated recall. Communicating the tacit knowledge of teaching practice is also not common among teachers. Rather, they share activities, procedures, and strategies, often both what does and does not work effectively in their teaching. Therefore, analyzing a group of teachers needs more than observation of their interactions, we need their reflection on these interactions (Loughran et al., 2004). While certain methods are best used to measure or observe the generation or application of teachers' PCK, researchers agree that multiple approaches are necessary to effectively capture it as a phenomenon of interest (Morrison & Luttenegger, 2015). This may include any combination of qualitative and quantitative techniques and protocols, but a common trifecta of methods seen in the literature is a combination of observations of instructional events, interviews with teachers (GTAs), and assessment of content knowledge. This assortment of methods is used in this study as well. The body of literature on PCK, including work on specifically the PCK of GTAs, is decided on which methods are best for measuring different aspects of PCK. Largely, it seems that studies using assessment instruments are best suited for learning about how GTAs think about their teaching, while observational studies are better for studying how GTAs exercise their PCK. The mixed-methods approach is common in studies that aim to investigate PCK change or characterization, as seen in studies such as Friedrichsen et al. (2009) and Barendsen & Henze (2019), which both combined the data from some form of observation, interviewing, and artifacts to investigate teachers' PCK.

Current understandings of PCK development show it is constructed through experience, and therefore most studies focus on investigating experienced teachers' already-constructed PCK of (Davidowitz & Rollnick, 2011). However, to better understand this construction, we also must find ways of observing the developing PCK of novice teachers. The ability to compare novices to their more experienced counterparts will also help to effectively understand how teaching development changes over time, and how these different stages engage with teaching knowledge development as a shared practice. The participants and their academic contexts bring significant features that are of interest to the conversations around PCK development, GTA training, teacher cognition, and CoP in educational settings.

3.2 Details of the Field: Site, Setting, and Participants

The University of Kentucky general chemistry program and its GTAs were chosen as the setting and participants of this study due to features of their teaching culture and experiences, as well as convenience of location and familiarity to the researcher. The known facts about what these GTAs do as part of their role are a critical component of the research design, as the methods have been designed to take advantage of the setting while respecting the many commitments of the participants. To fully understand the research design, planned analysis, and future conclusions, it is also necessary to understand the setting in detail.

3.2.1 General Chemistry in Context

While this study's objectives and motivations could focus on many different GTA populations, the methods used are better suited for studying only one group at a time. To achieve the objective of this study, the research design uses a case study of GTAs in the chemistry department at the University of Kentucky. Specifically, the study population is recruited from the general chemistry program GTAs. I am a graduate of this department and the same program as the study population and have experience as a GTA for multiple general chemistry courses. This not only helps with establishing the connections and rapport with current GTAs that are crucial for ethnographic work but also allows me to enter the scene with some prerequisite knowledge of the participants' academic experiences.

The general chemistry program at the University of Kentucky includes 11 courses that fulfill a requirement for the 50 majors at the university, which are shown in Figure 3.1. These majors come from the Colleges of Education, Arts and Sciences, Engineering, Agriculture, Food and Environment, and many Colleges of Health and Medicine. Additionally, certain courses within the general chemistry program also fulfill the requirement for the university general education program. Serving so many undergraduate programs as a foundational course means that these courses in total have an enrollment of 2000-2500 students on average. The collaboration and effort of 8-10 instructors and 35-40 TAs per year, consisting of both undergraduate and graduate TAs, is what sustains this high volume of students. As part of their offer for admission into the graduate program in the Chemistry Department, graduate students are guaranteed a GTA position for their first year in the program. Additionally, their program requirements include a teaching component. On occasion and when necessary, the chemistry department will recruit graduate students from other departments to help deliver the general chemistry courses.

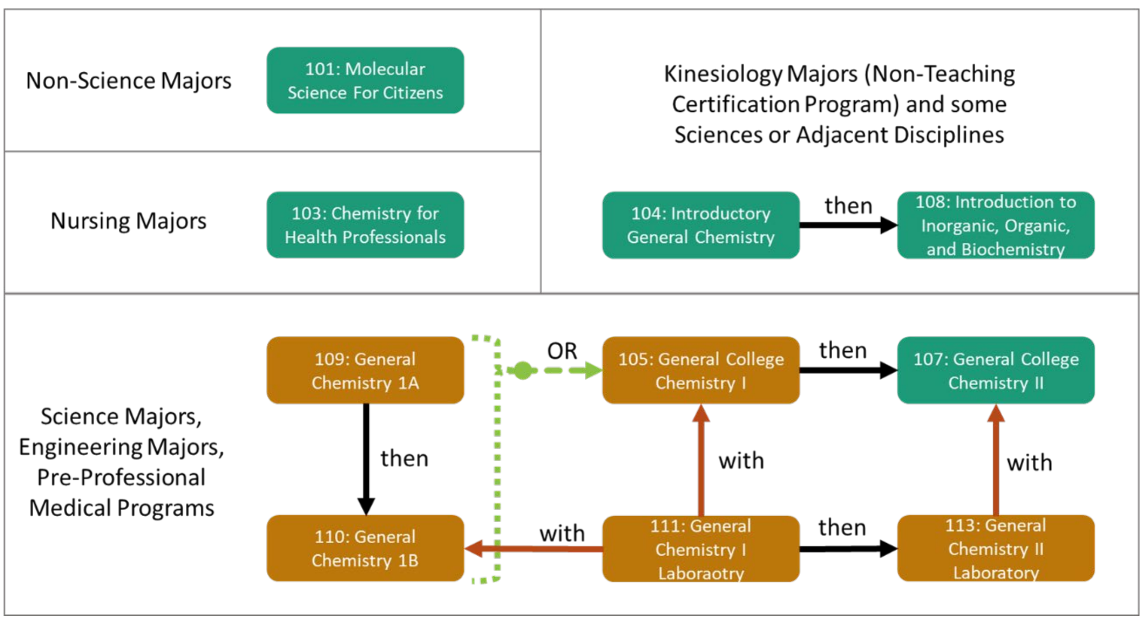


Figure 3.1 General Chemistry courses at the University of Kentucky. Courses in orange boxes utilize GTAs.

All GTAs at the University of Kentucky receive training through a two-day microteaching experience with other GTAs. Due to the structure of this training, there is no guarantee that a GTA from a specific department will be in a microteaching group with other GTAs from the same department. The chemistry department supplements the general microteaching training with specific training that occurs the full week before a semester starts. All chemistry GTAs receive training on how to conduct office hours, safety procedures for laboratory experiences, as well as examination proctoring. Training about class management, instruction, and course policies is conducted within the groups of GTAs for specific courses. Of the 11 general chemistry courses, 5 contain components run by GTAs. The GTAs are trained and work in three groups: Recitation, General Chemistry I Laboratory, and General Chemistry II Laboratory. For ease of writing, the different types of GTAs will occasionally be referred to with the course number that they teach: 105/109/110 for recitation, 111 for the first-semester laboratory, and 113 for the second-semester laboratory.

3.2.2 Being a GTA

Recitation GTAs are responsible for guiding students through practice applying the concepts learned in lectures, as well as providing clarification or alternate explanations for concepts when necessary. Each recitation GTA is responsible for teaching five to seven recitation sections of CHE 105, 109, and/or 110 that are 1 hour long each per week. The assignments for particular sections or courses are made based on the GTAs' schedules, meaning GTAs can end up assigned to teach any combination of sections of the three lecture courses, although generally, the supervisor tries to avoid giving any recitation GTA giving more than CHE 105 and either CHE 109 or CHE 110 teaching assignments. The topics that are covered in any given class are set on a schedule largely outside the recitation GTAs' control, as recitation is designed to follow the structure of the general chemistry lecture courses but remain approximately a week behind. Recitation GTAs receive practice-based training where they simulate guiding a 'class' of the other recitation GTAs through solving problems related to the first few weeks of the general chemistry I course. As the semester moves forward, this practice continues during weekly meetings with the upcoming week's content.

Recitation GTAs can choose to make use of whiteboards and/or projector equipment to communicate information to students, as well as the computer that is found in every classroom on campus. The recitation section is designed more for undergraduates to practice and reinforce their chemistry knowledge and to ask questions or get help from their GTAs rather than assess their knowledge and skills. This is very apparent given that the grade in a recitation class across the entire semester only constitutes 5-7% of an undergraduate student's overall chemistry lecture course grade, depending on if they are in the 109/110 track or 105 respectively. During class, recitation GTAs will lead a short discussion on a selected chemistry topic, and then they observe and assist students with completing a short worksheet that relates to the discussion topic. The worksheet typically includes 3-7 total problems for students to complete as practice with applying chemistry concepts, including at least one problem that is structured with scaffolded support to help students learn the steps to solving typical chemistry problems that they will encounter on homework assignments and exams.

Laboratory GTAs are responsible for overseeing the completion of chemistry experiments conducted by undergraduate students. In a direct comparison of the roles, laboratory GTAs have more responsibilities and less freedom than the recitation GTAs. The laboratory courses are separate from the general chemistry lecture but are designed to be taken concurrently. The CHE 111 GTAs teach three 2-hour long, 1-credit sections on three different days each week, while CHE 113 GTAs teach two 3-hour long, 2-credit sections on two different days each week, barring special circumstances. As courses that are separate from the chemistry lecture, they have a separate grade, which GTAs determine 60% of through grading laboratory reports. A typical class meeting for the laboratory courses includes a pre-lab lecture during which GTAs cover necessary conceptual, procedural, and safety information for the day's work. During this lecture, the GTAs are encouraged to provide students with opportunities to demonstrate their knowledge through question and response as well as practice application problems. After the lecture, the remaining class meeting time is devoted to undergraduate students completing their laboratory work, assisted and guided by their GTAs. GTAs must move throughout the laboratory, answering students' questions, providing indirect help to students (the GTA should not perform a lab procedure for a student), and maintaining a safe and clean environment.

Laboratory GTAs receive practice-based training before the semester begins that involves the completion of all experiments for their assigned course, along with the following data analysis, course technology onboarding and training, laboratory management (both safety and general classroom management), course policies, the course syllabus, instructional time expectations, and practice delivering a pre-laboratory lecture with the other GTAs. The weekly meetings of laboratory GTAs cover important safety and materials information for the following week's upcoming classes, deadlines for both students and the GTAs (they are expected to grade laboratory reports by exactly one week after students submit them), and crucial information that the GTAs should include in their pre-laboratory lecture for the upcoming week.

The laboratory GTAs are also supported by a few lead GTAs, who are experienced GTAs that are selected by the laboratory supervisor based on the student's motivation and expertise. These lead GTAs assist the laboratory GTAs with their teaching largely by helping maintain the laboratory environment, although their experience may also be a useful resource for new GTAs. Lead GTAs also assist the laboratory instructor with the course delivery, as they can organize the laboratory GTAs, allowing the instructor to handle student concerns.

It is common for these GTAs to change roles between semesters so that they have to learn and adapt to a new teaching position within general chemistry. For example, GTAs may transition between the two laboratory courses or even between recitation and laboratory teaching assignments (or even more drastic a shift from a different chemistry focus, like organic chemistry, to general chemistry). The demands of their teaching roles also promote the sharing of information among the communities of GTAs, not only within one singular course but also between courses, so that the GTAs may perform their job duties effectively. During the timeframe of this research, three GTAs shifted from CHE 111 in the fall to CHE 113 in the spring and two GTAs shifted from recitation to laboratory from the fall to the spring, one to each laboratory course. Several GTAs left the general chemistry GTA community, either due to graduating, moving onto a research assistantship, or moving into more advanced chemistry courses.

3.2.3 GTA Responsibilities Beyond Teaching

All GTAs are more than just teachers in undergraduate classrooms. The graduate chemistry program has many significant features that impact the commitments that GTAs can make toward their teaching roles, additionally impacted by GTAs' attitudes and motivations toward teaching. The demands of their teaching duties also encourage collaboration to successfully perform to their supervisor's, and the department's, expectations. Firstly, all graduate chemistry students are required to teach a minimum of one semester as part of their program requirements. First-year students are tasked with determining who they want to do research within the department, as well as initiating the process of finding an advisor and joining their lab within their first semester. First-year students are also required to attend weekly departmental seminars as part of the requirements in a mandatory seminar course. Coursework typically lasts for three semesters of regular graduate-level courses (10 credit hours in the first semester, 9 credit hours for the second and third), and one semester of research credit enrollment, which requires the completion of a written research progress report for credit. This is just one path a graduate student may take through their coursework, and it is common for students to need additional coursework, whether to replace a poor grade or as required by their advisors.

Many faculty advisors expect new lab members to begin working in their lab as soon as possible, which may be as soon as the winter intersession between the graduate student's first and second semesters in the program, with the latest being the first summer in the program. Some students may also even have to change their advisor, which can delay research progress. Second-year students, who are often GTAs as most faculty advisors do not employ students as research assistants until they complete their candidacy requirements, will begin their written qualifying examination at the end of their third semester in the program, and they complete the written exam part of the way through their fourth semester. Many students advance to candidacy during their third year, and they may or may not be a GTA at this point depending on their advisor's funding resources and preferences. During all of these program requirements and standard operations, any student that is employed as a GTA is also expected to perform their teaching duties effectively.

During this study, many of the GTAs, both those included in data collection and those that are part of the group but not in the study population, passed significant milestones in their graduate work. These milestones require a large amount of effort from the GTAs, which in many cases pull GTAs away from performing their teaching duties at a consistent quality. During the fall semester, two GTAs completed their Ph.D. work, a handful of GTAs completed their written qualifying examinations, and two GTAs completed their oral examinations, advancing to Ph.D. candidacy. In the spring semester, two GTAs completed their Ph.D. work, another handful completed their written qualifying examinations, and at least two more advanced to Ph.D. candidacy. Many of the GTAs attended conferences during the 2022-2023 academic year, which also took them away from their teaching duties.

The details of the instructional contexts and the learning environments, as well as the responsibilities of these GTAs, make for a fitting setting for investigating the development of personal PCK within an academic community of practice. Given that many of the GTAs employed in any one year within this chemistry department are first-to-third-year graduate students, they also have minimal teaching experience, or in some cases no experience at all. This allows for the observation of not only the development of these GTAs' PCK but also the initialization of it, starting with their training as a baseline.

3.3 Research Procedures and Data Sources

Immersion is key to capturing participants' lived experiences and generating rich ethnographic data. To achieve this goal, the proposed study's primary research procedures are built around participant observation, a research method aimed at generating data to represent a phenomenon or a culture through regular and sustained interaction with those who participate in it (Bogdan & Biklen, 1998). In participant observation, the extent to which the researcher actively participates in the culture is a spectrum. Complete participation involves taking on the same role as the research study participants, and complete observation involves the participants having little to no knowledge of the researcher's presence. In this work, I initially took on the role of the observer as a participant. This role means that the participants of the research study are aware of the researcher's presence and the purpose of the study, compared to complete observers or complete participants, approaches which often come with covert observation procedures. In the observer-as-participant approach, the researcher takes a peripheral role in group membership, being present in the settings of group activities but not involved to the same extent that the group member participants are (Adler & Adler, 1994). For example, I attended GTA orientation, but I did not complete the laboratory experimental work like all the laboratory GTAs were required to; rather I observed their experience in this activity. However, as the study progressed and my relationships with the GTAs grew stronger, I shifted into more of a participatory role, specifically in meetings and in the GCLC, and on occasion during class time. Given that I studied these GTAs as a community of practice, becoming immersed to the point of genuine contribution to the shared practice was an advantage to learning about the authentic experience of these

GTAs and their interactions. To make sure that I did not influence the setting significantly, I limited my participation to question-answering, for the benefit of the undergraduate students

3.3.1 Observational Procedures

Most of the data generated from participants came from the observation of their actions and behaviors while they perform their required teaching duties. I produced field notes in four settings: class meetings, office hours, departmental orientations, and GTA meetings. The departmental orientation occurred twice during data collection, at the beginning of each semester. GTA meetings happen once each week during the semester, at a time when no GTA for a particular course is teaching (for laboratory GTAs, these meetings are always on Fridays as labs are only taught Monday-Thursday). For both semesters, laboratory GTA meetings were at 8 and 9 am, a regular focus of complaints among the GTAs, especially if there was an exam the night before that GTAs were required to proctor. Recitation GTA meetings were at 1 pm in the fall and 2 pm in the spring. Observations of the training and the weekly meetings allowed for the observation of interactions between GTAs, as well as between GTAs and their supervisors. Both scenes were prime opportunities to observe information sharing between GTAs, a significant phenomenon characterizing CoP formation. These settings also helped me gather information about the department's goals and expectations for the GTAs, as well as the buy-in of GTAs to their roles through their behavior in these scenes.

During orientation and meetings, I focused on taking notes of the events of the meetings, quotes from consenting GTAs, and any useful observations of the physical and social environment. All field notes generated from orientation and meetings included start and end times, which were used to calculate the observational time for each event. I observed orientation for just over 30 hours across the two semesters: 22.78 hours total in laboratory orientation and 7.26 hours total in recitation orientation. These orientation sessions occurred during the same week, and since recitation orientation was much shorter than laboratory orientation, I prioritized attending with recitation GTAs when the different groups were training simultaneously. I attended 80 meetings across the two semesters of data collection: 27 meetings each for CHE 111 and CHE 113 (laboratory courses) and 26 recitation GTA meetings. On average, these meetings lasted approximately 47 minutes. Meeting observations contributed 62.65 hours to the total amount of observational time. Details about observations of orientation and meetings are included in Table 3.1.

Table 3.1 Observational time data for orientations and meetings

	Number of Observations			Observational Time (hours)		
	Fall 2022	Spring 2023	Total	Fall 2022	Spring 2023	Total
Orientation						
Laboratory	5	2	7	14.70	8.08	22.78
Recitation	3	1	4	5.70	1.56	7.26
Totals	8	3	11	20.40	9.64	30.05
Meetings						
CHE 111 Laboratory	14	13	27	12.77	10.00	22.77
CHE 113 Laboratory	14	13	27	11.97	10.83	22.80
Recitation	11	15	26	8.50	8.58	17.08
Totals	39	41	80	33.23	29.42	62.65

Instructional observations provided the most information about the GTAs' enacted PCK and by extension their personal PCK. Studies have shown that teachers' professional knowledge influences their in-class actions, so by observing in-class actions we uncover information about individual teachers' knowledge (Park & Chen, 2012; Alonzo et al., 2012). Field notes from observing classroom instruction in both laboratories and recitations focused on recording the instructional events of the class as inspired by Baumert (2004). These field notes included how the GTA starts the class, moves through activities, solicits student responses, provides questions and explanations to the students, and ends the class. I also took notes on the GTAs' use of their classroom space and tools, how long the GTAs took to finish the worksheet discussion or pre-lab lecture, and the time when the first group of students completed their work for the class session.

Class observations contributed to the overall observational and interaction time the most of all settings. I attended 65 CHE 111 classes, 19 CHE 113 classes, 38 CHE 105 recitations, 32 CHE 109 recitations, and 9 CHE 110 recitations for a total of 163 classes across the two semesters. Recitation classes run for a maximum of 50 minutes, but many of my observations started up to 5 minutes before class started, and sometimes extended to 5 minutes after class ended. CHE 111 laboratory classes last a maximum of one hour and 50 minutes, CHE 113 classes can be up to two hours and 50 minutes long, and for all laboratory courses, GTAs are responsible for allowing students to enter the lab starting five minutes before the class starts. This is also when I would enter the laboratory classrooms, and is the earliest any of the laboratory class observations would begin. I often left laboratory classes early, as they were both long and repetitive. In total, I spent over 162 hours observing in-class instruction. A detailed breakdown of this time is included in Table 3.2.

