UNDERSTANDING GRADUATE TEACHING ASSISTANTS' EXPERIENCES AND PEDAGOGY

by

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To my playlists for being the soundtrack to my life

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ABSTRACT

Although there have been efforts to advance undergraduate chemistry laboratory learning, how graduate teaching assistants (GTAs) negotiate their teaching within-the-moment is still underexplored. This dissertation addresses this gap by foregrounding GTA experiences and pedagogies as foci of interest. The present study is divided into two phases. The first phase consisted of understanding the contextual meaning of eleven GTA participants' self-recognized experiences via Communities of Practice and capital D Discourse analysis. The findings suggest that although participants recognize obligations to become better chemists as opposed to better teachers, they are active sensemakers of their pedagogies. However, due to obligations, the pedagogies they enact may inadvertently hinder learners' sensemaking in their attempts to mitigate learners' failures. Participants' reliance on accuracy, completion, and efficiency within the laboratory led me to delve deeper into the theoretical conceptualizations of learning from successes and from failures. After creating the *Play First, Reflect Later* (*PFRL)* conceptual framework, I endeavored to better understand the extent that the chemistry laboratory can be integrated with productive failure. Thus, the second phase takes a more fine-grained approach in which nine participants were video recorded during their teaching and were later prompted to explain their rationale via video-stimulated recall interviews. Combining both the video and interview analysis conveys overlaps and incongruities. On one hand, participants effectively enact teaching practices that draws their learners' attention to target concepts, leverage prior experience, and boosts affects. On the other, participants must not compromise learner agency and better prepare learners for long-term learning. Theoretically, errors and direct instruction should also be reconsidered for the laboratory context. I conclude by drawing implications for both researchers and practitioners. Namely, spaces in which GTAs learn to teach should be modified to be more learner-centric, collaborative, and inquiry based like the laboratories they are expected to teach. Furthermore, laboratory curricula (e.g., protocols and experiments) can be redesigned to facilitate learners to explore the hows and whys of their experiments with both their failures and successes. Changing the context of the chemistry laboratory itself, both in terms of teaching and curriculum, may be a more sustainable approach to enhance learners' chemistry experiences.

CHAPTER 1. RATIONALE OF DISSERTATION

Stains (2019) makes the claim that the field of chemistry education knows little about graduate teaching assistants' (GTAs) interests, beliefs, and attitudes towards teaching and learning within the chemistry context. On one hand, this statement can be interpreted as a call to action to better address the underexplored perspectives of chemistry GTAs. While there exist many studies whose focus is on undergraduate chemistry learning experiences, fewer studies foreground how GTAs learn about pedagogy. On the other, this statement also demonstrates that the field of chemistry education tends to rely on the relationship of these constructs (e.g., interests, beliefs, and attitudes) to analyze instructional practice. This arguably narrow lens may prevent researchers from understanding subtle but significant aspects of chemistry teaching and learning. If such features remain obscured from view, we as a chemistry education community may never capitalize on opportunities to advance chemistry learning.

I address this gap with my dissertation as described in the following chapters. Chapter Two focuses on a literature review that foregrounds recent reform efforts for laboratory learning as well as the studies done with graduate teaching assistants. This chapter serves to orient the reader to both the general chemistry laboratory context as well as the instructors who are tasked with orchestrating learners' experiences in said space. The information presented in Chapter Two will be utilized to inform the following chapters respectively. Chapter Three focuses on Phase One of the GTA project. Phase One is a broad approach to understand GTA participants' perspectives about their teaching and their learning to teach. The findings from Chapter Three suggest that participant GTAs are primarily obligated by themes of efficiency, completion, and learners' success. Chapter Four serves as a response to this emergent finding in which I conduct another literature review that focuses on the theoretical conceptualizations of success-driven and failure-driven learning and grounded examples in the field of video game design. With these theoretical constructs outlined, I present Chapter Five which begins with an assembly of a conceptual framework and the exploration of the extent to which participant GTAs enact pedagogies that support learning from failure. I showcase the incongruities between participants' pedagogy and the theory of learning from failure and highlight areas in which both can be improved.

Chapter Six serves as a cumulative conclusion. Using both phases of the GTA project, I summarize my analysis and I draw implications for theory refinement, laboratory redesign, and

GTA training redesign. Finally, Chapter Seven is my personal reflection on incorporating pedagogy that can promote learning form failure. I discuss my own struggles, negotiations, my perceptions of my learners' responses, and ideas of moving forward. A summary of the trajectory of the studies and the analysis of dissertation is highlighted in Appendix B, Figure B1.