Table 3.2 Observational time data for class time observations

	Number of Observations			Observational Time (hours)		
	Fall 2022	Spring 2023	Total	Fall 2022	Spring 2023	Total
Laboratory Classes						
CHE 111	48	17	65	60.52	17.53	78.05
CHE 113	0	19	19	0	21.15	21.15
Totals	48	36	84	60.52	38.68	99.20
Recitation Classes						
105	28	10	38	23.15	9.37	32.52
109	30	2	32	23.03	1.23	24.27
110	4	5	9	3.48	2.98	6.47
Totals	62	17	79	49.67	13.58	63.25
Grand Totals	110	52	163	110.18	52.26	162.45

For the office hours, which occur in a shared space with other GTAs and any general chemistry students, field notes focused on both GTA-GTA interactions and GTA-student interactions. GTAs often rely on the other GTAs' assistance to help students with classwork that they do not specifically teach. Observing the help-seeking behaviors that are common within a CoP was useful in characterizing how information moves through the members of this community. The GCLC was also the setting where I engaged in practice with the GTAs the most. As I will discuss in Chapter 5, demonstrating my knowledge and skills in the GCLC on some occasions allowed me to initiate the process of becoming a valued part of the community rather than simply an observer with experience in the role. Since I was engaging in practice during GCLC time (helping students, working with other GTAs, etc.) I did not always take field notes while in the GCLC. In the fall semester, I spent 65.52 hours observing in the GCLC, and I observed in the spring 50.08 hours. In total, GCLC observations made up 115.6 hours of my observational and interaction time.

While choosing which classes to attend depended on the schedule of the GTAs who participate, I initially planned to observe GTAs twice in the same week to collect data on the same lesson being delivered multiple times. To reduce the possibility of predicting the behavior of the GTAs I observe and bias in the field notes, I aimed to observe GTAs every other week, allowing for time to pass between class observations so the GTAs can develop their teaching without my presence, and allowing me time to 'refresh' my expectations and preconceptions of the scene for each particular GTA. I quickly realized that recitation GTAs do not significantly change their teaching practices within a single week that often, so instead of watching recitation GTAs twice a week every other week, I shifted to observing them in class once each week, but alternated the class I came to every other week. With the laboratory GTAs, I mostly stuck to the twice-a-week schedule during the fall semester, although sometimes I would observe two GTAs at once since the laboratory rooms are connected spaces.

Recording each scene into field notes was guided by Spradley's (1980) dimensions of descriptive observing: space, objects, acts, activities, events, time, actors, goals, and feelings. The focus of recording these scenes was GTA teaching behaviors, so data on undergraduate students was not collected, although notes about prompts from undergraduates were included when necessary for the ease of analyzing field notes (i.e. "A student asked for help with solving a worksheet problem"). Sketches of instructional spaces and how the GTAs used this space were made during the observations, and when possible pictures of the GTA's use of boards or other resources were taken. The questions that GTAs asked students were recorded verbatim in field notes. The field notes were used to construct a profile of GTA teaching behaviors and practices, allowing for the characterization of their personal PCK through their enacted PCK.

3.3.2 Interviews

Interviews provided the opportunity to ask each GTA about their personal PCK and generate data that helped to reveal how GTAs think about their teaching processes. Two interview formats were used in this study: semi-structured interviews conducted in the fall, and informal interviewing interspersed throughout the entire project. Initially, the semi-structured interviews were planned for both fall and spring, but the beginning of the spring semester was very rushed and chaotic for the GTAs, so scheduling 1-2 hour-long interviews was difficult. Instead, I chose to distribute the most important questions that I would have asked in this format over many interactions with the GTAs. The fall interviews mostly focused on teaching expectations, experiences, knowledge, and interactions with other GTAs and supervisors. Given that they were semi-structured, other topics were pursued as they came up and were of interest to me or to the GTA participants, such as discussions on students' mathematics skills and GTA perspectives on departmental events that impact their experience as GTAs. Just under 40 hours of interview data were collected in the fall semester, with all GTAs who participated in these interviews except for one completing two interviews each.

The semi-structured interviews contain two activities to elicit discussions on GTAs' PCK. Content Representations (CoRe) is an approach to uncovering teachers'

TSPCK and how it is crystallized into planning and delivering a lesson on a specific big idea topic. This method is useful for gaining insight into science teachers' PCK processes, or how they take their chemistry content knowledge and transform it into teaching (Bertram & Loughran, 2011). Initially developed and used by Loughran et al. (2004), the prompts in the interview are taken directly from Mavhunga (2016), who adapted the curricular saliency focus of the Loughran et al. CoRe prompts to include more directed items concerning aspects of TSPCK such as knowledge of representations and student misconceptions. While in most procedures using CoRe, the participating teachers choose a big idea topic on their own to focus the exercise on, I pre-selected the topic that our discussions focused on: stoichiometry. This concept, which is the ratios of chemical species in a chemical reaction and the arithmetic that can be done with these ratios, is foundational and central to not only general chemistry but is also important for all future chemistry courses. Both general chemistry lectures and laboratory courses demand that students can recall, understand, and apply specific information from these three overarching concepts.

The final component of each interview asks the GTAs to pretend that I am an undergraduate student and to simulate how they would assist me with a chemistry problem during their office hours. The problems used for this part of the interview come from the UK Department of Chemistry's publicly available general chemistry exams to establish the content validity of the question. This exercise is also changed each semester of data collection but remains of similar difficulty, which is noted by the combination of multiple chemistry concepts or different arithmetic procedures within the same problem.

The interview prompts are included in the interview guide in the Appendix. The semi-structured interviews were all audio-recorded and transcribed for analysis and storage.

3.4 Sampling and Participant Information

Respecting the time commitments of the GTAs who participate in the study is important to establishing both rapport and an ethics of care. Therefore, every GTA in the study is given the choice of which research procedures they choose to be involved in. For the observations, this choice is also broken down by observational setting. In both the fall and spring semesters, 36 GTAs worked in some capacity in the general chemistry department. In the fall semester, I recruited 15 GTAs to the study, and 3 of these GTAs left the study after this semester. In the spring semester, I managed to recruit an additional 2 GTAs for the study, bringing the number of participants in the spring to 14. In total, there were 17 participants across the two semesters. Table 3.3 contains information about the study participants. Note that for participants 'Bobby' and 'Morgan' there are no in-class observations. Rather, these two participants were observed in all other settings instead, with a majority of their contribution to the overall data coming from meetings and office hours observations. GTAs listed as "lab support" in Table 3.3 did not hold an in-class teaching role during that semester but worked closely with all of the laboratory GTAs, and as such they were crucial to understanding the community of practice. They were included in the field notes of other GTAs' in-class instruction whenever they came to assist so that I could capture their interactions.

Table 3.3: Study participant information

Pseudonym	Year in Program	Gender	Number of times observed in class	Fall 2022 Role	Spring 2023 Role
Augustus	3	M	15	111 Lab	111 Lab
Bobby	1	M	0	Recitations	-
Bianca	3	F	12	Recitations	Recitations
Brittany	1	F	11	Recitations	-
Cassandra	4	F	0	-	Lab Support
Cristofer	1	M	11	111 Lab	-
Clark	1	M	9	Recitations	Recitations
Courtney	2	F	19	Recitations	Recitations
Fiona	1	F	10	Recitations	Recitations
Hoda	1	F	17	111 Lab	113 Lab
Louis	5	M	4	-	113 Lab
Morgan	2	M	0	113 Labs	Lab Support
Olena	6	F	0	Lab Support	-
Patrick	3	M	14	Recitations	113 Lab
Portia	2	F	20	Recitations	111 Lab
Ruben	4	M	3	111 Lab	111 Lab
Talia	1	F	18	111 Lab	113 Lab

3.5 Analytic Procedures

In doing this work I did not seek to make conclusions about which practices or behaviors of GTAs are effective, 'best', or counterproductive. Rather, I aimed to focus on the construction of individual GTAs' personal PCK through academic experiences, specifically GTAs' current teaching experiences and their interactions with others in their academic communities. As a reminder, the research questions of this study are:

1. What are the characteristics of the general chemistry recitation and laboratory GTAs' pedagogical content knowledge (PCK)?

2. How do recitation and laboratory GTAs interact with their communities of practice to develop their PCK?

These questions frame the research design to understand how social learning practices from a community of practice influence PCK development among chemistry GTAs. First, the characteristics of each role's PCK are explored and characterized, answering question 1. PCK frameworks consider the specialized teaching knowledge within a discipline as a synthesis of different knowledge bases, and understanding the depth of each knowledge base is necessary to understand the resulting PCK. With this characterization as a foundation, I discuss PCK development with respect to interactions from the GTAs' communities of practice, answering question 2. Together, these two research questions help us understand the lived experience of being a GTA regarding how they learn from their peers to develop their teaching skills.

3.5.1 Coding Qualitative Data

Transforming qualitative data from my observations and interviews into assertions about the participants and the phenomenon I aim to capture requires structured coding of the data into similar themes and the components of the CDPCK model that they inform. To code my field notes on instruction (in class and during office hours), I first separated each instance of an 'instructional moment' as the unit of analysis. Then, I used top-down coding to group each moment with the knowledge bases included in the refined consensus model: content knowledge, pedagogical knowledge, knowledge of assessment, knowledge of learners, and curricular knowledge. For example, when a GTA reminds students to stay on task, this shows pedagogical knowledge. An event in which a GTA uses a common representation to explain a chemistry concept displays content knowledge and pedagogical knowledge. Once these moments were coded by their representative knowledge bases, I re-coded the moments that were categorized as displaying content knowledge. Since content knowledge is required for creating PCK (especially TSPCK), only these moments could truly be said to show a GTAs' PCK, rather than just a form of PK. Moments with content knowledge were secondarily coded by grouping them based on similar examples of PCK, such as the use of representations, specific teaching strategies, and identifying and addressing misconceptions. Both levels of coding were used to characterize the GTAs' knowledge bases and the commonalities between their personal PCK as a group. Categorizing the different manifestations of PCK was done from the bottom up, in which I grouped the different examples based on similarity (e.g. addressing misconceptions, using representations, engaging students with critical thinking). The data in each code was supplemented with information from the interviews that fell into the same categories.

Table 3.4 Samples of data from observational field notes, research memos, and interview transcripts with associated coded category from the PCK knowledge bases.

Code/Knowledge Base	Examples from observations	Excerpts from interviews
Content Knowledge	• Explanations of chemistry concepts • Answering questions • Laboratory equipment usage • Laboratory safety information	"I still don't fully understand the redox stuff. Like how do the electrons move around exactly?" "I like that experiment a lot because it's kinda related to what I do for research."
Pedagogical Knowledge	• Classroom management (specifically actions taken to guide students through class activities) • Technology usage • Student solicitation • Engaging students	"For the more involved experiments I find it easier to almost tell each group what they should do and when while checking in with them." "I started writing extra tips on the board because I got tired of answering the same questions over and over.
Knowledge of Learners	• "A lot of you probably won't like this class and the work you have to do for it." • Discussions about student patterns during meetings/training	"The thing that our students struggle with the most is math skills." "They do not always know what they don't know because many of them are freshmen, and so they won't ask for help because they don't know they need it yet."
Knowledge of Assessment	• Explanations of examinations and how knowledge is assessed • Grading discussions • Rubric usage	"It's hard to want to give good feedback when you know your students aren't looking at it." "I know that exam two always has a hard titration problem on it."
Curricular Knowledge	• References to the other general chemistry content • References to other chemistry courses • Connections between chemistry topics • Inter-/multidisciplinary examples • "Do you all remember covering this recently in lecture?"	"I usually tell students that if they don't like the math, then they may actually end up enjoying organic chemistry more because it's more conceptual." "I think it's strange that they cover gases after doing a bunch of quantum and structure stuff."

Field notes from orientation and meetings were coded by organizing the different interactions the GTAs had and how the activities they engaged in furthered their knowledge bases. Activities were coded similarly to the instructional settings field notes as described above. Interactions among GTAs and how the study participants acted and reacted during these scenes were categorized based on the type of interaction (e.g., requesting information, problem-solving, asking for advice), as well as the information or knowledge that transferred between GTAs during these interactions. Certain excerpts from interviews were also relevant to these codes and were included in the coding analysis of the community of practice. To code these interactions, I used examples of how members of a CoP build their practice as described by Wenger-Trayner and Wenger-Trayner (2015) as another set of top-down codes, examples of which are shown in Table 3.5. Given how communities of practice engage in developing their central activity and knowledge, many of these interactions overlap. For example, to problem solve it may be necessary to first request information of seeking experience. Once the data was organized by these codes, the data was then used to describe the different ways that the GTAs interacted with each other and how these interactions served to build their practice. I was not able to use all of the examples provided in Wenger-Trayner and Wanger-Trayner (2015), as I did not code sufficient amounts of data in certain codes to provide in-depth analysis. The examples of argument building, documenting projects, and coordination and synergy were not easily found in the data I collected, although this is not to say they are not possible or not present. Similarly, I ended up creating a new category and code out of a series of examples that shared a similar theme of GTAs policing each other's teaching behaviors, a code that I call "ensuring consistency."

Table 3.5 Samples of data from observational field notes, research memos, and interview transcripts with coded categories regarding the actions of a community of practice

Code/Interaction	Examples from Observations	Excerpts from Interviews
Requests for Information	Asking for facts, procedures, or details	"Sometimes I have to go ask some of the more experienced TAs for the stuff we didn't cover in meeting."
Problem Solving	GTAs working together to determine solutions	"I didn't know what was going on with the MeasureNet, so I grabbed the other TA and we figured it out eventually."
Seeking Experience	Meeting discussions with prompts to other's experiences in the GTA role	"I had no idea how to handle a student in that situation, and when I asked the others they hadn't ever dealt with it either."
Reusing Assets	GTAs using examples, explanations, representations, etc. from other GTAs	"I actually got that example from [GTA]. I saw them use in the GCLC one time and I liked it so I use it in class now."
Growing Confidence	Discussions between GTAs about trying new things and new teaching behaviors	"I was worried about doing things a little differently than last semester, but the others seemed to think it would work."
Ensuring Consistency	GTAs correcting each other's knowledge or behavior in any context	"We all do it the same way so that the students can't complain about one of us doing it different or better or worse than the others."
Discussing Developments	Conversations between GTAs about things that change	"I was skeptical about the new recitation format, and I know some of the others were as well, both recitation and some of the lab ones I talked to about it."
Visits	GTAs present in other's classes to learn from observation	"I go watch [GTA] teach before I do it so I can get some ideas and be prepared for what could go wrong."
Mapping Knowledge and Identifying Gaps	Discussions about content knowledge and teaching knowledge, focusing on what is and is not known by individuals and the group	"We like to meet up on the weekends to prepare for teaching lab the next week, and we can figure out what we don't know together and what we want to do in the pre-lab."

After this initial coding, I also reorganized the data within each code to investigate any connections to other details about this group of participants and the scene I studied. I analyzed the coded and organized data for each participant to understand how the data shows each GTA's knowledge of teaching as well as their personal PCK and their enacted PCK. I compared this to the set characteristics of their role-based community of practice collective PCK to understand what each GTA retained from their training and their peers. Both of these facets were analyzed over time by comparing the data for each participant at various points in the study. I also grouped the data and the information for each GTA based on their role to understand their communities of practice. This allowed me to compare and contrast the different methods used by the members of each CoP and how the specifics of their roles and their PCK influence their experience as part of their community.

3.6 Validity and Reliability

Successful ethnographic research depends on immersion into the field and with the participants of the research study, often even being present at events and activities that may be outside of the focus of the study, or capturing data that at first may seem irrelevant. Small and Calarco (2022), in their book on evaluating ethnographic and interview work, focus on the necessity of exposure in establishing credibility for this kind of research. Accruing a high degree of exposure was a main goal for my methodological design, and as a result, I was able to record over 400 hours of documented exposure time across observations and interviews. Being involved to such an extent may be taboo in a quantitative or experimental study, but when the work depends on the richness and depth of the experience of those being studied, it serves as validation of the results of the research. Additionally, many ethnographies include immersion for a full 'cycle' of the participants' experience, in this case, a full academic year. As observing the change in teaching behavior based on interacting with others is an objective of this study, I observed one of these cycles to capture the transition of participants between significant steps in their graduate careers and to observe how their roles as participants in their communities of practice change at the same time. This sustained presence can also help with refining early assertions and proving or disproving potential associations between behaviors and actions (Maxwell, 2013). For these reasons, the length of the study will be of great benefit to its validity.

The group of participants that contributed to fieldnotes, interviews, and other data is reflective of the larger group of all general chemistry GTAs based on gender demographics and experience in the program but is not representative of the ethnic, racial, and nationality demographics. However, as my research questions are not explicitly focused on uncovering the relationship between certain identity components and experience as a GTA, this does not significantly impact the assertions I form. Regarding what I am seeking to answer with my research questions, the group of participants in each role is sufficiently heterogeneous. In the overall study population, there were 8 recitation GTAs and 11 laboratory GTAs. From the fall to the spring semester, two recitation GTAs moved off of general chemistry GTA duties and two more recitation GTAs shifted from recitation to laboratory. The overall recitation GTA population size shrank from 11 to 6 from the fall to spring, and my recitation study population shrank from 8 to 4 participants. In the laboratory group, the overall GTA population changed from 25 in the fall to 26 in the spring, and the laboratory study participants changed from 7 to 9 following the loss of 2 participants from the fall, the transfer of two recitation GTAs to the laboratory courses, and the gain of two new participants in the spring.

Ethnographic data is rich and its depth increases with continued immersion, but it needs support from other sources of data to build convincing assertions that may be generalized across the study population. Two approaches to strengthening the validity of these assertions are built into the research design. First, the participants who participate in multiple research procedures have the opportunity to engage with me in regular discussions about the data I collect from observing and interviewing them. This allows me to ask participants about the observational data, therefore properly ensuring the connection between an etic observation of an action or event and the participant's emic perspective on the same action or event. This respondent validation is sued to support assertions crafted from the qualitative data sources, providing more validity to the evidence and conclusions drawn from them (Bryman, 1988; Maxwell, 2013). For example, an assertion I developed halfway through the Fall 2022 semester was validated by asking participants about parts of what I was theorizing during later interviews, both informal and the end-of-semester semi-structured interviews. The second approach to supporting the ethnographic conclusion is through methodological triangulation. By drawing from different sources and using different research procedures, the same setting is observed and analyzed from multiple perspectives, allowing for a more in-depth understanding of the participants and their experiences. In the research design, observational data is obtained from different settings and scenes, allowing for observation of similar behavior in different contexts. Additionally, interviews supplement this data by allowing me to ask participants about their perspectives outside of immediate moments, which encourages them to reflect on their actions and experiences. I also supplement my observational and interview data with information gleaned from departmental documents, procedures, and events, such as the GCLC schedules, departmental research seminars attended by GTAs, discussions about a wellness survey administered by the chemistry department's graduate student orientation, and exam proctoring, which all GTAs in the department are required to help with.

CHAPTER 4. RECITATION

4.1 Characteristics of Recitation GTAs' PCK

4.1.1 Foundations of PCK: Prior Experience and Orientation

Recitation GTAs are only hired from within the chemistry graduate program (compared to laboratory GTAs, which will often hire graduate students from other departments), and while not every chemistry graduate student holds a previous degree in chemistry, they all likely completed at least general and organic chemistry in the past. Additionally, all new incoming chemistry graduate students are required to complete a series of entrance exams to establish their prior chemistry knowledge, one of which is the ACS general chemistry exam. This exam is used to assess their knowledge of general chemistry to help determine their first semester GTA role and to construct a remediation plan if they do not obtain a sufficient score in a certain sub-area of the exam so the department can be comfortable with the level of content knowledge needed for teaching.

Some of the recitation GTAs have previous teaching experience in chemistry before coming to UK and working in their current roles. During the first interviews with GTAs, I asked them about their previous education experiences, and if they had any kind of prior teaching experience, not just in chemistry. Of the eight recitation GTAs that participated in the study, two told me they had worked as a peer tutor during their undergraduate studies for at least general chemistry, three had worked in a teaching or laboratory assistant position, and the remaining three had no prior teaching experience before coming to UK. Of these last three, one was a new first-year GTA, getting their first taste of teaching as a recitation GTA. Teaching experiences among this group were diverse, but as will be seen, they do not drastically differ in their approaches to teaching general chemistry recitation and their PCK.