CHAPTER 2. CHEMISTRY LABORATORIES AND GRADUATE TEACHING ASSISTANTS

This chapter serves as a literature review of reformed laboratory efforts as well as chemistry graduate teaching assistants (GTAs) to inform subsequent chapters of this dissertation. First, I present three categories of popular laboratory designs: Process Oriented Guided Inquiry Learning (POGIL), Peer-Led Team Learning (PLTL), and Problem-Based Learning (PBL). I discuss strengths and weaknesses for each laboratory design. Towards the end of this portion of the literature review, I provide a summary by distilling key design principles that inform general chemistry laboratory written curricula. I will also relate these design principles to more specific research endeavors and create an overall description of how learning in the laboratory is idealized. The second half of my literature review presents a comprehensive overview of general chemistry GTAs' experiences. I discuss their expected responsibilities in the laboratory, their training, and their emergent identities.

2.1 Process Oriented Guided Inquiry Learning (POGIL)

POGIL is a research-based, student-centered pedagogy that has presence in both K-12 and post-secondary science education. Markedly defined as a departure from the traditional, teacher-centric design, POGIL emphasizes a constructivist approach where students collaborate in groups and actively participate through learning cycles to develop process skills (Atkin & Karplus, 2002). According to Chase, Pakhira, and Stains (2013), while the learning cycle may vary, there is a general pattern that characterizes this type of pedagogy: 1) an orientation phase (learners are provided initial information, learning objectives, and the criteria for success), 2) an exploration phase (learners interact with models and a series of questions), 3) a concept formation phase (learners develop a critical understanding of a concept), 4) an application phase (learners reinforce and extend their understanding by answering additional questions), and 5) an evaluation phase (learners share their results and reflect on their learning). Abrahamson (2011) corroborates with this learning cycle, adding that POGIL encourages students to synthesize and transfer ideas in order to make more in-depth sense of complex problems. POGIL thus shifts the attention away from the instructor as a purveyor of information, instead refocusing on the activity of the students with embedded, step-wise learning goals such as content mastery, oral and written communication, problem-solving, and metacognition (Moog & Spencer, 2008).

Recent studies have shown that incorporating POGIL has produced mixed results of both benefits and detriments. Hein (2012) reports that chemistry undergraduates who experienced the POGIL method have a statistically significant improved understanding of content knowledge, evinced by higher final exam scores as well as better proficiency on ACS standardized exams. POGIL has also been more explicitly incorporated in chemistry laboratories whose curricula involved undergraduates making predictions, collecting data, modeling, and discussing resultant meaning (Hunnitcutt, Grushow, & Whitnell, 2015). These researchers provide evidence to suggest that POGIL helps improve both content knowledge and associated laboratory practices. Latimer and colleagues (2018) add that laboratory skills their undergraduates develop via POGIL (e.g., separation and characterization of structures) can even be pragmatically transferrable to future research laboratory contexts. While success is usually associated when instructors use POGIL, it is not necessarily guaranteed. For instance, Chase and colleagues (2013) exhibited no improvement in terms of grades, attitudes towards chemistry, or self-efficacy despite using POGIL as the default structure for discussion sections. Such shortcomings could be attributable to how POGIL is facilitated, warranting additional attention to workshops that train instructors on how to implement this type of pedagogy (Stegall, Grushow, Whitnell, & Hunnicutt, 2016).

2.2 Peer-Led Team Learning (PLTL)

Researchers have defined the instructional model of PLTL as an active learning environment where students collaboratively construct their own knowledge, ask questions, and enact higher-level reasoning to solve problems (Varma-Nelson, 2006). Usually in small groups of six or eight students, PLTL differs from POGIL in that there is also a designated peer leader who supports students by facilitating the discussion of problems and assisting in conceptual understanding (Gafney & Varma-Nelson, 2008). Emergent discourse typical of PLTL includes students evaluating ideas, negotiating differences, and defending their understanding (Kampmeier & Varma-Nelson, 2009). PLTL derives its theoretical foundations from Vygotsky's (1978) social constructivism, specifically in terms of his zone of proximal development. Here, the peer leader (typically a student who had prior success with the course before) serves as a more knowledgeable source who can help scaffold the learning of novices and extend the realm of their conceptual understanding through facilitation and role-modeling (Wilson & Varma-Nelson, 2016). Although there may exist different variants of PLTL such as the online version (Feder et al., 2016; Mauser et al., 2011) and the one situated within the laboratory (Foroudastan, 2009; Weaver et al., 2006), PLTL still relies explicitly on the prospective benefits of having students interact with one another to boost their collective and individual performance.