Before the semester starts, all of the general chemistry GTAs participate in a week-long orientation, regardless of their level of experience. The purpose of orientation is to prepare the GTAs primarily for their in-class and role-specific responsibilities. Since orientation lays a foundation for the GTAs' teaching practice and behaviors, it is important to detail what they learn from orientation to understand their personal PCK. Additionally, within the CDPCK framework synthesized for this study, orientation, along with weekly meetings, shows the facets of the GTAs' collective PCK within each role. Understanding the impact of orientation is needed to answer both of the research questions at the center of this study.

When I attended the recitation orientation sessions, the mood was relaxed, and there was no urgency in completing the various training activities. Although orientation is considered to last the entire week before classes start in the fall semester and the Wednesday to Friday before classes start in the spring semester, the recitation GTAs only met for part of this time to discuss role-related specifics and practice teaching behaviors needed for their classes. In the fall I attended three of the recitation orientation sessions: Tuesday morning, Thursday afternoon, and Friday afternoon, for a total of only five and three-quarters hours. In the spring, I attended one recitation orientation session for the full-time, which was only an hour and a half. One may question how such a short orientation can prepare these GTAs for their in-class roles, but the structure of their class-related responsibilities greatly restricts what training is even necessary, especially compared to the laboratory GTAs, as will be discussed in Chapter 5. In the fall, three main activities guided the structure of orientation. These activities set the stage for the recitation GTAs' PCK moving forward through the rest of the semester, as well as their continued teaching experiences in the future.

After introductions between the GTAs and the recitation supervisor, the first order of business was to cover the course policies, including what students are expected to do in class and how the GTAs need to run class, engage students in their work as well as work with their classmates, and how the GTAs will determine students' grades for recitation. This part of the first orientation session was led by the recitation coordinator and consisted of a presentation-style overview of the previously mentioned topics. The most significant takeaway for this research comes from when the supervisor discussed the purpose of recitation: for undergraduate students to have a learning environment in which they practice recalling, understanding, and applying chemistry concepts. Furthermore, the GTAs' responsibility is to facilitate this environment through their instruction and interactions with their students. This is the primary job of the recitation GTAs, and what their in-class teaching should support.

The second time I came to observe recitation orientation in the fall, the GTAs were practicing delivering their first-day presentations. These presentations were simple PowerPoints made by the recitation coordinator, and during this training activity, the main goal was to get the GTAs used to talking in front of a crowd to prepare them for leading a class of undergraduate students. I specifically got to observe Clark, one of the new first-years in my study, give his practice presentation to the group. I noted that he seemed nervous, but I would later learn that this is just his usual demeanor, a characteristic I would not have figured out had I only attended the orientation or only one of his classes the entire semester. He also demonstrated other characteristics of good classroom presence, such as eye contact, volume, and most importantly, the ability to work anything thrown his way by the 'students' regardless of how confusing or non-sequitur it may seem. This is a key component of his teaching style, and would both shape and reflect how his PCK develops as he gains experience teaching.

There was only one opportunity to demonstrate PCK during orientation. On my last visit to the fall recitation orientation, the GTAs practiced working through chemistry problems that they created, with the other GTAs and the supervisor serving as undergraduate students in a roleplay exercise. The GTAs created and developed problems based on early general chemistry I content, mostly unit conversions and dimensional analysis. Unfortunately, the GTAs that practiced their instruction with this activity while I was present were not part of the study population, so I cannot include any information here on the specifics of their practice problems or their demonstration of teaching. However, I include my experience watching this activity as it helped me develop a sense of what teaching might be like for the recitation GTAs in their actual class meetings. Since this was the only chance to demonstrate content knowledge, and by extension any PCK the GTAs possess, it was also the only moment they received any direct feedback from their peers and their supervisor on their teaching and its components. Since I could not include details of the GTAs practicing their teaching at this point in the study due to the timing of participant enrollment, I will note here instead that all of the feedback I observed during this activity pertained to classroom presence and student-GTA interaction, such as suggestions to practice speaking volume and intonation, soliciting different students for participation rather to encourage engagement, and answering questions in different ways.

The spring recitation orientation was considerably shorter than in the fall, and I only attended one session. During this session, the supervisor focused on updates and changes that were made from the fall to the spring. The major updates were that the GTAs now had different rubrics available for grading worksheets rather than one general rubric and that based on GTA feedback, some of the class flow has changed. The supervisor promoted the use of more productive struggle with the students rather than immediately giving the next step in a problem or the technique for finding the final solution. Additionally, the GTAs were also told to spend more time on the discussion they lead at the beginning of each class, making sure to connect the discussion questions to the parts of the worksheet students work on during class. There was not considerable discussion on strategies the GTAs could use, similar to many of the other parts of orientation. As will be discussed in the next section, these guidelines for how the recitation GTAs should teach will contribute to the development of preferred teaching behaviors and styles during in-class instruction.

4.1.2 Applying and Demonstrating PCK

The best context for studying PCK in action is in the classroom. Regularly observing in-class instruction allowed me to develop an understanding and sense of each GTA's teaching practice and knowledge, furthering my aim of characterizing their PCK. Each recitation class lasts a maximum of 50 minutes, during which time the recitation GTAs are responsible for assisting undergraduate students with completing a worksheet focused on a certain topic, concept, or type of chemistry problem. These worksheets are intended to follow the content covered in the main lecture component of the course but also allow students to practice recalling and applying what they have learned to practice problems that are similar to what appears in their homework assignments and on their exams. The recitation coordinator chooses the worksheet topics based on the semester schedule and what is historically known to be difficult material for undergraduates. The recitation worksheet topics for the 2022-2023 academic year are listed in Table 4.1. Since CHE 109 and 110 are slower-paced versions of 105, some of the worksheets are shared between 105 and those courses.

Table 4.1 Recitation worksheet topics for the 2022-2023 academic year. Italics indicate a worksheet that is used in both CHE 105 and either 109 or 110.

CHE 109 Worksheet Name	**CHE 110 Worksheet Name**
Measurement & Density	*Electromagnetic Waves*
Significant Figures	*Bohr Model*
Dimensional Analysis	*Electron Configurations*
Isotopes & Atomic Mass	Periodic Trends
Molecular & Ionic Compounds	*Lewis Structures*
Chemical Nomenclature	Bond Energies
The Mole	Simple Geometries
Empirical & Molecular Formulas	Molecular Geometries & Valence Theory
Precipitation Reactions	*Molecular Orbital Theory*
Oxidation-Reduction Reactions	Simple Gas Laws
Limiting Reactants	Ideal Gas Law
Heat Transfer	Partial Pressures & Gas Stoichiometry
Calorimetry	**105 Only**
Enthalpies of Reactions	Electronic & Molecular Geometries

These worksheets do not cover all of the content in general chemistry I (there is no recitation for general chemistry II), and as a result, the recitation GTAs do not engage with certain overall lecture material for their in-class duties. This means that there are general chemistry topics for which it was not possible to observe any instruction, and thus I cannot make any statements about topic-specific PCK for that content. This restriction effectively bounds the possible PCK (at least for in-class instruction) since it is well-accepted among PCK scholars that content knowledge is needed to develop PCK, regardless of the model or framework used to conceptualize it. Since the GTAs' primary teaching responsibility is to help students with the worksheets, I will use the worksheets and their content to help structure the analysis in this section.

Each class begins with a short discussion led by the GTA, intended to be interactive with the undergraduate students. This discussion focuses on primarily reviewing factual and conceptual information and consists of the first 3-4 questions on any given worksheet. This is when GTAs demonstrate a large part of their ability to convey and effectively explain chemistry material, as well as ask students to share their chemistry knowledge, revealing part of their PCK. As an example, the following is a reconstruction of Brittany's discussion during one of her 109 sections in the fall semester, combing the worksheet questions and quotes from her teaching.

> Brittany: "Okay, it's eleven so let's go ahead and get started with class today. As always, don't forget to fill out all the information at the top of your worksheet, including your name, your group name, and my name, which if you forgot is Brittany. Today we're covering redox reactions, which I'll admit can even be a hard thing for me sometimes; they're not my favorite part of gen chem."

> Worksheet Prompt: In an oxidation-reduction (redox) reaction, what are transferred?

> Brittany: "So, in an oxidation-reduction, or redox, reaction, who can tell me what is transferred?" (Here, she waits for a student to respond. After a few seconds, she re-prompts the class) "When we have these redox reactions, how does the same chemical change from reactants to products?" (this time, a student provides an answer of "charges are different"). "Right! In redox reactions charges transfer in the form of electrons." (She waits again, giving students time to write down this answer).

> Worksheet prompt: What is oxidation? What is reduction?

Brittany: “So, the next question asks what is oxidation and what is reduction. Have you guys learned the way to remember which is which? LEO GER or OIL RIG?” (a student says they learned the LEO GER acronym). “And what does LEO GER mean?” (the student responds again). “Right, this acronym tells us that the loss of electrons is oxidation and the gain of electrons I reduction.” (Brittany writes out “LEO: loss of electrons = oxidation” and “GER: gain of electrons = reduction” on the board, and again waits for students to write down the answer on their worksheets).

Worksheet prompt: What are oxidation numbers? How do we use them to determine if a species is oxidized or reduced?

Brittany: “So can anyone tell me what an oxidation number is?” (A student responds with a correct answer) “Yeah, it’s like the charge on the atom. How do we use that oxidation number to know if something is oxidized or reduced?” (the lapsed time before a student responds is longer this time, but Brittany still waits until a student responds to move on. Eventually, a student replies). “Yeah, we can see how the number changes to figure out if it is oxidized or reduced. I like to just remember that if it’s reduced, that the oxidation number reduces, or decreases.” (again, Brittany provides time for students to write their answers).

Worksheet prompt: In a redox reaction, can one process occur without the other, that is, can we have oxidation only or reduction only?

Brittany: “So last question for the discussion, can we have just reduction or just oxidation? Or do they have to happen together?” (multiple students respond that they happen together) “That’s right, they are always coupled together. So, now you guys can get in your groups if you’re not already with them and start working on the worksheet. I’ll come around to take attendance and answer any questions.”

As can be seen in this example, Brittany asks the discussion questions to the class, waits for student responses, and then uses the responses to offer answers in her words. While this example was only a four-minute piece at the beginning of the class, it is still possible to characterize Brittany’s PCK from this vignette. In the transcript above, comparing the worksheet prompts to Brittany’s spoken questions shows that she does not always read the prompts exactly to her students when asking them questions to solicit student responses. Additionally, she also will provide follow-up questions to clarify the original question or provide a simpler first step to engage students and build their confidence in participation. This was observed when she asked "When we have these redox reactions, how does the same chemical change from reactants to products?" after first trying to only use the worksheet prompt as the question to her class. Here, Brittany changes the question into a simpler form to help students work up to the original question. It also helps Brittany understand the current knowledge of her students, and if she wanted she could ask a question of intermediate difficulty to better map the knowledge of her class. This is one of the strategies that the recitation GTAs covered during orientation, so while it is not surprising to see it utilized not only by Brittany but by all the GTAs I observed, it is nonetheless a key part of the recitation PCK.

After the discussion at the start of class, students work in groups of 3-5 on the questions in the remainder of the worksheet. These questions are typically procedural, designed so that students can practice applying their chemistry knowledge and complete problems using specific methods and techniques that they learned in class. During this time, the GTAs observe their class to see when students need assistance and move to help individuals or groups when asked. Some GTAs prefer to wait at one location in the classroom until a student raises their hand for help, some will wait in various locations until they are needed, and others take the more engaged route of constantly moving around, checking, and making themselves available for assistance. The remaining demonstration of PCK during class time comes from GTAs interacting with their students to help them. By combining their content knowledge and the skills they practiced during orientation and in weekly meetings, the GTAs develop PCK to effectively help their students work through example problems. One characteristic of an educator's PCK is how they adapt their teaching and material to the needs of different students. This was the most common characteristic of PCK among the recitation GTAs that I observed, in the sense that every time I observed a GTA help students in class, they had to assess the student's understanding and decide on the best way to assist and instruct. Among the seven recitation GTAs that I observed in their classes, I found some common strategies and behaviors that constitute a shared PCK motivated by

Revisiting Brittany's class on redox reactions shows an example of using a memory device to help students recall factual information and concepts they learned in their main lecture and now are asked to apply in class. Specifically, when asking about how one can determine which chemical species in a redox reaction is oxidized and which is reduced, she brings up the mnemonic devices known as "LEO GER" and "OIL RIG,' both of which are very commonly used throughout chemistry instruction on this topic. Interestingly, during a conversation later in the semester about teaching redox reactions she made a comment that makes this observation even deeper.

> "I actually don't use either of those tricks for remembering oxidation-reduction myself, I just remember that the oxidation number reduces when the chemical is reduced. But I know that the students learn them, and they like to have the tricks, so I use it and tell them about it."

This statement shows that not only is this strategy part of her topic-specific PCK for redox reactions, but it also specifically transforms both knowledge of her students and content knowledge into part of her PCK. Additionally, she does not use the strategy in her normal application of her content knowledge and is specifically only used in teaching. The use of these specific devices can be observed with every recitation GTA that participated in the study, and while all the other recitation GTAs do use them personally, unlike Brittany, this does not invalidate their inclusion into PCK.

Another common device among the recitation GTAs pertained to identifying the names of common polyatomic ions. The general chemistry undergraduates are required to memorize the names of 25 polyatomic ions. Many students often ask GTAs if there are any tricks they can use to help them learn and remember all of their names and chemical formulas. While there is not a simple mnemonic device like the one used for remembering redox reactions, the GTAs do have a shared strategy for remembering that they rely on for helping students with this task. For example, Courtney tells students the following often:

> "The ions with '-ate' at the end always have one more oxygen than the ions with '-ite.' So, if we know that sulfate is S-O-four, then sulfite has to be S-O-three. You still have to know which 'ate' ions have 3 or 4 oxygens, but this helps to not have to memorize as much stuff."

Across the length of the study, both during in-class instruction and while teaching in the GCLC, I documented all but two of the recitation GTAs in the study rely on some version of this fact, disguised as a "trick" to help students. This is a strategy for specifically helping students with chemical nomenclature, so it is a part of their shared PCK. Strategies like these memory devices are a key characteristic of the recitation GTA PCK. There may be more devices, and some of my observations alluded to other mnemonics or tricks that individual GTAs know and use, but here I am focusing on the major components of the collective shared PCK, and the exploration of all possibly used strategies will be left to the success for future research in this and similar settings.

A common example of PCK in any classroom is how an educator addresses their students' misconceptions, as well as how they can answer questions or provide support to prevent misconceptions from forming in the first place. This action is a major part of the recitation GTAs' PCK and is often called upon during teaching. During one of Patrick's classes, I observed him addressing and correcting a student's understanding before a misconception could form. In his class on this day, students were working on the Lewis structures worksheet which contained a problem about drawing the valid resonance structures for the nitrate ion. When working on this problem, one student asked why it is necessary to draw three different structures when they are all the same if you just rotate them. Indeed, the three correct drawings for this problem can be rotated to look the same. Patrick responded with the following answer:

> "Well, do you remember isotopes? If we make these oxygen atoms all different isotopes, then we see that the double bond in our drawing bonds to the different oxygen atoms. If you rotated one of these drawings the bond would still be attached to the same oxygen. So, we draw three resonance structures to show that they are different structures, not just one rotated in different ways."

This response surprised me, as I was expecting Patrick to bring up an explanation involving how for resonance structures, we draw multiple structures that average out to a true structure with bonds that are between single and double bonds. Curious about this decision, I decided to ask Patrick to explain what led him to this particular action. We had the following conversation about this example after class ended:

> Walker: "That was an interesting explanation for [student's] question about the different drawings. I'm curious though, why not bring up anything about how we use the separate drawings to account for the real bond length in molecules?"
>
> Patrick: "I think that would've just reinforced the idea that he was asking about. If we say that three drawings average out to represent one real structure then why draw three drawings at all, you know? Also, I think he would have argued with me if I talked about the bond length stuff."

As Patrick revealed in this follow-up conversation, he choose a specific approach for answering the student's question to prevent the student from holding onto a misconception about chemical structures. He knew that while one approach to answering the question is correct, it would not serve this particular instructional moment well. So, Patrick chose instead to use a different explanation to correct a misconception and prevent further related misconceptions.

The example with Patrick also shows another characteristic of the recitation GTA PCK: the use of connections between content to guide students through problems that use knowledge from different times in the entire course. Many of the concepts in chemistry build upon each other or are better explained with another concept as a starting point. In Patrick's example above, he used the student's prior knowledge from chemistry classes about isotopes to structure his response. Making connections between concepts to guide students was a behavior observed in all of the recitation GTAs, although not always in the same way.

A final characteristic of the recitation PCK that I observed in all of the study participants is best demonstrated in one of Portia's classes at the start of the semester. 30 minutes after the end of the GTA-led discussion, Portia suddenly collected all of her students after a few minutes of being asked questions continuously by different students in the class. She announced that she was "going to talk about the last problem on the worksheet because she's getting a lot of questions about it." I documented the following instructional moment in which Portia guided the students through the problem.

Portia: 'Okay so on this last problem, it says 'What is the mass in milligrams of a cube of silver that measures 2 inches on each side?' And then it gives you the density. So what is density equal to?"

(she waits, and then after a student responds with the answer she is looking for she continues.

Portia: "Right, density equals mass over volume."

(While talking, she writes "d = m/V and d = 11.34 g/cm^3" on the board)

Portia: “So we want to find mass, and since we already have density we need to find the volume first. How do we get the volume of a cube, does anyone know?”

(Again, she waits for an answer)

Portia: “Good, we just cube the side length. So, 2 inches to the third is 8 inches cubed. Now, this part is what a bunch of people are missing. We also have to cube our conversion factor to go from inches cubed to centimeters cubed. Then once we get our volume in centimeters cubed, we can use our density to find the mass. What units is the mass going to be in after this step?” (students respond “grams”) “Alright and what units does mass need to be in for the problem?” (students respond “milligrams”) “Right so don’t miss that.”

Here, Portia recognizes that her students are missing some key information they need, or are broadly not understanding an important part of the problem due to the number of questions she is being asked. To address this problem, rather than continue to answer every student’s question individually, she decides to regroup the class and cover all the common questions at the same time. Interestingly, I observed Bianca do almost the same process during her class later in the week that was completing the same worksheet, except Bianca did this at the start of the class right after the discussion to get it out of the way earlier on, writing the steps on the board so students could reference them when they got to the problem later. After that class, she also told me that this has been an issue all week with her students and this particular worksheet problem. This behavior and instructional decision are an element of PCK for this specific problem and topic. The recitation GTAs often displayed this behavior, especially in the classes later on in the week or when they covered a worksheet for the second time in a given semester. Their experience with being inundated with the same questions over and over becomes a part of their PCK for the specific topic covered in the worksheet.

For the recitation GTAs, how they approach helping students in class is not far from how they help students in the GCLC. In the GCLC, GTAs help students either one-on-one or in small groups, which matches exactly with how the recitation GTAs interact with their students during class. All of the teaching strategies and behaviors discussed so far were also commonplace for the recitation GTAs when working in the GCLC, as long as they were helping a student with something they were familiar with. When approached with homework or exam questions over content from the lecture but not included on recitation worksheets, the GTAs' would usually still try to help, either working the problems with the student, looking up resources to help them explain concepts to students, or engaging with other GTAs that may have more information on the student's problems. The main exception is when recitation GTAs are asked to help with laboratory work. In theory, the recitation GTAs are expected to be able to help students with this work. However, they are not trained on this material, and while they may know certain pieces of experimental work or have completed similar experiments during their undergraduate degrees, they cannot easily form PCK around the laboratory content.

As seen through these examples and vignettes, the shared characteristics of the recitation GTAs' PCK generally serve to help both the GTAs and their students in teaching and learning chemistry. The recitation GTAs tend to use specific strategies for different topics, such as memory devices or making connections to other chemistry concepts. They use their teaching knowledge to address misconceptions, a common manifestation of PCK. It's also common among these GTAs to develop a set of topics or specific problems that they approach teaching differently by providing more information or resources to students as a form of assistance during instruction (although this may dampen the benefit of productive struggle, which is a preferred experience of the recitation coordinator). In the next section, I will detail how the recitation GTAs interact with each other to discuss their teaching experiences and develop their PCK as a community of practice.

4.2 The Recitation GTA Community of Practice

4.2.1 Social Elements of the Recitation Community of Practice

A community of practice is a social structure that provides support for a group that engages in a shared practice to improve and expand their knowledge of the practice. As a system of social learning, its effectiveness is dependent on how the members interact with each other. The relationships between members are crucial to the continuation of the CoP and the advancement of their practice, which in the case of this research is the communal development of PCK. The recitation CoP is socially advanced when the recitation GTAs interact with each other. Granted, this can happen in any context and setting. This study only observed and documented interactions during events related to the GTA job: in class, during orientation and meetings, and in the GCLC. However, GTAs continue to develop relationships with their peers and colleagues outside of these settings, in the courses they take together for their degrees, at seminars and other departmental events, and in the labs they conduct research in. While these settings are not part of the study scene and likely do not have a strong influence on teaching practice or PCK development in the CoP, it is still important to remember there are social details that I did not capture and cannot speak to.

Regarding the recitation GTAs, I did not find any drastic aspects to the social workings of their group that would lead to significant impacts on the community of practice and the communal development of PCK. In both semesters the population of recitation GTAs was majority female, and there was only one international recitation GTA. There are some interesting patterns among their relationships and interactions, but they were either not lasting or did not have an impact that I could easily trace through the data. For example, at the start of orientation, there were discrete groups based on experience (i.e. the first years, the returning second and third years, the fourth years and older) that would only sit with and talk with each other. However, these groups quickly dissolved, partially due to the relaxed nature of the orientation sessions that allowed for ease of communication and getting to know each other. The most negative impact on the social workings of the group typically had to do with recitation GTAs slacking in certain aspects of their job. For example, a GTA who missed multiple meetings became seen by some as not willing to do the job the same way everyone else does, and a different GTA who was consistently behind in grading was often talked about. In the long run, neither of these issues resulted in permanent changes to the social structure of the group, as far as I could observe. Across the semesters the recitation GTAs were willing to help each other out, seen by how easy it was to organize substitute instruction for when someone was sick or out of town. Among recitation GTAs, they largely seem to set aside any conflicts they have to work together professionally.

The ethnographic approach to this study allowed me to be immersed with the GTAs in many relevant contexts, and as a result, I became an actor in the community of practice, especially since I have my own experience in this role. During meetings, I would occasionally contribute to the discussion on teaching recitation, including offering my PCK to the group, as well as contributing a pseudo-external perspective on certain discussion points. This level of immersion was not only a boon to the validity and reliability of the study methods and data but also allows me to access my reflections on these events as research data.

4.2.2 PCK Development in the Recitation Community of Practice

Members of a community of practice will engage in different actions that serve to help them gain experience in the shared practice as well as collaborate with their colleagues' efforts to evolve everyone's ability to participate in the practice. Among the recitation GTAs, I observed actions and behaviors among the members primarily focused on the way that everyone teaches and how their growing experience is similar or different to each other. The main actions I can assert that the group of recitation GTAs use to develop their PCK as a community of practice are information and experience seeking, discussing developments related to teaching, ensuring consistency of teaching among GTAs, reusing assets of each other's PCK, and growing confidence in future teaching developments through interaction with their peers.

In a community of practice, members can advance their knowledge of the practice and their experience in the community by seeking out the experiences and knowledge of other members. This activity is especially valuable for newcomers, who may look to experienced members of the community to help them understand how to engage with the shared practice and may want to adopt their behaviors. Among the recitation GTAs, seeking others' knowledge or advice was often motivated by the desire to know if there are any shared experiences. For example, during a meeting discussing Lewis structures, I documented the following group conversation:

> Fiona: "I do have a weird a question for everyone. Has anyone else had their students tell them a really strange way to figure out how the number of bonds in a Lewis structure? Mine told me about this weird formula and that it was the way they learned in class. I had never seen or heard of it before."
>
> Brittany: "Oh, was it the formula where they add up the all valence electrons and then subtract the group number or something like that? That was really weird, and I just said, 'If it works for you to get the right answer then do it.'"
>
> Bianca: "Wait, what? They have some equation to figure out Lewis structures now?"
>
> Courtney: "Was it like the equation for formal charge calculation?"
>
> Fiona: "No it was something new. I guess one of the lecturers used it in class because the students were adamant it was the way to do Lewis structures."

In this interaction, Fiona was seeking the experience of her colleagues in the CoP to help her figure out this new experience she had that relates to the shared practice. For the specific experience she had, she was wanting to know if the other GTAs had witnessed this new piece of chemistry knowledge so that she can figure out if she needs to adapt to it for her teaching. When Brittany confirms that she knows what Fiona is talking about, this helps to affirm Fiona's experience. Bianca and Courtney's further questions are intended to ask Fiona and Brittany to expand on their experiences and what they know, indicating that the experience is not fully shared among the GTAs. This is not entirely surprising, as there are multiple lecturers for all of general chemistry and they often end up teaching things differently, so the different recitation sections sometimes have different chemistry knowledge, another aspect that these GTAs are constantly adapting to. Through seeking the experience and knowledge of her peers, Fiona acted to further her own PCK. In addition, the other GTAs' responses to Fiona help to advance the group's collective PCK.

This particular discussion also demonstrates how this group uses discussions of new developments related to the role to advance their PCK. In the above example, Fiona had noticed something new relating to her teaching, and after bringing the experience to discussion among her CoP colleagues, she knew that it was a common experience and thus she needs to consider it when teaching, therefore developing part of her PCK. Discussing various changes and events is common among the recitation GTAs, most often during meetings or when they see each other in the GCLC. For example, I found that the GTAs are very curious about undergraduate exam performance, asking each other, the recitation coordinator, and even their students after exams how the undergraduates generally fared on their recent test. The GTAs would also discuss changes in the homework their students are assigned, which GTAs often have to help with in the GCLC. Discussing changes to the homework helps to provide the group with knowledge about how they may need to adapt teaching in or out of class.

Occasionally, discussions during the weekly meetings would reveal unexpected aspects of the group's PCK as they talk about what is currently happening in recitation. One such discussion started when in the third meeting of the fall semester (Sept 16), the recitation coordinator asked the group if there were any general questions about recitation now that all of the GTAs have had a few weeks of practice. Third-year Bianca asked bluntly but simply "Why our students are having so much trouble with doing math this semester," indicating that she had already had experiences with her students struggling to do various arithmetic operations on the worksheet problems during class. When asked to explain a bit more she told the group a recent experience from one of her classes.

> "Earlier this week I was helping students with the calculating atomic mass problems, and I had this one girl that just did not understand any part of distributing over the parentheses. Her problem wasn't why she should distribute, or for me to see if she did it right, it was that she actually did not know what it was at all. And when I showed her why we need to do it and how to do it for the problem, she still was completely lost on the entire idea." (This is the same event that was explored in Bianca's class in the previous section).

The other GTAs corroborated this point, adding that they had also begun to notice a common difficulty with mathematical knowledge that the students were assumed to have. For example, first-year Fiona stated that she had a student say, "They didn't know what I meant when I said that you need to find the inverse." While this discussion appears to be educators simply complaining about student performance in class, it reveals part of the GTAs' knowledge of their students, in particular how their students interact with the arithmetic and mathematical knowledge required to learn and apply chemistry knowledge. After this discussion, the recitation coordinator provided some strategies that the GTAs can use to help their students with the mathematical aspect of solving chemistry problems, so discussing the development resulted in the change to the collective PCK.

Another major development that was the topic of discussion in the meeting was the change from the previous system of recitation to what GTAs did during the 2022-2023 academic year. For the new recitation GTAs, who have no first-hand experience and sense of what was done in the past, these discussions were a look into what teaching was like before they joined the group. For the returning experienced GTAs, this was a major development. At the beginning of the fall, during orientation, was when the recitation coordinator explained that recitation was changing from a lecture-focused format to the student-focused short discussion and worksheet system that has been explored already in this work. This shift sparked a shared concern among the returning GTAs, who were now unsure of whether their previous teaching experience would help set them as separate from the new GTAs, or if they were all now on the same level. In a sense, this separation helped to further the community of practice, as the returning GTAs now had to figure out if anything they did previously could be applied to the new system. When they could rely on previous experiences, such as Portia explaining that students always forget the formulas they need for quantum problems or when Patrick shared his experience with varied problem-solving algorithms, it served to make the experienced GTAs a source of group knowledge that the newcomers could benefit from. On the other hand, when the experienced GTAs were forced to the same level as the newcomers, this served to strengthen relationships among the group and develop everyone's PCK simultaneously.

The members of a CoP can further their shared practice by bounding and standardizing how they work to advance their knowledge and gain experience. Ensuring that the recitation GTAs are consistent with their explanations of chemistry concepts is important to facilitate the smooth operation of all the recitation sections. The GTAs' common explanations of concepts, which are a component of topic-specific PCK, need to not only be consistent with each other but also consistent with what the undergraduate students learn in their main lecture courses. One way that consistency in content knowledge and teaching is ensured in the recitation CoP is driven by the recitation coordinator. The recitation GTAs are required to complete the worksheets a week in advance before they teach so the coordinator can confirm the GTAs' correct understanding of the relevant topics and concepts. Then, in the meetings, practicing teaching helps to make sure everyone is using similar explanations, representations, and methods in their in-class instruction. When the practice is properly bounded, but not restricted, then the members can better develop the practice together, since they all know what they are doing in the practice.

During one fall recitation meeting, the worksheet discussion focused on mass percentages and empirical formula problems. Finding the empirical formula of a chemical from mass percent information has a very consistently taught algorithm, and all of the GTAs both know and teach this method. Portia was set to present the worksheet problems that day and had already finished, but another GTA chimed in and added that he had a different approach to solving these problems. The recitation coordinator was intrigued, so she let him demonstrate this alternative method. Before he started, he made sure to point out that "this way of doing the problem came from a student" and that "last year when I tried to show everyone this I just got laughed at." At this point, Bianca chimed in to add that he was laughed at because "that method is harder to understand and that's why we disagreed with it." He continued to demonstrate the different method, and afterward, the group had a brief discussion about it. Across the rest of the group, they agreed that yes, the method is valid for certain problems. However, because it is not generalizable to all empirical formulas problems they should avoid showing it to the students. Even without considering these caveats to the alternative approach, the group decided rather quickly that this was not the current way to teach, which in turn meant that this method should not be included in the collective PCK.

Another activity taken on by members of a CoP to advance their knowledge and experience is the reuse of assets among members. In this context, an asset is simply something related to teaching general chemistry students: an explanation, a learning tool, a representation, a problem-solving strategy, or even more tangible l assets such as presentations and technology. Reusing assets allows recitation GTAs' to directly share their enacted PCK. For example, during one of Courtney's 110 classes, she admitted to me after the discussion that she was not very confident in the way she answered a student's question. I told her that while her answer was correct, there is a simpler way to explain the concept (identifying emission and absorption spectra). I shared with her the way that I explain this concept: "An emission spectrum is stripes of color appearing in black like the atom is giving us colors to see, and an absorption spectrum is discrete colors being taken away from the whole color spectrum." Later on in the semester, I documented the following during a similar discussion in one of her 105 sections:

Worksheet prompt: The spectrum below is a result of what process? (Absorption or emission?) Briefly explain your answer (The worksheet shows an absorption spectrum)

Courtney: "So, who knows if this spectrum shown here is an absorption or emission spectrum?" (a student answers emission). "Good try, but this is actually an absorption spectrum. They can be kinda difficult to remember, but a good way to keep them straight is to think that these black lines are the atom absorbing color away."

Courtney took our previous conversation into her PCK and chose to reuse my preferred explanation of the concept in her teaching. I noticed this and briefly asked her about it after the discussion portion ended. She told me that she liked my version much better than what she was working with to help students remember which is which, and that she is using it instead. Courtney took my asset (an explanation of a concept) into her own teaching practice, developing her personal PCK. The recitation GTAs share their method of leading a discussion at least once per semester in front of the group, allowing everyone to observe each other's teaching style and part of their enacted PCK. In one instance, I observed They can then reuse various assets from each other's teaching, advancing everyone's knowledge of the practice together through these group-owned elements of the practice.

Recitation GTAs often engage in collaborative problem solving specifically in the GCLC. From my observations, this typically happened when the recitation GTAs needed to help students with laboratory content. The GCLC schedule is set by the GTAs based on their availability, and the recitation GTAs typically get the schedule their shifts first. Summary information for the GCLC schedule for each semester is included in Table 4.2, which shows how often recitation GTAs worked shifts in the GCLC without laboratory GTAs present. In the Fall, there were at least two hours on Friday mornings in which only recitation GTAs worked: Brittany, Bobby, and Fiona for the first hour, and then only Bobby and Fiona for the second hour. I observed the GCLC at this time slot every week since it was right after the morning laboratory GTA meetings. Often, the students that came in at this time were a mix of those requesting lecture course help and those needing laboratory course help. For the lecture courses, these GTAs had no problem. This particular set of GTAs told me they enjoyed their time working in the GCLC, which was evident in their willingness to help out students even when they were not confident in their chemistry course knowledge (such as helping students with laboratory or general chemistry II homework).

Table 4.2 GCLC schedule information for the 2022-2023 academic year

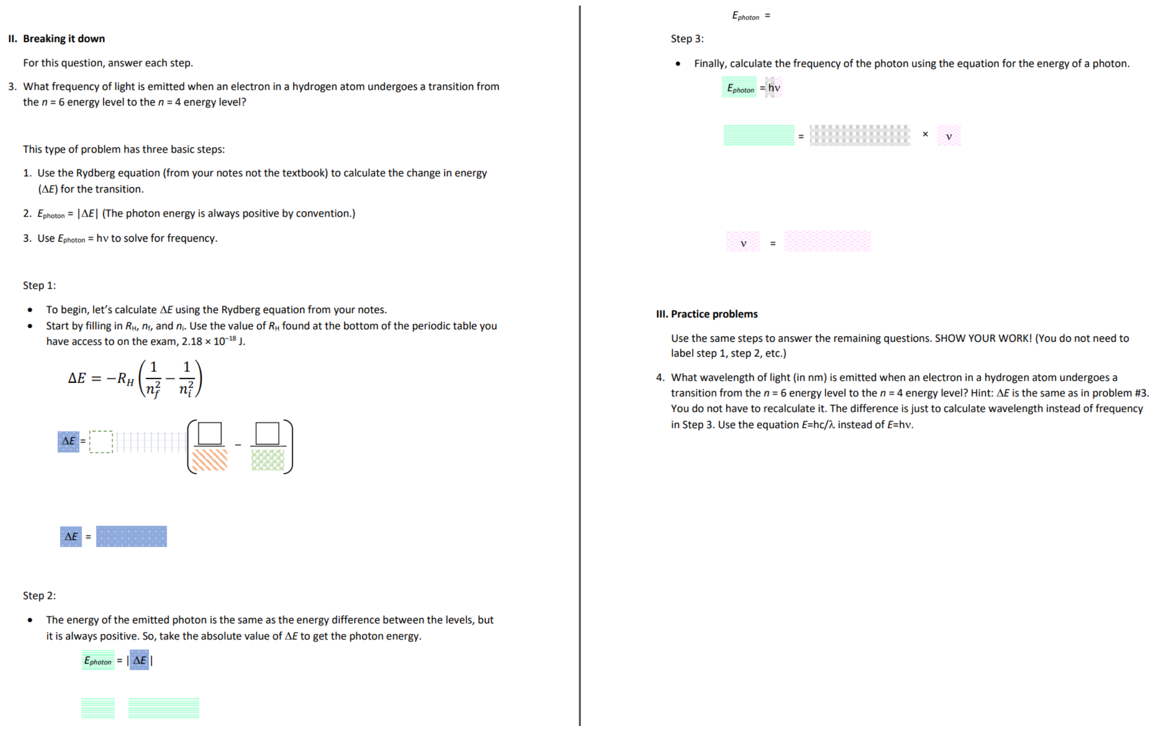
	Fall 2022	Spring 2023
Number of GTAs		

• Recitation • CHE 111 • CHE 113	11 9 16	6 15 11
One-hour blocks with…		
• 1 GTA of each type • Only 1 type of GTA • Only 1 GTA total • Only Recitation GTAs • Only Lab GTAs • No CHE 111 GTAs • No CHE 113 GTAs	8 10 0 5 14 7 19	2 19 10 3 25 17 9

On one Friday morning in the GCLC, these three GTAs tackled a laboratory problem together. Some students had come in to get help with their post-lab assignment for experiment 16, a general chemistry II laboratory experiment focusing on making and testing buffers. As first-year recitation GTAs, Brittany, Bobby, and Fiona had no knowledge of what happens during this experiment, but they did have some knowledge of the underlying chemistry. Bobby was the first one to begin helping the students with their data analysis, but he quickly got stuck. He was unsure how to interpret a specific step in the assignment concerning using a graph of student data to calculate buffer capacity. When he got stuck, he went to ask Brittany for help, because Fiona was assisting another student at the time. Brittany, looking through the students' lab manuals, eventually found a formula for calculating buffer capacity that the students were to use. However, they still did not have all of the information, because the formula requires knowing the concentration of the test acid and base used in the lab, which was not included in the laboratory manual and the students had not recorded this in their notebook. At this point, none of the recitation GTAs could move forward with solving this problem because they simply did not have the correct information. They even tried asking me, but I also did not know the value they needed. Finally, the 113 GTA Morgan showed up, and Bobby asked about this value, and he was able to provide the necessary information. After finishing helping the students, the recitation GTAs made sure to ask Morgan for other information on this experiment so they can help other students in the future. In this example, the recitation GTAs worked together and combined their knowledge to solve a problem related to their role. In solving this problem (how to help these students with their post-lab assignment) they develop more PCK, specifically for this assignment and its associated chemistry topics.

The final component of how the recitation GTAs advance their PCK as a community of practice appears when the meeting discussion shifts to focus on how things may be changed in the future. During discussions in meetings, often about the content of the worksheets or how a certain class procedure is conducted, the GTAs will bring up complaints or concerns about how the class works. This helps to advance the PCK through discussion and additionally allows movement for the newcomers when they are the ones making suggestions. This impact can be even greater if the recitation coordinator approves of or endorses an idea from the GTA, as they represent a sort of leader of the CoP. The best example of this pertains to the structure of the first problem on the recitation worksheets after the GTA-led discussion. This problem, named the "breaking it down problem" is designed both pedagogically and visually to scaffold students through the steps and applications needed to solve chemistry problems that they will see on their homework and exams. As seen in Figure 4.1, this problem guides students through each step needed to solve a problem and is physically structured to help students learn how intermediate calculations or important information from the problem is used in each step.

The recitation GTAs noticed that this scaffolding is not always effective, and that spend more time than they would like in class helping students just understand how to interpret this part of the worksheet. Across both semesters, GTAs contributed suggestions for how to improve this section for ease of understanding and the benefit of their students. For example, the GTAs discussed changing the color-coding system the problem uses to show where similar values are placed in setting up calculations, changing the type of the problem used in this section of the worksheet, and even whether or not this problem should be allowed to be part of the worksheet graded for accuracy. All of these discussions revealed parts of the GTAs' personal and collective PCK through their understanding of their students and scaffolding in instruction. These conversations also help to promote the collective PCK through sharing of information and discussion of developments, in particular how their students interact with this instructional material and mode.



II. Breaking it down

For this question, answer each step.