PLTL has a checkered history in terms of its success, relative to that of POGIL. The literature review conducted by Eren-Sisman, Cigdemoglu, & Geban (2018) shows that most research endeavors using PLTL indicate an improvement in either course or standardized testing performance. Furthermore, these authors show that PLTL can reduce situational and social anxiety which may mitigate student attrition rates. Similarly, other studies have corroborated with PLTL's strengths in improving student retention by showing evidence that PLTL can be advantageous for first-year undergraduates inexperienced in college-level coursework (e.g., Frey, Fink, Cahill, McDaniel, & Solomon, 2018). However, Lewis (2014) argues that while students may experience success using PLTL for one chemistry course, accrued skills from this context are ill-fitting for other courses later in the chemistry sequence. Even the improvement in performance can be questioned; McCreary, Golde, & Koeske (2006) contribute that students learning with PLTL may have better descriptions of experimental goals and responses but comparable quality of data analysis and reasoning. PLTL may also have very little impact on students' decision to persist in general chemistry when the pedagogy reverts to the traditional lecture-only instruction, necessitating more widespread change across multiple curricula (Mitchell, Ippolito, & Lewis, 2012).

2.3 Problem-Based Learning (PBL)

Like the previous laboratory designs, PBL is a student-centered approach where the problem comes first and learners, on a need-to-know basis, discuss the solution within a practical context (Latimer et al., 2018). Typical benefits to student skills that are associated with PBL include improvements in critical thinking, efficient usage of resources, and productive communication among peers (Flynn & Biggs, 2012). Having roots in Dewey's philosophy of real-life learning (McDonald, 2002), PBL foregrounds two primary constructs in its design: fostering greater levels of intrinsic motivation and spurring independent learning to break the habitual tradition of being spoon-fed information (Williams, Woodward, Symons, & Davies, 2010). These two constructs are closely intertwined, culminating into a pedagogical tool that aims to maximize learner engagement and scientific processing skills (Tosun & Taskesenlgil, 2013). Thus, the problem presented to students must have some basis in real-world settings such that students can perceive the task as being authentic and open-ended (Woods, 1994; Yoon, Woo, Treagust, & Chandrasegaran, 2014). As Budner & Simpson (2018) describe, when PBL is purposed for the chemistry laboratory, it affords greater opportunities for students to develop and take ownership of authentic research practices.

PBL possesses strengths and weaknesses that, like other pedagogical approaches, signify its inconsistency in terms of deliverables. Veale, Krause, & Sewry (2018) incorporated PBL in their pharmaceutical chemistry course and observed their participants developing an appreciation for the value of teamwork and presented high-quality projects. However, emergent challenges such as non-participating group members marred effective implementation of PBL which prompted the researchers to reconsider their design for future iterations. Williams and colleagues (2010) demonstrated that using PBL in an introductory chemistry course led students to perceive that they had accrued skills (e.g., communication, teamwork, and organization) that may be relevant in future contexts. Although these researchers lacked substantial evidence to show positive changes in student performance, they did find that PBL provided social benefits in promoting friend groups among first year chemistry students. In another study, using PBL for year-one chemists led to faculty recognizing greater engagement but also dissatisfaction with the problem being too limited in scope and with the explicit reliance on others to develop a solution (Williams, 2017).

2.4 The Ideal Laboratory

Indicated by the designs of POGIL, PLTL, and PBL, the laboratory is a multifaceted space utilizing various constructs that facilitate inquiry learning within the laboratory. From this literature review, I have identified three salient themes that guide reformed laboratory curriculum design features. First, laboratory curriculum requires student-centric inquiry learning that is properly scaffolded for gapless conceptual understanding. Cooper & Klymkowsky (2013) similarly use this design feature in their Chemistry, Life, the Universe, and Everything (CLUE) curricula as learners engage in inquiry-learning to gradually develop an understanding of submicroscopic to macroscopic phenomena in terms of structure, energy, and properties. Second, the laboratory must enable learners to model authentic scientific practices and understand the rationale. For instance, Course-based Undergraduate Research Experiences (CURE) is a new approach to laboratory design where undergraduates iteratively participate in self-designed, discovery-based projects to produce publishable data and encouraging later learners' involvement with actual research (Cascella & Jez, 2018; Pagano, Jaworski, Lopatto, & Waterman, 2018; Williams & Reddish, 2018). Third, laboratory curriculum design needs to promote learners' motivation and engagement. Whether this is done by legitimizing learners' lived experiences for more meaningful science learning as other programs have done (e.g., Upadhyay, 2006; Schwarz, 2009) or marketing chemistry as a more cohesive framework embodying its subdisciplines (McGill et al., 2019), laboratory learning needs to be affectively appealing.