3. What frequency of light is emitted when an electron in a hydrogen atom undergoes a transition from the $n = 6$ energy level to the $n = 4$ energy level?

This type of problem has three basic steps:

1. Use the Rydberg equation (from your notes not the textbook) to calculate the change in energy (ΔE) for the transition.
2. $E_{photon} = |\Delta E|$ (The photon energy is always positive by convention.)
3. Use $E_{photon} = h\nu$ to solve for frequency.

Step 1:

- To begin, let's calculate ΔE using the Rydberg equation from your notes.
- Start by filling in R_H, n_f, and n_i. Use the value of R_H found at the bottom of the periodic table you have access to on the exam, 2.18×10^{-18} J.

$$\Delta E = -R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

ΔE =

ΔE =

Step 2:

- The energy of the emitted photon is the same as the energy difference between the levels, but it is always positive. So, take the absolute value of ΔE to get the photon energy.

$E_{photon} = |\Delta E|$

E_{photon} =

Step 3:

- Finally, calculate the frequency of the photon using the equation for the energy of a photon.

$E_{photon} = h\nu$

= × ν

ν =

III. Practice problems

Use the same steps to answer the remaining questions. SHOW YOUR WORK! (You do not need to label step 1, step 2, etc.)

4. What wavelength of light (in nm) is emitted when an electron in a hydrogen atom undergoes a transition from the $n = 6$ energy level to the $n = 4$ energy level? Hint: ΔE is the same as in problem #3. You do not have to recalculate it. The difference is just to calculate wavelength instead of frequency in Step 3. Use the equation $E=hc/\lambda$ instead of $E=h\nu$.

Figure 4.1 The "Breaking it Down" problem from the Bohr Model recitation worksheet in Spring 2023

4.3 Chapter Summary

In this Chapter, I discussed the shared characteristics of the recitation GTAs' PCK. Within the CDPCK model proposed in Chapter 2, this is their collective PCK, which I was able to characterize by observing and analyzing the recitation GTAs' enacted and personal PCK. I found that the recitation GTAs use specific strategies for specific chemistry concepts and topics, such as memory devices and tools for recalling facts and making connections between different parts of content to help students learn. The GTAs use their PCK to address students' misconceptions and prevent future misunderstandings. They will make connections between various chemistry concepts and topics. Exploring these aspects of the recitation GTAs' PCK helps to answer research question one, in which I aimed to characterize the PCK of recitation and laboratory GTAs.

To help answer research question 2, I explored the recitation GTA community of practice, which I also became a member of through participant observation. The recitation GTAs work together in a tight-knit community of practice in which the members feel comfortable trying new approaches to their teaching. At the same time, it is important to the recitation GTAs to ensure that everyone is teaching similarly, promoted by the reuse of various assets in their teaching practice. They discuss various developments and ask each other for advice or information to help them with their own teaching, which works to advance their collective PCK at the same time. Newcomers to the recitation community of practice can easily fold into the rest of the group and become a member whose knowledge and experience is treated as equally valuable as the more experienced GTAs. While the recitation GTAs do not interact much outside of meeting times and the GCLC, their interactions help them to develop PCK consistently and continuously with respect to the specifics of the recitation role.

CHAPTER 5. LABORATORY

5.1 Characteristics of Laboratory GTAs' PCK

5.1.1 Establishing PCK: A Crash Course in Laboratory Instruction

Laboratory content knowledge can be thought of as containing two aspects: chemistry conceptual knowledge and experimental procedural knowledge. Effectively performing experimental work requires knowledge in both domains. As mentioned in the previous chapter, all chemistry department graduate students are required to earn passing scores in every subsection of the ACS general chemistry exam upon entering the program. For any subsections they do not earn the required score, they must complete a remedial assignment based on each subsection's main topic. This system allows the general chemistry faculty to have confidence that their GTAs have completed some standardized content knowledge benchmark before teaching, similar to the recitation GTAs.

In contrast to the recitation group, the laboratory coordinator also regularly hires GTAs from outside of the chemistry department. I went through the out-of-department hiring process when I last worked as a general chemistry GTA, so I know first-hand the background requirements for these specific GTAs. First, the laboratory coordinator requires that the graduate student has completed organic chemistry in their undergraduate program. This helps to ensure that they have sufficient chemistry concepts and chemistry laboratory knowledge. The potential GTAs are also required to complete an interview in which they discuss some general educator social-emotional skills with the laboratory coordinator, then demonstrate their PCK through a role-play demonstration of how they would teach an example chemistry problem. This system helps to ensure consistency among the out-of-department and in-department laboratory GTAs, although it could be argued that the out-of-department GTAs have greater requirements to complete, compared to simply taking an exam and/or completing some assignments.

The laboratory coordinator has to work with a greater breadth of experience and background among the GTA population compared to the recitation group. The coordinator also has to train and supervise a greater number of GTAs. Compared to the recitation GTAs, the laboratory GTAs have significantly more job-related duties with greater complexity, which is reflected in the rigor of their orientation. I mentioned in Chapter 4 that I only attended three of the fall recitation orientation sessions during the entire week, out of six total morning and afternoon sessions across the five days of orientation. When I was not with the recitation group, I was with the laboratory group. Recall also that I described the recitation orientation as relaxed and slow-paced. In great contrast, the laboratory orientation is filled with activities and discussions to prepare the GTAs for their in- and out-of-class duties. The laboratory orientation feels much more like a crash course in everything general chemistry laboratory GTA, covering all parts of the job in enough detail to get GTAs prepared for the first week of classes, with the remaining training completed during the first two weeks of the semester and regularly throughout the semester during meetings. The spring semester orientation is largely just a condensed version of the fall and with different cohorts of GTAs. I will focus on describing the fall orientation, and when necessary, bring in examples from the spring that are distinct or useful for providing a thick description of the scene.

Monday morning's orientation session for the laboratory GTAs begins with introductions and an overview of the course policies. There are two laboratory courses:

one each for general chemistry I and II. Throughout the remainder of this discussion, I will refer to each group by the corresponding course number: “111 GTAs” are those that teach general chemistry I laboratory, and “113 GTAs” are those that teach the second-semester laboratory. The group is fairly quiet, focused on absorbing everything the coordinator says, although it is also stressed that the GTAs need to become comfortable with talking to each other and in front of everyone since speaking in front of a group the same size is a main part of their in-class experience. After initiating everyone, the coordinator covers all of the expectations for the GTAs, including how they are expected to run their classes, interact with students, complete grading, conduct office hours, and complete any other tasks relating to the position.

The next time I returned to the laboratory group was Tuesday afternoon. This time, I joined the GTAs in the laboratory classrooms. The most stressful part of orientation, as relayed to me by all of the GTAs I spoke with, is completing all of the experiments for the class they are teaching the upcoming semester, including all of the post-experimental data analysis. Since the laboratory curriculum is not as standardized as what is covered in general chemistry lecture courses, there is no guarantee that a laboratory GTA has performed a specific type of experiment or procedure in their prior teaching and learning experience. Therefore, all of the GTAs are required to complete the experimental work so they are familiar with the content they are teaching. Orientation is structured so that it is possible to complete all of the experiments during the week of orientation if a GTA works optimally, but I found that almost all of the GTAs in my study had to finish up their experiments during the first two weeks of the semester. While this specific activity does not contribute directly to PCK, it is important for establishing the necessary content knowledge to generate PCK around.

During this Tuesday afternoon session, the laboratory coordinator also gave a demonstration of delivering a pre-lab lecture, which all laboratory GTAs are required to create and deliver in the first 10-20 minutes of class. Before and after the demonstration, the coordinator stresses that the GTAs should focus on the pedagogical methods she displays, as this is what will help them the most when it comes to teaching. Specifically, the coordinator focuses on how GTAs should engage students in active learning through interaction, participation, and connecting concepts to broader ideas. The supervisor's lecture demonstration established many of the practices I would see throughout classes I observed, including how the GTAs ask questions, structure the content of their lectures, solicit student participation and questions, and how they use the classroom equipment as a supplemental tool for their teaching.

On Wednesday morning, the GTAs practiced delivering their pre-lab lectures in small groups, similar to the one the laboratory coordinator demonstrated the previous day. While the GTAs show differences in their teaching styles, such as how formal or personable they prefer to be, they also display differences in their preferred PCK. For example, Talia asked many more questions than the other GTAs during the spring practice activity, while Hoda preferred to only ask questions at select moments to highlight key parts of her lecture. After the practice lecture activity, all the laboratory GTAs reassembled to discuss what they identified in each other's lectures as good qualities and aspects that should be improved. Among the positive qualities were the presentation of chemistry concepts and facts, lecture organization, and the use of the whiteboard as a supportive aide. Areas for improvement included classroom presence (projection, addressing students non-verbally, and facing the class when talking) and relaying information about laboratory safety. At the end of this session, the supervisor delivered a statement to the group that succinctly describes the expectations and freedom granted to the laboratory GTAs regarding their teaching behaviors: “As much as you are teaching your own sections, you are teaching them the way I want you to.” This sentiment holds for many of the characteristics of the laboratory GTAs’ PCK, as I will explore in the following section. The GTAs have teaching preferences and construct personal PCK, but many of the characteristics come directly from the laboratory coordinator, enforced by experienced GTAs as well.

I attended two other sessions of laboratory orientation. Thursday morning included an overview of the course's learning management system, Canvas, and how the GTAs will interface with it and explain to their students how to find, complete, and submit assignments. There was also a discussion on what needs to be covered by the GTA and completed by students during the first day of class, which demonstrates just how much the laboratory GTAs have to know for their role. For example, this was the list of everything required for the first class:

- Announce the class and section information, and help students in the wrong place get to the correct place (8 laboratory classes can run simultaneously)
- Cover GTA and laboratory coordinator information, including contact information and office hours schedules
- Take attendance
- Read through the course syllabus and schedule
- Tell students about required materials and how to get them
- Explain the various technological tools used in the course: Canvas and Achieve (pre-lab and post-lab assignments)
- Cover laboratory safety, including PPE, appropriate behavior, and the location of safety equipment

- Announce upcoming assignments for students to complete: the post-lab work for the first week's experiment and quizzes over course policies and safety
- Guide students through completing and submitting information and laboratory safety contract sheets on Canvas
- Lecture over experiment 1 (CHE 111)/10 (CHE 113) and guide students through working on the tasks during class time

Friday's morning session focused on grading practice. Grading is what many laboratory GTAs consider to be the most time-consuming part of their job, and also the point of contention when compared to the amount of work the recitation GTAs are required to do. Most of the orientation grading practice was to expose the GTAs to the grading system in Canvas (speedgrader) and how to assign grades, work with student submissions, and leave feedback. It also highlighted the need for the GTAs to be consistent in their grading: both within their sections and among each other. Further grading practice is done regularly in the weekly meetings, and I will explore it more in that context.

As discussed, being a laboratory GTA involves a large amount of work both in and out of class. The orientation is designed to introduce everything to the GTAs so they have a baseline that they can then build upon during the semester in weekly meetings, interactions with their peers, and while gaining teaching experience. This training sets many of the aspects of their PCK, such as how to solicit student questions, how to structure their lectures, and how to deliver important laboratory information to their students. As I mentioned earlier, the week of orientation is not enough time to effectively cover, practice, and internalize everything that the GTAs must learn to do. Rather than condense the orientation even further (although I heard a rumor towards the end of the study that orientation will be extended in the future), the weekly meetings are used to cover experiment-specific PCK, and additionally, they serve as a setting to continue to refine their PCK regarding specific activities of their role.

5.1.2 PCK Demonstration in the Laboratory Classroom

The chemistry laboratory course represents a controlled environment in which we can explore how chemistry applies to the physical and human world. For general chemistry education, the laboratory course also serves as an application of lectured material. Each general chemistry laboratory course at UK consists of 9 experiments that connect to core concepts from the lecture courses. As with the recitation GTAs, the laboratory GTAs can only develop PCK for the material that they know, otherwise, they are more or less relaying a script for what to do in class. Table 5.1 shows the main concepts that each experiment focuses on, with laboratory-only concepts in unformatted font and connecting concepts from the lecture in italics. Without PCK for their discipline, GTAs could lead students through solving a problem or applying their knowledge, but they cannot effectively adapt to a changing teaching environment. PCK is necessary for a laboratory GTA to succeed in their role, as the laboratory is a constantly changing environment.

Table 5.1 Main topics for each experiment in CHE 111 and 113. Concepts that are connected to lecture courses are shown in italics.

Exp Number	CHE 111	Exp Number	CHE 113
1	Scientific Writing and Integrity	10	Scientific Writing and Integrity
2	Measurement, *Accuracy vs Precision,* Lab equipment	11	*Calorimetry, Hess's Law*
3	*Density*, Writing an experimental procedure	12	*Colligative Properties, Freezing point depression, molality*
4	*Stoichiometry*, Filtration/Gravimetric analysis, writing an introduction for a lab report	13	Intro to analytical chemistry: *dilution*, absorbance, conductivity, turbidity, *measuring concentration*
5	*Limiting reagent*, recrystallization, purity, writing a discussion of experimental results	14	*Reaction rates, rate laws, activation Energy, the Arrhenius Equation*
6	*Net ionic equations, solubility*, qualitative analysis	15	*Chemical Equilibrium, Le Chatelier's principle*, Beer-Lambert Law
7	*Titrations, pH*, writing a conclusion, MeasureNet/Instrumental Equipment	16	*Buffers, Henderson-Hasselbalch Equation, Buffer Capacity*
8	*Oxidation-Reduction reactions*	17	*Solubility product*, standardization with titrations
9	*Molecular geometry*	18	Qualitative Analysis, *Solubility, Chemical Properties*

The general chemistry undergraduate laboratory students are required to complete a pre-lab assignment, write procedures for the experiment before coming to class, perform the experiment and collect relevant data, analyze the data in a post-lab assignment, and write a laboratory report for all but three experiments in each course. The GTAs' role in the students' workflow for each experiment is to check that they have written a complete procedure before attending class, delivering a laboratory lecture, assisting students with completing their experimental work, helping students with post-lab data analysis during office hours, and grading laboratory reports, including providing feedback on content and style. Observing the different parts of the GTAs' job shows different characteristics of their PCK.

Each laboratory class starts with a pre-lab lecture to introduce the experiment, convey important information about the procedures, and make connections to chemistry concepts covered in lecture classes. During the spring orientation, the laboratory coordinator had the GTAs come up with the necessary components of the pre-lab lecture: GTA and coordinator contact and office hours information, upcoming deadlines and due dates, underlying theory for the experiment, equipment setup, safety information, waste disposal, and tips for both the procedure and post-lab work, whether it be data analysis or report writing. The GTAs also said that this should all be done in 15-20 minutes, which reflects the coordinator's expectations. I found out that the length of the pre-lab lecture is one of the benchmarks used by the laboratory GTAs to gauge each other's ability, as shown in this conversation with Morgan, one of the experienced GTAs:

> Walker: "Tell me about what you think makes for a good pre-lab."
>
> Morgan: "You need to cover the important parts of what students are doing in the lab and what they need to focus on to do the post-lab work correctly. You also cannot go too long, or you cut into the students' working time, as well as lose their interest. I would say anything after 15 minutes is questionable for most experiments and after 20 minutes is wasting time."

GTAs teach in classrooms that occupy one-half of a large suite, with some open space between each laboratory room. This allows for not only movement between the rooms but also means that GTAs can hear when their suite-peer is finished with their pre-lab. I found it was common for GTAs to make comments about the length of other's pre-lab lectures, both to the tune of "[GTA] finished in 10 minutes- what did they even cover?" and "[GTA] is still talking; if they don't finish pre-lab soon their students are not going to finish their work today." The timing of the pre-lab lecture, which connects to its organization, is a crucial component of these GTAs' teaching ability. The way that a lecture or lesson is structured, including the flow and pace, is part of how we teach specific content and is thus part of these GTAs' PCK.

When comparing GTAs' pre-lab lectures, it is easy to see where they differ in their preferred approaches. Most of these lectures contain a large volume of information and have to move between topics quickly, but by analyzing the pieces, the characteristics of PCK are revealed. Experiment 5 in CHE 111 has students perform the synthesis and purification of aspirin from salicylic acid and acetic anhydride, along with a purity test on their final product. After the experiment, students use their data to determine the limiting reagent of their synthesis and conduct a purity test to determine if they successfully converted all salicylic acid. The difficulty in this experiment for students and GTAs alike comes in time management, as many of the steps for this experiment require sufficient time to pass or the procedure fails. GTAs are encouraged to keep the pre-lab lecture short so their students have enough time to complete all of the experimental steps properly and without rushing. Recall that the laboratory coordinator wants GTAs to promote active learning by engaging students to participate during the lecture and by asking questions. But how do the GTAs balance this expectation and the rush for this experiment? Table 5.2 contains the documented questions three GTAs asked their students during their pre-lab lectures. By comparing the amount and the content, elements of personal PCK are revealed.

Table 5.2 Questions recorded from pre-lab lectures for experiment 5 for GTAs Cristofer, Talia, Augustus, and Portia

Cristofer (1st year)	"If we don't have salicylic acid, do we have aspirin?"
Talia (1st year)	(during an example problem) "Where should I start to begin solving this problem? "So, which chemical is our limiting reagent? (student responds) Yes, why?" "Does anyone know which solvent we are using?" "The purity test is for phenol, where do you see this in the reaction?"
Augustus (3rd year)	"Which of these chemicals is the limiting reagent in this problem?" "Look at these drawings of chemicals I put on the board. If the purity is looking for phenol, which looks like this (points to drawing of phenol), which chemical is the purity test picking up?"
Portia (2nd year)	"If you're testing your compound and it doesn't turn purple, does that mean it's pure?"

It is easy to see that some GTAs use questions more or less than others. Cristofer and Portia only asked one question to their students during their lecture, while Talia asked four, two of which were during an example problem that students would do during their post-lab work. These differences in the number of questions allude to an aspect of each GTAs' personal PCK. A greater component of their PCK is the motivation behind asking the questions. Talia and Augustus are engaging their students in critical thinking, application of knowledge, and problem-solving with their questions relating to an example chemistry problem. In contrast, Portia and Cristofer ask a question about an important outcome of the experiment and its results, focusing on what the students need most immediately after the experiment. While representing different styles, both approaches to asking their students relevant questions is a characteristic of their PCK.

Portia's question to her students also shows another element of PCK for the laboratory GTAs: addressing possible misconceptions that students may hold. In the specific example of this experiment, the students are attempting to purify their aspirin products, but the purity test only tells about the presence of salicylic acid. It is easy for students to make the wrong conclusion from the results of their purity test, and Portia makes sure during this experiment to try and prevent this misconception early. I find that laboratory GTAs are constantly trying to help their students avoid developing misconceptions, especially when it comes to connecting the experimental work to post-lab assignments. With Portia's example, the misconception focused on understanding and interpreting experimental results. Laboratory GTAs do also address misconceptions in the chemistry content as well, as seen by this part of Talia's experiment 15 pre-lab lecture:

> "Can anyone tell me what it means for a reaction to be in equilibrium?" (After some wait time, a student tells her that the rates are the same). "Right, the rates for both directions of the reaction are equal. Does this mean that the amounts of reactants and products are equal? What about the overall rate, does the reaction stop or keep going at equilibrium?"

In this example, Talia was employing her typical strategy of asking her students many questions as a means of engaging them with the lecture content. When a student responded with the correct answer to her first question, she still wanted to make sure that she addressed possible wrong answers that other students may have thought of because of misconceptions around the chemical equilibrium concept. She asks about two common misconceptions before moving on so that she can address and correct any incorrect ideas her students have. While these examples show GTAs addressing student misconceptions through questioning, it was also common to witness GTAs simply correcting students' incorrect ideas that produce misconceptions.

The content of pre-lab lectures among the laboratory GTAs contains a degree of personal preference but largely sticks to what the coordinator wants them to include as well as what the group decides is important during the weekly meeting. One way that GTAs demonstrate personal PCK is through the use of the whiteboard or other visual aids during class. The GTAs are required to use the whiteboard as part of their pre-lab lectures, at least to have it as a written resource for students to follow along with and reference back to during their class. I found two primary styles of board usage among the laboratory GTAs: as a teaching tool and as a reference guide.

Some of the GTAs interact with their board during their pre-lab lectures. At the start of class, their board will have empty spaces reserved for student or GTA contributions. For example, in the top row of photos in Figure 5.1, Talia includes spaces on her board layout to write down student responses to questions she asks, such as "What is the precipitating agent for this reaction?" a knowledge-testing question she asked during her experiment 4 lecture. In the bottom row of Figure 5.1, the different colored text shows parts of the board layout that Talia added to during her pre-lab lecture, such as the purpose for the experiment ("Determine equilibrium constant" on the far left) and her students' answers to her question about what factors impact equilibrium (the list of items in the green marker left of center in the image). Talia uses the board display as an interactive teaching tool, one that she (or her students, and she often does during peer review exercises) can add and contribute to. This is her way of making her lecture more engaging for her students, a key part of her PCK.

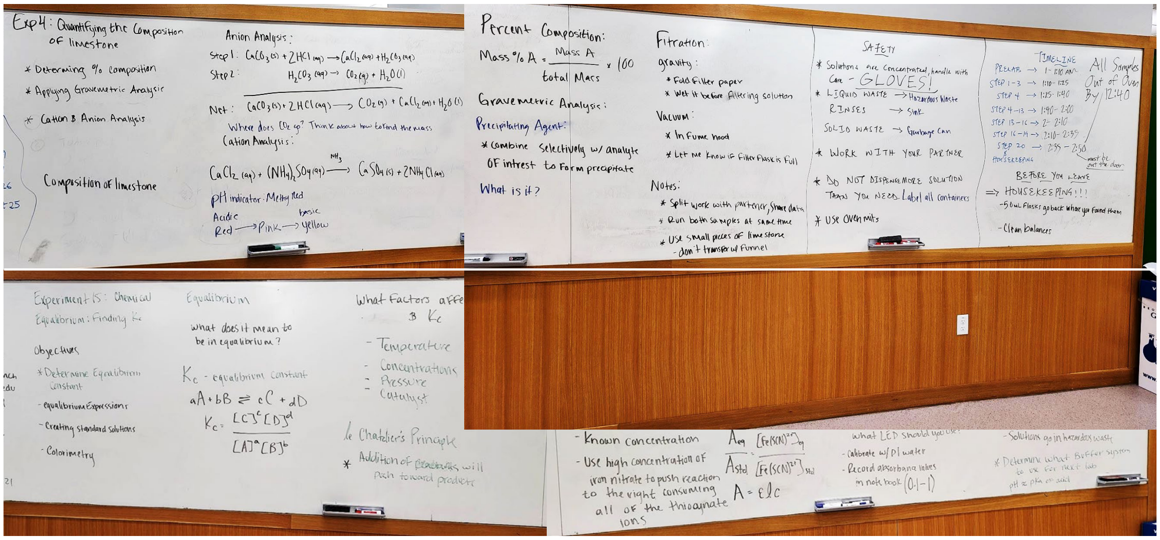


Figure 5.1 Two of Talia's boards from her for pre-lab lectures. Top: photos taken during experiment 4 in the fall. Bottom: photos taken during experiment 15 in the spring.

On the other hand, some laboratory GTAs will primarily use their board as a guide or reference, simply covering the information on it without adding to it during class. For example, half of Cristofer's board for experiment 4 is shown in Figure 5.2, and half of Augustus' board for experiment 9 is shown in Figure 5.3. In contrast to Talia's board, both Cristofer and Augustus are using the board display to deliver information and for students to reference back to during the class. In the previous discussion on questioning styles, I noted that Talia preferred to ask many questions of various types compared to Augustus and Cristofer, and this more engaged approach is reflected in how she uses the board. This tracks for other GTAs as well: Portia asks minimal questions and her boards were typically only used to convey information, while Louis constantly has his students contributing through question-response and writing on the board.

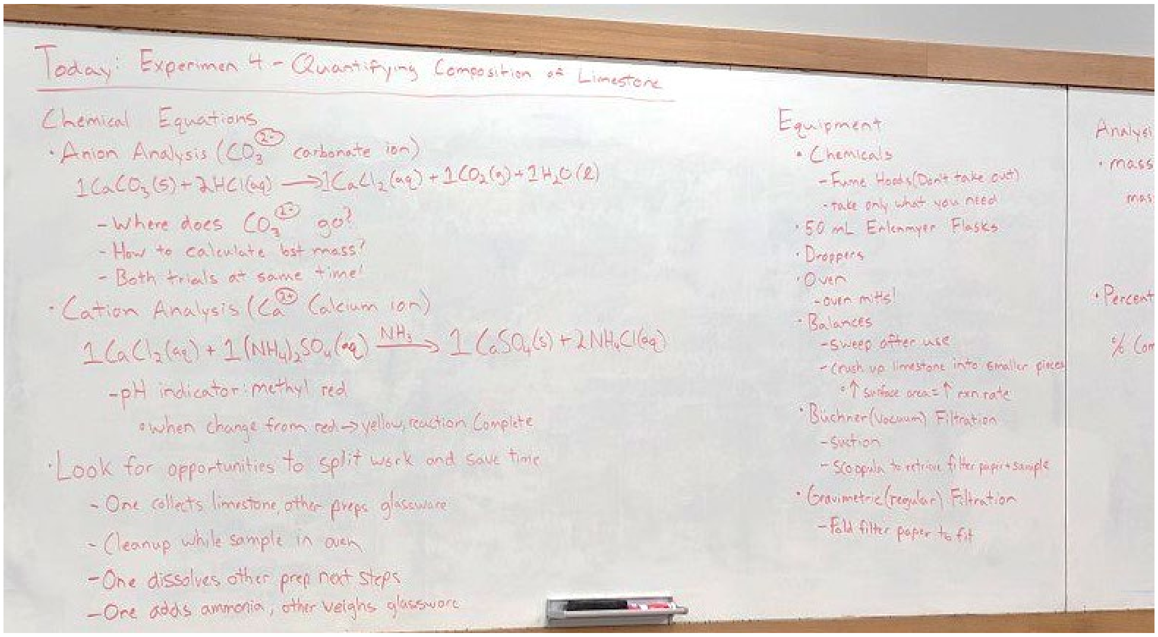


Figure 5.2 Photo of Cristofer's board from experiment 4 in the fall semester.

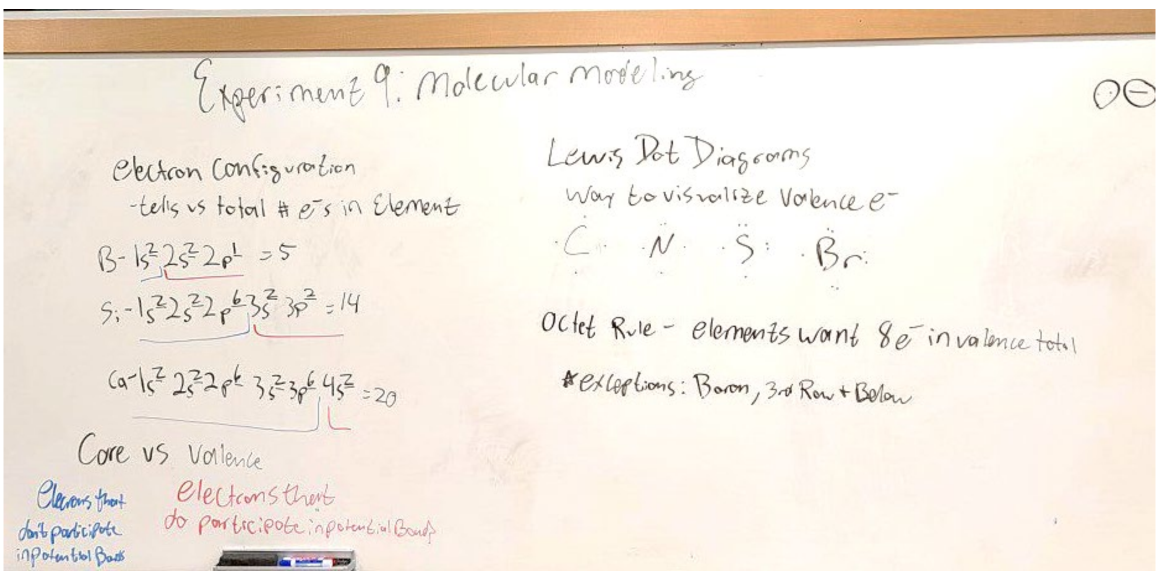


Figure 5.3 Photo of Augustus' board from experiment 9 in the spring semester.

As discussed so far, some laboratory GTAs primarily use the board as a guide or resource for their students to look back to during class. For example, Augustus defined the octet rule to help students with the work for experiment 9. For Augustus, referencing back to what he covered during the pre-lab lecture is one of the ways that he helps students during their experimental work. The remaining in-class responsibility for laboratory GTAs after the pre-lab lecture is to assist students with the experiment, making sure they complete all the steps and collect useable data for post-lab assignments, all while making sure students are working safely and efficiently. Bond-Robinson (2005) categorizes how GTAs help students in the chemistry laboratory according to the level of chemistry knowledge that is accessed and used. In her model, no chemistry content knowledge is drawn upon to provide simple procedural and technical help, and the depth of chemistry content knowledge included in a GTAs PCK when assisting students increases up to the ability to fully direct the laboratory learning environment to help students make connections between the theoretical and applied realms of chemistry learning. I found that not only does this system hold for my laboratory GTAs, but also that these GTAs tended to stick towards the lower levels of Bond-Robinson's scale. I often talked with GTAs about the way they prefer to help in class to understand how they might fit in this model. For example, this conversation with Portia shows why she prefers to stick to just helping students get through the procedure while in class:

> Walker: "What do you think about the idea of trying to engage with students and get them to talk to you about chemistry ideas while they are doing the lab? Would that help with improving their report writing?"
>
> Portia: "No. During the lab, they just want to get all the steps done and get out of there. There are some students that I can tell, like, they want to make sure they know everything, but when you're doing the experiment it's hard to focus on that stuff. I just make sure that they're doing all the steps correctly and they keep moving forward because after the lab if they don't have their data, they're screwed either way. They can come to the GCLC for help with the chemistry."

Portia's perspective and teaching behavior are influenced by her knowledge of her students. Her knowledge of students is that they will not make use of chemistry connections while focused on the experimental work, so she chooses not to use this approach. Bond-Robinson would consider this teaching behavior to not use any chemistry content knowledge, and therefore it would not be traditional PCK. However, I consider Portia's approach to be a carefully made decision for teaching chemistry laboratory and experimental knowledge, making it a version of topic-specific PCK.

In contrast to Portia's avoidance of chemistry concepts, some GTAs attempt to engage students in thinking about the applications of chemistry or how chemistry concepts they learn in lectures manifest in the laboratory. For example, in experiment 4, students determine the percent composition of calcium carbonate in a sample of limestone. During the procedure, students perform a reaction that releases carbon dioxide gas. This outcome often surprises students because they added acid to their sample, but after the reaction, the final mass is lower than at the start. When Augustus teaches this experiment, he uses this phenomenon as a chemistry teaching moment:

> "So, let's think about why you recorded less mass than what you started with. What all did you put in the flask?" (Student responds) "Right, your limestone sample and hydrochloric acid. When we look at this reaction on the board what do we see happens?" (Augustus gestures to the board where he wrote the chemical reaction between calcium carbonate and hydrochloric acid, which produces calcium chloride and carbon dioxide) "Look at the products, one of them is a gas. What happens to gas in an open container, where is it going to go?" (student responds) "Right, the gas leaves. So, if the gas is gone, can you measure its mass?"

Here, Augustus engages with a student to apply their knowledge of chemical reactions, as well as the properties and phases of matter to help them understand the chemical phenomenon they witnessed in the experiment. I found that GTAs may choose to engage students when helping during experimental work in either way and that sticking to one style is not set in stone. While Portia's comment about not focusing on chemistry when students are focused on completing steps makes it seem like she does not engage students with chemistry applications and apply her chemistry content knowledge, she does ask questions about the underlying chemistry when the experiment is not as chaotic. Additionally, she was teaching laboratory for the first time during the study, so she may develop PCK that focuses more on incorporating chemistry knowledge as she gains experience.

The final component of the GTAs' job that demonstrates an important component of PCK is how the GTAs engage with laboratory reports, both teaching students how to write them and grading them, including how they provide feedback. Experimental laboratory report writing is a crucial part of scientific communication, which itself is a major learning outcome of the laboratory courses at UK. Knowledge of report writing includes understanding how to construct and convey a scientific argument using a hypothesis or purpose, relevant background knowledge, reproducible methodology, summaries of key results and how they relate to the hypothesis or purpose, and concluding the entire argument concisely with proper conventions. The GTAs spend a large amount of both the orientation and weekly meeting time discussing what should be in laboratory reports and how students should write them. Overall, two areas of information are included when GTAs teach about report writing: the content of the report and the style. Take for example the following quotes from Augustus during various classes:

> "Peer review in this lab is to help you learn how to do science." (showing knowledge of the scientific process and the purpose of peer reviewing).

> "A good procedure is one that someone with very little scientific background can use well." (showing knowledge of effective procedure writing).

> “Explain the background so that someone with no knowledge can understand the experiment.” (showing knowledge of introductory writing).
>
> “Science is not communicated with ‘I’, ‘we’, and ‘us.’ However, the conclusion section is your opportunity to use first person if you find it useful for describing what you specifically learned from the experiment” (showing knowledge of field-specific writing conventions).

In the first quote, Augustus makes sure to explain to his students why we do peer review, an important part of the writing process not only in the laboratory class but in science as a whole. He finds it helpful to explain why we do reviews so that the students do not get the impression that reviewing others’ work is just another task to complete, but that peer feedback is useful and necessary for conducting good scientific work. In the second and third quotes, Augustus explains what to include in certain parts of the report, and how to write them effectively. He knows that to best teach this part of laboratory knowledge, he should explain what a reader will get out of reading a well-written report. In the final quote included here, Augustus discusses a writing convention that students must follow, but he does so in a way that is more engaging than simply stating “No first-person writing, it’s what professional scientists do.” All of these examples demonstrate PCK around laboratory report writing, a subset of broad laboratory PCK that these GTAs develop while teaching.

Regarding the content of reports, I often noticed GTAs’ directly telling their students what they should include in the introduction and discussion sections of their reports. For example, in one pre-lab lecture, I documented Hoda saying “Make sure you talk about these topics in your introduction” after covering the background component of her pre-lab lecture, and then “Include these results in your discussion, this is your most important data for the report,” (in this case, limiting reagent, percent yield, and purity test result for experiment 5) toward the end of her lecture. For GTAs, seeding this information in their lecture for their students may serve multiple purposes. It can help to guide students in the right direction, but it can also provide some relief for the GTA when the students write their reports outside of class, lightening the workload for the GTAs. Talia once told me during a chat in the GCLC that this latter reason helps her out on occasion:

> "Chem21 guides them to the key results, and if they would look in their lab manuals that would also tell them what the most important results are. But sometimes it's just easier to tell them what to include. I won't tell them how to interpret the results or how to present them, but I'll say 'Make sure to give me the average and the standard deviation in your discussion' or something like that so they have that direction. That way they aren't all coming to the GCLC or emailing me over and over asking what to include and what to leave out."

This sentiment was mirrored by all of the other laboratory GTAs in the study. Sometimes, it was simply easier to point students in the exact direction of what they needed rather than deal with trying to engage them in productive struggle.

When it comes to grading laboratory reports and students' writing, the GTAs use an in-depth rubric that covers the sections of the laboratory report, their content, and overall style. The GTAs receive regular training on how they should grade students' reports and also work together to determine how they will grade certain components (discussed more in the following section on the CoP).

5.2 The Laboratory GTA Community of Practice

5.2.1 Social Hierarchies and Fluctuations Among Laboratory GTAs

As mentioned previously, the community of practice is a social learning system, so its success and function depend greatly on the relations and interactions of its members, as well as their willingness to engage with each other around the shared practice. Again, the shared practice for the GTAs in the context of this study is the development of PCK, so the most important interactions of interest are when GTAs communicate, collaborate, and work together with a focus on their GTA duties. During orientation, it is made clear that newcomers should look to their experienced peers for advice, information, and assistance for all aspects of the job. The laboratory coordinator promotes these interactions often and will identify key members of the group that have been working in the role for a long time or perform well at a specific job responsibility. Typically, these members are those in the 'lead' role, whose job duties focus on providing support to both the coordinator and the instructional GTAs to facilitate the smooth operation of all of the laboratory sections. However, the coordinator is also known to offer up experienced GTAs as a source of information and reference for newcomers.

The presence of lead GTAs in the study helped me to better understand the laboratory CoP and the social systems that regulate it. In particular, lead GTAs have an overview of what happens in all of the classes that take place while they are working. As a result, talking to the lead GTAs gave me insight into the GTAs who were not in my study, as well as what was happening in other classes that I was not observing. Additionally, the GTAs often made it very clear which of their colleagues they do not like working with, and I do have data from both lead and instructional GTAs about others that are not in the study population. I am not going to include specific mentions of GTAs or events that could be tied to a GTA that did not consent to be the study in the following examples, but I will still use the data to present my understanding of the social dynamics at play in this CoP.

For a few weeks in the spring semester, there was a GTA outside of the study population who was causing problems for the coordinator and the lead GTAs. While one of the lead GTAs would tell me in detail everything that happened, I am going to limit the explanation of the circumstances that got this particular GTA in trouble. Rather, I will simply say that they were not following the expectations of the job in many areas. This caused the lead GTAs and the coordinator to have to spend extra time in this GTAs' class to ensure they were completing their job duties, and supplementing the GTAs' efforts (or lack thereof) when necessary to ensure that the class ran the way it was expected to. I was able to observe this happening a few times, as the GTA in question taught in the classroom adjacent to one of my study participants that I observed each week. As a result of lead GTAs and the coordinator being preoccupied with helping this problematic GTA, other GTAs' needs for assistance fell by the wayside. Since word travels fast in the group, thanks to the existence of lead GTAs and the GCLC, all of the GTAs knew why they were not able to get fast assistance when they needed it while teaching, and who was to blame. I observed the impact of this social stigma in the meetings: when that GTA would try and contribute to the shared practice the other GTAs would not pay attention, or would not take their contribution as valuable to the group and its efforts. I talked to Portia about this in the spring, and she had the following to say:

> "Well, why would I think that anything [GTA] has to say in meetings regarding how to teach is useful, when I can see how bad [they] do in class? I know my pre-labs are short but I always see [them] going 25, 30 minutes and afterward [their] students look confused and lost the entire class. And I've heard from students in the GCLC that [they] are a bad teacher and don't know what is going on. So, I'm not going think that [they] can actually give me any good advice."

The GTA had earned a bad reputation due to their in-class efforts, and as such they were unofficially expelled from participating in developing the shared practice with their colleagues. This was not the only example of the impact of a bad reputation among the laboratory GTAs, but it was the most extreme.

The GCLC was another context that played into GTAs' reputations within this group. To many of the laboratory GTAs, the GCLC is a rather annoying part of their job. On top of the time they spend in class and preparing for class, and the time they spend grading laboratory reports (maximum of 72 per experiment for 111 GTAs, and 48 per experiment for 113 GTAs), they additionally have to work three hours in the GCLC each week, during which they are often looked to for help not only by students but by the recitation GTAs since most students come to the GCLC for help with laboratory assignments (or at least, it feels this way to myself and the GTAs). When a laboratory GTA is known to not pull their weight in the GCLC, i.e. not show up to work, show up and leave early, show up and not help, or constantly defer to other GTAs, this makes the job harder for other GTAs. Word travels fast among the group when someone regularly does not perform their job duties and failing to fulfill GCLC obligations to the same level as everyone else quickly marks a GTA as unhelpful. In turn, this causes them to hold less authority within the group as a whole. (I did also observe this among the recitation GTAs, but it happened to a much smaller extent, with only one GTA in the fall semester earning a reputation regarding their GCLC performance).

One more important element of this group is the hierarchy created by the existence of separate GTA roles within the broad laboratory GTA group. The laboratory coordinator oversees all GTA activity, but she delegates the tasks of assisting and managing the class operation to the lead GTAs (and in part to the stockroom GTAs). The lead GTAs are responsible for making sure that the instructional GTAs are sufficiently supported so they can run their classes and teach effectively. If something goes wrong in a particular class, it is not only on the GTA assigned to teach that section to make sure it is rectified but also on the lead GTA to help and make sure that similar events are prevented in the future. In this sense, the instructional GTAs are at the bottom of this organizational hierarchy, followed by the lead GTAs and then the coordinator. The stockroom GTAs exist somewhere between lead and instructional GTAs in this system. They support all the GTAs by making sure equipment and materials are prepared before class and managing the delivery of additional supplies to classes. The instructional GTAs should listen to requests and warnings from the stockroom GTAs, especially regarding materials usage, but the stockroom GTAs do not hold any sense of power over the instructional GTAs, at least not during class time.

5.2.2 PCK Development in the Laboratory Community of Practice

Similar to the recitation GTAs, laboratory GTAs have weekly meetings that are intended to prepare them for the upcoming week of teaching. Laboratory meetings were Friday mornings in both semesters, with the larger group at 8 am and the smaller group at 9 am (in the fall, the larger group is CHE 111, in the spring it switches to CHE 113). Most meetings started with and focused solely on discussing what is important for the upcoming week's experiments unless there was a peer review conducted the next week. In those cases, the meeting would typically focus on more practice grading sample laboratory reports. Meetings are one of the most useful resources for the GTAs, as this is the setting in which they can ask questions to both their peers and the coordinator, get information for the following week, and learn new strategies for teaching the laboratory course. Meeting activities serve to advance specific parts of the GTAs' PCK, both personal and collective.

In addition to the weekly meetings, the laboratory GTAs also regularly interact with their colleagues during class. The lead GTAs regularly check in on each class and with each GTA, and the instructional GTAs contact the stockroom and lead GTAs for assistance during class. GTAs teach in multi-room suites, so even though they are supposed to stay with their students the entirety of class time, they can step into the other room to ask the other GTA a question, seek advice, or get assistance when the lead GTAs cannot quickly make it to their classroom. I observed this happen often, especially when unexpected events happened during the experiment. GTAs typically get to their classrooms 10-20 minutes early to start writing their board display, and I often observed laboratory GTAs looking at their room partner's board before class, either to compare the information or organization to their board layout.

In a community of practice, sharing information between members helps to advance others toward the same level of knowledge. To further one's standing in a community of practice and transition from newcomer to continuing member, individuals can ask other members for information about aspects of the shared practice. Teaching laboratory courses and performing all of the associated tasks is a complex job with many moving parts, so it is easy to understand that the volume of information relating to the shared practice is impossible to fully remember. This one feature of the laboratory GTA role requires that the GTAs ask for help and details when they need it, or they will not be able to do their job effectively and to the standard demanded of them. Requests for information typically happen between GTAs during class and can be as simple as "Do you know what value we should have students use for the pressure in the room?", which simply needs a factual response, or as complex as "Do you know why my students are seeing a yellow solution when it should be green?", which accesses more chemistry knowledge.

Given that I was present in every GTA meeting and thus knew what was happening in every class, as well as attending all the classes so I experienced the specific events of every course each week, I quickly became a reference for information. I had interactions with every GTA in the study, and even many of those outside of the study, involving a request for information, whether it be related to their specific class and current content of focus, or another class so they can know what is happening in the other courses concurrently. This second purpose I found common among the laboratory GTAs, as they rarely had an idea of what was going on in the lecture courses, but wanted to try and connect their pre-lab lectures to what students were learning in their other classes.

The GCLC was a common scene for observing requestions for information between laboratory GTAs. The GTAs only cover the experiments for their course during orientation and meetings, so like the recitation GTAs, they must often seek out help from the GTAs in the other course (111 vs 113) to best help students in the GCLC. On occasion, they must also reach out to recitation GTAs for help, particularly when it comes to topics that are not touched on in the laboratory course at all, such as the quantum mechanics material in general chemistry I. Because the chemistry laboratory course represents an application of specific chemistry concepts, it cannot cover every topic that the lecture does. As such, the laboratory GTAs develop topic-specific PCK for more in-depth applications and knowledge than what would be seen in recitation. The laboratory GTAs focus on making sure they know this specialized content, sometimes at the loss of the broader content. I know this first-hand because the first time that I was asked by a laboratory GTA to assist in the GCLC was because she had no idea how to help with quantum mechanics questions that a 110 student brought to the GCLC.

Requests for information and asking questions of peers may sometimes be motivated by attempting to solve a problem. For example, the following interaction between Hoda and Talia in the fall when they taught experiment 7, which is the first time they have to teach students how to use MeasureNet, a laboratory instrument.

> Hoda: "Hey, Talia, can you come here when you have a moment and help me with something? The MeasureNet is being weird and I don't know how to fix it."
>
> Talia: "Oh this is weird. What happened?"
>
> Hoda: "I don't know, the student tried to save their data but then it just vanished from the screen and I don't have it on the laptop."
>
> Talia: "Is it possible that the student didn't hit the buttons correctly? I think they always do 'start/stop' then the file options button and save if they want it to go to the computer for you to look at."
>
> Hoda: "Maybe try pressing the display button. That should show the graph again, right?"

In this example, Hoda went to Talia for her experience and advice, but when it was a problem that Talia didn't immediately know the answer to, she and Hoda worked together to find a solution. Problem solving is one of the most common ways that I found the laboratory GTAs engage with each other during class, especially with the pressure to make sure that their students not only complete the experiment on time by the end of class but also have useful and sufficient data to complete their post-lab work. Most of these requests for help to solve some issue involved MeasureNet, as the GTAs only receive enough training with the system to get it running for their class and use it to view students' data, and learning how to troubleshoot mishaps and errors is left to learning on the job and during class. However, occasionally the GTAs would need to tackle unexpected chemistry phenomena in the laboratory:

Given my sustained presence in general chemistry settings and work with the GTAs, I eventually became part of the CoP, at least in the sense that I have knowledge about the role and the practice, and I can interact with the GTAs to develop shared knowledge of the practice. In class, this also meant that I was sometimes a resource for the GTAs. All of the laboratory GTAs that I observed teach asked me for help with some kind of problem during their time in the study. Whether it was a MeasureNet problem, an issue with equipment, or an unexpected chemistry phenomenon, I was sought after for help with certain problems in the laboratory. For some problems, I was able to provide information the GTA missed or had forgotten, and this solved the issue. Other times, however, actual problem solving took place, such as when Portia could not figure out how to instruct her students to perform an experimental step differently to generate better data. During experiment 7 in the spring semester, I had a conversation with Augustus about his student's performance during the experiment. He was lamenting to me that something seemed off with this group, and that compared to the past they were having a harder time understanding why and how MeasureNet is used to collect data. They also were confused about the instrument calibration and its role in the overall procedure. We talked more, and I suggested that perhaps there is an issue with understanding what the MeasureNet actually is, in the sense that to the students it's a new tool but it doesn't look like anything else they have ever used. Later in the week, I observed a change in his pre-lab lecture:

> "Sometimes, we want more information, more accurately. We use an instrument, in this case, the MeasureNet, to see a numerical change. Now, does anyone

> remember why we need to calibrate the instrument?" (He waits, but the students don't answer) "The instrument already has an idea of what pH is, but we don't know if it will read that correctly. We need to make sure that the computer reads accurately, so we tell it what it should think different standards are supposed to be."

Augustus and I collaborated to problem solve around the students' interaction with the laboratory content they were learning and how he was teaching it. When I engaged with problem solving with a GTA, both of us left the interaction with more knowledge of the context: I took away information about the participants for research and the GTA left with a new development to their PCK.

With so many moving parts and over 1000 undergraduates enrolled each semester, the laboratory courses are dependent on consistency among the GTAs to run efficiently. The coordinator stresses in orientation and every meeting that the GTAs should be teaching things similarly, using common explanations, representations, and strategies to those seen in their lectures to help students make connections between the separate contexts. From my perspective, ensuring consistency among what is included in pre-lab lectures is not a major concern of any of the GTAs. The GTAs have access to the same lab manual the students use, which includes background information, procedural information, materials lists, steps for using laboratory equipment, and post-lab data analysis questions. I found that almost all of the GTAs will use the lab manual as the basis for their pre-lab lecture, and might change an example or the way a definition is phrased at the most. On the other hand, consistency in grading is extremely important, enforced not only by the coordinator but also by the GTAs themselves.

Grading practice is a reoccurring activity for the laboratory GTAs. In one sense, they need to practice to become familiar with the rubrics used, otherwise, grading can take twice as long as it typically does. In another sense, the GTAs must practice grading together so that they can all grade similar levels of student work in the same way, with some room for a minimal margin of difference. Practicing grading is one of the ways that the laboratory GTAs develop their PCK, and it can impact how GTAs approach discussing report writing with their students in addition to their grading and feedback practices. Grading practice involves GTAs reading a sample laboratory report (taken from student work from a previous semester with student information redacted), assigning a grade as they typically would using the rubric, and then comparing everyone's assigned scores. The group then discusses major discrepancies to try and agree on how each part should be scored. Sometimes, these discussions turn into debates about the correct way to grade something and what it means to assign a certain grade. For example, during one spring 113 meeting, there was a debate over how to grade a student's conclusion that does not explicitly state what the student learned but did include other parts of what is required in this section. Louis, one of the most experienced GTAs in the room, wanted to follow the wording of what is included in the rubric (shown in Figure 5.4) since this is what the students are given to follow. This would protect the GTAs from any argument about how they determined the score for that part of the rubric. Other GTAs wanted to be more lenient and award the students more points for including connections to real-life situations and other chemistry concepts. In the end, Louis won out with the support of other experienced GTAs and an appeal to the coordinator by pointing out that GTAs are supposed to follow the rubric, no matter how much they want to try and award points on technicality or effort.

Conclusion – Conclusion convincingly	**3 pts**	**2 pts**	**1 pts**	**0.5 pts**	**0 pts**
	Specifically states what has been learned	Clearly states	States what has been	Poor attempt	Does not describe

describes what has been learned in the lab	and how it relates to other concepts or topics and/or real-life situations. Possibly gives realistic suggestions for improving the experiment.	what has been learned.	learned statement is vague.	to state what has been learned	what has been learned.

Figure 5.4 Part of the laboratory report grading rubric used for CHE 113.

With such a focus on consistency among the laboratory GTAs regarding their teaching work and interactions with students, it is no surprise that the GTAs would seek to share and reuse certain strategies and resources, especially if another GTA speaks of their usefulness or the laboratory coordinator provides her endorsement. Among the laboratory GTAs, many different kinds of these assets were reused. For example, I noticed that Cristofer, Talia, and Hoda all used the same exact example problems during their pre-lab lectures, but they were different examples than those used during the meeting or shown in the lab manual. I first documented and asked about this reuse during the week of experiment 5 in the fall. I first the example problem in Talia's Monday class, shown in Figure 5.5, but then I saw it again in Cristofer's Thursday morning class, during which I asked him about the reuse of Talia's problem:

> Walker: "That was a good pre-lab. That example problem you went over seemed really familiar."
>
> Cristofer: "Yeah, actually Talia came up with it."

Cristofer revealed where the problem came from, so later that day I asked Talia about the reuse:

> Walker: "Cristofer told me you came up with this example problem that you're both using, what's the story there?"
>
> Talia: "Oh yeah (laughing). Cristofer, Hoda, and I get together on the weekend to prepare for teaching each week. We go over the important concepts for the

labs and help each other understand the parts and we'll plan our pre-labs together. We decided we wanted to do a practice limiting reagent problem so I came up with this one."

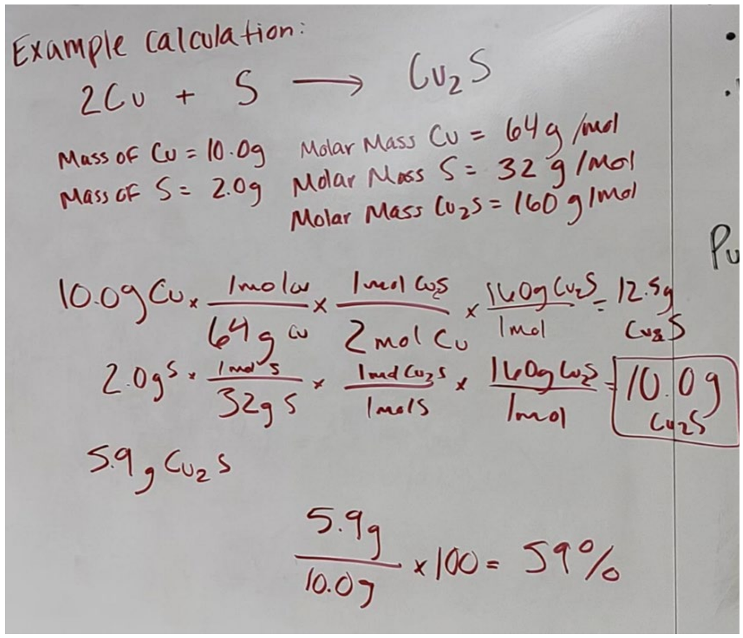


Figure 5.5 Talia's example problem from her pre-lab for experiment 5 (CHE 111), which was also used by Hoda, Cristofer, and another first-year GTA who was not a study participant.

By reusing Talia's problem, Cristofer brings it into his PCK. The reuse also happened to go the other direction in this case. Early in that week, Talia had a drawing of a chemical reaction all drawn in a single color, while Hoda and Cristofer both had theirs color-coded to highlight the specific structures in the drawing they wanted students to focus on. When I attended Talia's Thursday class, she added colors to her version of the drawings. In this case, she reused the others' use of color in their representation and brought this into her PCK.

By visiting others in the community of practice, members can witness their colleagues engaging with the practice, then use these experiences to develop in the practice themselves. For the laboratory GTAs, visits to other GTAs' classes are encouraged by the supervisor so they can see how their peers teach particular topics. Visits are sometimes required for the new GTAs so they can observe how an experienced teaches before they do it themselves. I observed visits happen fairly often, particularly among the international and out-of-department GTAs. Take for example this comment I captured from Hoda, explaining her plans to visit a GTA to observe their teaching.

> Hoda: "I'm feeling really nervous about teaching the experiment this week, so I'm going to go hang out in [GTA's] lab to see what they do."

Visits can also yield benefits to the GTA being observed, as in what Talia shared during the final meeting of the year regarding my visits to observe her teaching. While I was there as an observing researcher, and not as an observing GTA, a GTA could exist in the space in the same way that I did, and vice versa. Either way, someone is there to observe who knows the setting. Talia appreciates the presence of someone else that knows the inner workings of her position:

> Talia: "It's nice to have someone in the room sometimes that also knows what's going on and how things are supposed to go. I can ask questions, or they can help. Sometimes it's just nice to have the presence of someone else that knows my side of the lab, the teaching part."

Other GTAs also shared that they gained from my presence as a participating and knowledgeable observer, stating that not only was it helpful to have someone more present than the lead GTAs with both chemistry and laboratory knowledge, but also someone there with whom they could discuss their teaching.

While this behavior was encouraged by the supervisor, I would like to highlight that it shows an interesting aspect of the social hierarchy that modulates how these GTAs interact with each other within their community of practice. When a laboratory GTA attends another GTA's class to observe, they get to choose whose class they attend. Their choice reveals not only who they perceive to be an effective GTA, but also who they may perceive as the easiest to learn from. This decision could also be based on convenience, but I found in most cases that GTAs had other reasons for choosing to observe specific GTAs. For example, Portia only chose to observe Augustus, partially out of convenience but also because she did not want to observe anyone else.

> Portia: "Yeah, I've been watching Augustus teach his section since it's right before mine so that I can see what he does and how I could teach the lab better, especially since he's been doing it for so long. I also don't really know any of the other 111 GTAs that well so I just go to his."

Portia also demonstrated a high degree of asset reuse from Augustus' board displays, which she obtained from visiting his classes. When I would observe Augustus' classes on Monday, followed by Portia on Tuesday, I could easily identify reused parts of the pre-lab lectures: similar illustrations, definitions, board layouts, and flow.

The final activity that I documented laboratory GTAs regularly engaging in to develop PCK together is the mapping of knowledge. Previously, I mentioned that Talia, Cristofer, and Hoda work together outside of work time to help each other prepare for teaching each upcoming week. When they worked together in these instances, they would determine what they already knew about the experiment and the chemistry topic, as well as how to teach it. In this process, they map the collective knowledge of their shared practice, then use this mapping to identify gaps they need to work together to fill. The GTAs also engage in this practice regularly during the weekly meetings. Many of the discussions about teaching experiments revolve around the GTAs constructing an inventory of what they know about the experiment, its underlying and background chemistry concepts and theory, the procedures, safety, material handling, and how to teach that specific experiment. I will say that this mapping exercise often revealed significant gaps in the collective content knowledge of the laboratory GTAs, such as when the coordinator tasked the 113 GTA group to collaboratively construct a concept map of experiment 12, and there were only three cells in the first version of the map that actually contained chemistry concepts. Even in version two (which was guided by the coordinator), the group struggled to include and connect the important chemistry theory behind the experiment to what was being performed in class by the students. In this instance, the GTAs literally mapped their knowledge to identify and fill the gaps, but even without the visual aid of a drawn concept map they still regularly engage in this activity.

5.3 Chapter Summary

This chapter covers the general chemistry laboratory GTAs at UK, characterizing their PCK and aspects of how they interact as a community of practice to develop their PCK. I explored how their orientation and training establish many of the hallmarks of their PCK for teaching the laboratory courses, such as how they solicit student questions, deliver lectures, grade student work, and engage students in doing science. In doing so, I seek to answer research question 1, which asks about the characteristics of recitation and laboratory GTA PCK.

The laboratory GTAs interact with their colleagues in varied ways and do so often. In regular meetings they map out their shared knowledge to identify gaps and help each other to figure out how to teach the following week's experiments, contributing as a group to collective and personal PCK. They seek information from each other and regularly ask for advice, as well as seek out their peers to engage in problem-solving.

Visits among GTAs to each other's classes are common, which help them gain new resources for their own teaching and reuse each other's teaching strategies and resources they find useful or effective. However, this group is very susceptible to letting social standings influence who they interact with or who they consider a valuable colleague when it comes to helping with teaching. If a GTA is marked as difficult, or one that does not pull their weight in the role, then they will have a difficult time interacting with this community.

CHAPTER 6. RESEARCH CONCLUSIONS

In the previous two chapters, I presented findings for the two general chemistry GTA roles as two separate cases of community-based PCK development. The GTAs develop PCK as a result of their roles and the interactions they have with their colleagues within their roles. As mentioned in Chapter 3, the research design facilitates not only the analysis of each case separately, but also the comparison and contrast of the two cases. In this concluding chapter, I lay out the significant similarities and differences between the two roles and their PCK development from the previous chapters. Then, I revisit the CDPCK framework assembled in Chapter 2 to assess its effectiveness in capturing how these GTAs develop PCK as a community and learn from each other to advance their teaching practices. I discuss the impact work has on similar research areas, limitations of the study, avenues for future research, and finally the implications this work has for the practice of training GTAs, both in this specific context and broadly, as much as I can claim given the research design. As a reminder, the research questions of the study are:

1. What are the characteristics of the general chemistry recitation and laboratory GTAs' pedagogical content knowledge (PCK)?
2. How do recitation and laboratory GTAs interact with their communities of practice to develop their PCK?

6.1 Two Cases of PCK Development Among GTAs

The recitation and laboratory GTAs develop some similar traits to both their collective PCK and their role-based communities of practice. Addressing misconceptions is important to both groups and is a concrete aspect of how they approach teaching chemistry. Both roles watch out for how their students make mistakes in their work and then move to correct them, as well as try to provide instruction to prevent future misconceptions. It does seem that the laboratory GTAs are less prepared to approach to engage in this behavior, given the wide variety of content knowledge shown in the meetings, but they do seek to prevent misconception and misinformation nonetheless.

While laboratory GTAs often engage in visits to each other's classes to learn, the recitation GTAs do not attend their colleague's classes to advance their teaching practice and engage in communal PCK development. This is not to say that recitation GTAs never attend each other's classes, but whenever I observed this behavior among the recitation group, there was no such intention behind the decision to attend. I believe that this also explains why it was less common to see asset reuse among the recitation GTAs: they do not see each other in action and therefore do not experience each other's teaching strategies except for during the short demonstrations in the GTA meetings. When you visit a laboratory class, you witness the GTAs lecturing, including how they ask questions and their content, how they organize their board display, what examples they use, and how they explain chemistry to help their students during experimental work. In comparison, attending a recitation class you get to see mostly the same delivery of the worksheet discussion, followed by some interactions between GTA and students, in which you might be able to glean a new way to explain a concept.

Socially, the recitation CoP is more stable than the laboratory CoP. This is likely due to the smaller size of the recitation group, but also due to the fewer regular interactions among its members. Recall that laboratory GTAs are in orientation sessions for longer, their meetings are filled with more content, and they interact with each other while teaching, be it between two instructional GTAs or with a lead GTA. The lower number of interactions or even just the lower stress of a simpler role may make it easier to interact with colleagues. It could also be the case that the lack of international and out-of-department GTAs, especially compared to the laboratory group, makes for easier introductions and interactions among the recitation GTAs.

The recitation GTAs often make connections between concepts and topics to assist with their teaching, both during the worksheet discussion and when they are helping students with worksheet problems in class. While I observed laboratory GTAs do this as well, it was not nearly as common or as effective as when the recitation GTAs did it. While GTAs like Augustus and Louis could make connections to other chemistry concepts, future chemistry courses, and even other scientific disciplines during their pre-lab lectures, GTAs such as Hoda and Talia struggled to get their students to recall information from their lectures to use in class.

During my time with this group of GTAs, two recitation GTAs transferred to the laboratory from the fall to the spring. Conveniently, one each went to the separate courses: Portia to 111 and Patrick to 113. These GTAs were often able to apply their recitation PCK to help them teach the lab. Patrick found it easy to engage with students and get them to participate in his pre-lab lectures, as well as instruct them during their experimental work (although he did have prior experience in the labs, and two years of prior GTA experience in total). Portia was able to make connections to lecture content for her 111 students due to her knowledge of not only the flow of the material in the lecture course but also knowing what kind of problems and applications they see on homework and exams. It is not common for GTAs to transition back in the other direction, and that did not happen during my time with the group, so I cannot speak on the practicality of applying laboratory PCK to teaching recitation.

The major differences between the recitation GTAs' and laboratory GTAs' communities of practice largely are related directly to the structure of their jobs. Recitation GTAs have less complex work when compared to laboratory GTAs, and this is reflected in how they interact with each other to develop their PCK. The recitation GTAs do not face significant challenges in their role: in class they are only responsible for leading a short discussion and answering students' questions, they grade only one problem on each worksheet for accuracy, and they attend meetings in which they practice what to present in discussions, so they do not do much planning for class each week. A recitation GTA could complete their GTA work in any one week in under 12 hours of total work. The laboratory GTAs, on the other hand, are constantly pushing the 20 hours maximum for their position with the university. This discrepancy is known among the GTAs, and it almost seems that learning about this difference is part of the GTA initiation process. Take for example the interaction between first-years Hoda and Clark, who are laboratory and recitation GTAs respectively.

Hoda: "Wait, are you working on grading right now?"

Clark: "Yeah, it doesn't take long so while the GCLC is empty I figured I'd get it done."

Hoda: "What do you have to do for grading?"

Clark: "Oh, we just pull up the student's worksheet and follow this rubric."

Hoda: "Oh hey we use rubrics for the lab reports! Can I see the rubric? I wanna see what all it has."

Clark: "Sure, here."

Hoda: "Wait, this is it? What do you even have to do here?"

Clark: "We check for their info, then see if they completed the whole worksheet, and then we grade one of the problems for if they did it correctly."

Hoda: "Wow. Really? Man you should see what we have to do for lab the report rubric is so much longer and detailed. And it takes so long to grade the reports. That's so not fair we have to do so much more than you guys."

6.2 Revisiting the CDPCK Model

Regarding the CDPCK model that I presented in Chapter 2 as a new framework for understanding how PCK can develop within a community of educators, I think that it better models the interactions and developments of the laboratory group compared to the recitation group. The model was assembled to help understand how collective, personal, and enacted PCK all change due to the interactions between educator peers, in the case of this particular study, general chemistry GTAs. Using the communities of practice framework provided a lens through which to view interactions between GTAs in which they exchange information about their personal PCK and the collective group PCK. By combining these frameworks, we can understand more about how a group makes its shared PCK, or knowledge for teaching specific content and domains, and helps it evolve through member engagement.

For the site, setting, and participants of this study, the CDPCK model works better for understanding how the laboratory GTAs interact to develop PCK together than it does for the recitation GTAs. The laboratory GTAs engage much more frequently and in deeper ways with each other around the shared practice than the recitation GTAs do. In part, this is because of the activities that the laboratory coordinator has the GTAs participate in. She encourages regular interactions between members, specifically newcomers and their experienced peers. She has members of the group share their experiences and knowledge in group settings so that everyone can learn from, and advance their knowledge together as a community. The laboratory role's complexity also encourages interactions among the GTAs to work together and get better at their teaching, and develop their PCK further.

The recitation GTAs can be understood with this model, but based on what I found they better fit the part of the model not focused on in this particular study and its research questions. In the refined consensus model, collective PCK is applied through individual context into personal PCK, and personal PCK is applied through the context of a specific lesson or class into enacted PCK. The authors of the refined consensus model and other researchers that engage with it also believe that PCK can transfer the other direction, from enacted to personal, then personal to collective. Movement in this direction likely involves reflective practices, which I think all of the GTAs in this study engage in, but the recitation GTAs utilize more often than they do interactions with their peers to develop their PCK. In the current system, the recitation GTAs are not as encouraged to interact with their colleagues to perform their role-based duties well, and there is also minimal motivation to do so due to the simplicity of their job responsibilities.

Regarding the entire group of GTAs, this model does sufficiently help to understand the phenomenon of communal PCK development. This is seen in how the GTAs interact both within and between their roles in the GCLC. As I mentioned throughout both Chapters 4 and 5, the GTAs rely on each other in the GCLC to help each other help all students in the GCLC. This requires the GTAs to interact with their peers, again both those in the same role and those in the other role, to gain information and resources relating to their job, which in this moment s assisting students in learning chemistry in the GCLC. Together, they amass a collective PCK for instruction in the GCLC, which they draw from to influence their personal style of helping students and apply to helping students with specific problems. They have to work with others to access the collective PCK, thus making them active members of the larger, all-GTA-encompassing community of practice.

6.3 Impact on Research Areas

The impact of this research on the field manifests in two ways: the development of a new framework design to model how PCK is developed within a community of interacting teachers (specifically GTAs), and the completion of an ethnographic analysis of GTAs. Regarding PCK frameworks and models, the refined consensus model that this new framework is based on was the closest to a framework for social learning of teaching practices in the field had come. The refined consensus model as described by Carlson et al. (2019) and Rodriguez and Towns (2019) connected the different realms of PCK: enacted, personal, and collective. The framing of these realms focuses on how context creates these levels, with the context of a specific teaching role funneling collective PCK into personal PCK, and the context of specific lessons, groups of students, and learning environments producing enacted PCK from personal PCK. Carlson and coworkers initially conceived the collective PCK as the shared research-backed (or those provided in teacher education) practices among all teachers, but by instead placing the collective PCK as the shared practices among any group of educators, we can study the movement for their teaching practices within their specific group.

The other major impact of this work is the contribution to the literature on GTA experiences. Compared to the work conducted involving K-12 teachers and even post-secondary faculty, the volume of research focusing on graduate instructors is much smaller. This work documents an in-depth description of the GTA experience by taking an immersive approach, one that was not seen in the literature on GTAs, even with recent qualitative explorations focused on specifically chemistry GTAs. In addition to providing more information to researchers about the GTA experience and how it relates to their teaching, this work also showed that the context of the GTAs' role greatly impacts their teaching. Specifically, the conclusion that GTAs' change in cPCK over time is greatly impacted by what is asked of them in their job. Research into the teaching practices of GTAs, as well as how GTAs learn to teach, is growing steadily and this study provides an ethnographic account of one group that can be used as a starting point for other studies focused on GTAs.

6.4 Study Limitations

This study focuses only on one cohort of GTAs in a single level of courses in a single discipline at one university. Therefore, generalizability is not easily achieved for specific assertions that relate to the unique qualities of this group, the context of their roles, and their individual characteristics. However, the developed assertions are possibly applicable to other similar groups of GTAs, and perhaps even other contexts of educators, such as peer tutors. In addition, I was not able to observe the teaching practices of every member of the group, which can make claims about group behavior weaker. The primary reason for this limitation is connected directly to the research design: pursuing the desired level of immersion means that only a small number of individuals can be thoroughly understood through the associated research methods.

In addition to general group claims, I also was not able to fully explore the major differences in experience based on language, gender, race, and ethnicity. Other research already shows that when an instructor is female, speaks the dominant language as a secondary or auxiliary language, speaks with an accent, is a racial or ethnic minority, or any intersection of these characteristics and identities, they are discriminated against in academic settings by students and their colleagues. Of my total study participants, only two were international GTAs, and one of them had completed their undergraduate education in the U.S. However, international graduate students make up a large part of this group of GTAs, particularly the laboratory GTAs. Therefore my study conclusions may be missing some modulating effect based on domestic or international GTA status. I know from my experience in the study that international GTAs and domestic GTAs are treated differently by the undergraduates, and I heard from various GTAs and graduate students in the department that the domestic GTAs believe that are passed over for recitation roles because of their international status. There is a basis for a need to investigate this impact further, but this study simply did not achieve it, nor was it specifically interested in it. I did achieve fairly representational demographics regarding the gender of participants compared to the breakdown of the overall group, but I did not obtain sufficient enough data on the experience of being a specific gender within the focus of this study. Therefore, no claims could be made about how gender impacts the teaching practice development of these GTAs.

6.5 Future Work

In this study, I did not aim to categorize any particular teaching approaches or decisions made by the GTAs as good or bad. The focus of the research was on how the GTAs develop in their teaching practice both individually and within their cohort of peers. While I collected information on what practices were deemed useful by supervisors and among the GTAs, discerning their actual effectiveness and how this relates to developing teaching practices was not explored. Therefore, a future extension of this work with this specific group could involve also researching the undergraduate perspective on the changes that GTAs make as they develop their teaching practice. Understanding how the students perceive teaching approaches yields another perspective on the scene, one that would serve to further validate the ways that GTAs reflect on their instructional practices.

While this study explores the group of GTAs as a community of practice, it only focuses on the GTAs. There is no inclusion of the undergraduate students and how they interact with GTAs or perceive their GTAs' teaching ability. I discussed the expectations for GTAs that the recitation and laboratory coordinators hold, but I also did not include any of their perspectives in the study. Both of the groups are crucial to understanding the entire GTA experience, but the community of practice is additionally impacted by the coordinators. In an analysis of the structure of a CoP, the coordinator represents a leader role: they are responsible for organizing the members in the CoP and the activities they engage in to develop their knowledge and experience in the shared practice. Future work in this realm, especially focusing on PCK development, should include the influence that these supervisors/coordinators have on the CoP and its members.

Another avenue of research that can be explored specifically with GTAs and designed around the CDPCK framework is that of the motivation behind changes made to personal PCK. I debated frequently with myself about whether the central shared practice for these GTAs is truly PCK development or if it is the practice of being a GTA. It may seem like there is not much difference, but when we consider motivation a separation appears. PCK development and refinement could be said to be motivated by the desire to improve one's teaching for either the sake of becoming a better educator or for the benefit of one's students. However, for GTAs, especially in rigorous graduate programs that are influenced by the working norms of academia and competitive scientific research, teaching is not their priority. It follows then that improving one's teaching may not be a shared motivation. For example, these two utterances about the same behavior show different motivations for the same action.

> Fiona: "I noticed that I kept getting the same question over and over again, so I decided to just cover the topic early and ask my class about their confusion to see if that helps them out."
>
> Bianca: "I had to answer the same question for almost every student so I just decided to give the answer to the question to the whole class at the start so they wouldn't have to ask me individually over and over again."

Fiona had a more student-focused response to the behavior I asked about, while Bianca appears to be motivated by a desire to make her experience easier. This difference in motivation may extend to other aspects of PCK and how it develops over time, especially when we consider the changing obligations of these GTAs through their time as educators.

Lastly, the CDPCK framework joins a social learning model with a PCK model. In theory, this framework could be used to track how specific examples of PCK, such as a specific representation or example, move throughout a community of educators. A social network analysis could improve this application of the framework, allowing for a researcher to understand the underlying network of social relationships that mediate the transfer of knowledge within the CoP. I discussed how reputation based on how well a GTA does their job impacts their ability to participate in the CoP, but having a more in-depth understanding of the relationships within the group can better explore the development of this phenomenon over time.

6.6 Implications for Practice

Motivating this study was not only a desire to explore the teaching developments of a community that I used to be a part of, but also a goal to use the collected data and the assertions produced to find ways to improve the GTA experience for the benefit of GTAs, undergraduate students, and the chemistry department. The research succeeded in constructing an in-depth understanding of how these individuals engage in their teaching practices, learn from their experiences, and learn from each other. It also found that there are large influences from social elements and the structure of the roles themselves. This information can be brought into discussions about the academic experience these GTAs have, and what part this time as a GTA plays in each student's graduate school career. The specific approach to studying these GTAs also revealed that GTAs continue to engage in developing their teaching practices outside of their explicit training experiences. They continue to learn while actively performing their teaching roles, and they can identify what they learn when prompted to think about their teaching practices.

Understanding how the CDPCK model manifests in these educators' teaching practices helps us to better develop training methods and activities to regularly engage the GTAs in situated teaching practice development. Supervisors can utilize the different activities to help their GTAs build their teaching practices both individually and together. Providing space, time, and the methods by which GTAs can reflect on their teaching and then extract useful information from this reflection can better help GTAs understand how they change their teaching over time. In turn, this can then help GTAs learn how to recognize what they deem effective teaching, and how this aligns with what is expected of them. Encouraging experienced GTAs to regularly share their knowledge and experiences will help newcomers learn how they could engage with teaching in different ways, and encouraging newcomers to share their new experiences more easily allows them to become contributing members of the community of practice.

A direct suggestion I have for the UK general chemistry department upon completing this research is to find ways to better promote interaction between all of the GTAs, both within their role and between their roles. I saw and documented that interactions drive PCK growth in the GCLC as well as in the laboratory courses. However, during orientation, the GTAs are mostly segregated based on their role. Including some way to have the GTAs properly meet and get to know each other will help to facilitate future interactions. The only time that any of the GTAs could have had this opportunity during orientation was in the session on instruction in the GCLC, but during this academic year, this session was minimal, and mostly led by the GCLC coordinator without much GTA participation. Additionally, the coordinators and the general chemistry faculty may want to regularly meet to provide information to the GTAs about what occurs in the lecture courses each week. In my coding process, I organized my data based on the PCK knowledge bases (content knowledge, curricular knowledge, pedagogical knowledge, etc.) and I found that the GTAs as a whole had minimal knowledge of what is happening in the lecture course and the other GTA classes at any point in the semester.

APPENDIX: INTERVIEW GUIDE

Interview items were adapted from Loughran et al., 2004; Luft & Roehrig, 2007; and Mavhunga, 2016.

If the interview is the participant's first interview as part of the study, include the following questions:

What are your plans for after graduate school?
Tell me a little about your previous education. (What/where/when?)
Tell me about your undergraduate chemistry courses – what were they like?
What did you (or didn't you) enjoy most about these courses?
What features of these classes helped you learn (or inhibited your learning)?
What were your interactions with instructors/faculty like in these courses?
What were your interactions with your peers like in these classes?
What are some ways that these courses/your experience as a student influence how you will teach chemistry?
Do you have any prior teaching experience before UK?

(if yes) What was your teaching experience like?
(if yes) Did you have any training for this teaching?
(if yes) What was the training like?

Tell me about the lesson you created for the UK microteaching (initial)

Beginning of Semester Semi-Structured Interview Guide:

Tell me about your expectations for teaching this semester.
What are some concerns you have about teaching this semester?
What are some characteristics of a good class session?
How do you expect your interactions with students to go this semester? (in class? During office hours?)
What was the most useful thing you did or learned during the departmental GTA orientation and training?
While you are teaching, what are your goals?
How do you accomplish these?
How do your goals for teaching compare with the broader course and instructor goals?
How do you know when your students understand the material?
When you have a student really struggling to understand a concept, how do you respond?
How do you decide when to move to a new topic?

CoRe Exercise (The following items are adapted from Loughran et al., 2004 and Mavhunga 2016):

What would you intend for your students to know about stoichiometry?
Why is it important for students to know about stoichiometry?
What concepts need to be taught before teaching stoichiometry?
What else do you personally know about stoichiometry that would not yet want your students to know?
What do you consider easy or difficult in teaching stoichiometry?
What are typical students' misconceptions about stoichiometry?

What representations will you use in your teaching?
What are the strategies you would use in teaching stoichiometry?

The following item is taken from a University of Kentucky publicly available General Chemistry Exam from a previous academic term.
"Guide me through how you would help a student during office hours with this problem: What volume of 0.235 M H2SO4 is required to completely react with 15.0 mL of 0.575 M NaOH?"

End of Semester Semi-Structured Interview Guide:
Tell me about your overall teaching experience this semester.
Tell me about your best teaching experience session this semester.
Tell me about a teaching experience this semester that was challenging.
Who or what helped you the most in your teaching this semester?
Tell me about your GCLC experience this semester.
Guide me through your thought process when you go to help a student in the GCLC. How do you start the interaction? What do you do when it's something you're not sure about?
    When do you try to help anyway vs passing it off to someone else?
What would you change about the lab space after this semester?
Anything you have encountered so far that you wish was covered in training?
Did you learn anything about general chemistry this semester? (What and how?)
Did you learn anything about teaching this semester? (What and how?)
Did you learn anything about teaching chemistry this semester?
How well do you think your students did this semester, overall?
How well do you think all of the gen chem students did this semester, overall?
What are the most important concepts for students to master to do well in general chemistry/111/113?
Does a student's success in lab depend more on the TA's class management or the student's lab skills?
Do you think it might be more helpful to be able to do the upcoming week's experiment the week or 2 before you teach it, or keep the current orientation schedule and perform all of the experiments at the beginning of the semester?
Is there anything from this semester that will influence how you teach in future semesters?
Which of the chem courses would you like to TA if you got to choose?
What are the important math concepts that students need to do well in chemistry?
Is it part of your job to also ensure that students have sufficient math knowledge and understanding?
Are TAs responsible for teaching the mathematical concepts needed for general chemistry?
Tell me about your evaluation.

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Thomas, J., **Mask, W.**, Jong, C., Fisher, M., & Schack, E. (2022, November). Deciding Quality: Lenses Challenges, and Opportunities. [Brief Report Presentation]. Psychology of Mathematics Education North American Chapter (PME-NA) Annual Conference. Nashville, TN/Virtual.

Jong, C., **Mask, W.**, Thomas, J., Schack, E., & Fisher, M. (2022, April). Exploring Professional Noticing and Equity Among Preservice Elementary Mathematics Teachers

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