2.5 Graduate Teaching Assistants in the General Chemistry Laboratory

In many colleges and universities, general chemistry laboratories are often taught by GTAs who are pursuing an advanced degree in chemistry. General chemistry GTAs are expected to teach procedural skills and conceptual knowledge as well as create a learning environment conducive to chemistry learning in the laboratory settings (Bond-Robinson & Rodriques, 2006). With regards to GTAs' teaching within the chemistry laboratory, a recent study has catalogued their instructional styles as the waiters, busy bees, observers, and guides on-the-side, reinforcing that GTA-student interactions are both numerous and complex (Velasco et al., 2016). GTAs also have numerous responsibilities outside of their teaching laboratories. GTAs facilitate recitation sessions, grade student assessments, and at times develop additional curricula for their learners (Gardner & Jones, 2011). Furthermore, they may also conduct review sessions and provide advice during and outside of class (e.g., Jacobs, 2002; Peterson, 1990). Just assuming GTAs only need to teach is a conflated perspective. GTAs possess a staggering list of responsibilities, demonstrating that GTAs serve a pivotal role in their learners' sensemaking of chemistry.

To assist GTAs in their pedagogical preparations, researchers have developed and implemented numerous GTA training programs. Dragisich, Keller, and Zhao (2016) created a training course where GTAs would spend 80 hours over the span of two weeks through various activities such as departmental orientation, confidence building, laboratory safety training, and future career network development. Mutambuki and Schwartz's (2018) Engage PD model trains GTAs on literature-recommended classroom practices, inquiry instruction, assessing learning outcomes, and making real-world connections. Bond-Robinson and Rodriques' (2006) Laboratory

Teaching Apprenticeship aims to improve GTAs' "pedagogical chemistry knowledge" through directed coaching that provides explicit guidance on, for instance, identifying essential chemistry concepts, recognizing pedagogical strategies to explain procedures and concepts, and employing moves that direct students' reasoning. Some programs utilize cutting-edge technology in GTA training. Ke, Lee, and Xu's (2016) Mixed-Reality Integrated Learning Environment (MILE) provides simulated teaching contexts, such as lecturing, mentoring, and classroom management, in which GTA trainees are required to teach and interact with virtual student characters.

While varying in the implementation details, these training programs share several key principles. First, many training programs view building a learning community (Ryan, 2014) among GTAs as a productive component. In a learning community, GTAs can support each other's learning about pedagogy and improve their pedagogical practices through fruitful and supportive peer interactions. Second, from a pedagogical perspective, most training programs are grounded on constructivist learning approaches (Flaherty, O'Dwyer, Mannix-McNamara, & Leahy, 2017) wherein learners' sensemaking is supported through active use of prior knowledge and dialogic interactions. Instead of giving monologic instructor-centered talks, GTAs are encouraged to scaffold their learners' experiences by closely monitoring their progress and connecting to their prior knowledge and experiences. Finally, these training programs acknowledge the complexities embedded in laboratory teaching practices (Ke et al., 2016). For example, GTAs must attend to various aspects that impact their teaching practices, such as departmental policies and responsibilities, their image as a laboratory instructor, learners' affects, and safety. Thus, training programs focus on not only learners' conceptual understanding, but also the development of safe, respectful, and motivating environments.

Existing training programs within the literature also share several weaknesses. First, GTAs' pedagogical training is often limited to short bursts of meetings across a narrow time span. GTA training should involve ongoing learning experiences instead of workshops restricted to a few days (Flaherty et al., 2017; Marbach-Ad et al., 2012). Second, GTA training programs typically are not thoroughly grounded in GTAs' actual teaching and are limited to interactions via workshops, seminars, and/or staff meetings. Within the K-12 setting on the other hand, pre-service teacher education and in-service teacher PD programs have been increasingly embedded in their day-to-day teaching practices in real schools (Fischer et al., 2018; Huang & Shimizu, 2016). Finally, extant training programs may not explicitly provide GTAs with enough opportunities to reflect on their teaching situated within their laboratories. As a result, GTAs may lack the guidance to ponder upon their "teaching as inquiry" (Ball, 1993, p. 6). Prior professional development programs have shown that teaching practices are most effectively advanced through self-reflection that is supported by the facilitator and peers (González, Deal, & Skultety, 2016). If GTAs do not make sense of their pedagogy through channels such as the knowledge content, their learners, and surrounding contexts that facilitate learning, they may instead understand their pedagogical training to be a mimicking of prepackaged pedagogical moves. Altogether, there exists a contrasting divide between the learner-centric, collaborative, and inquiry-based nature of learning in chemistry laboratories (e.g., Budner & Simpson, 2018; Hein, 2012) and the oftentimes transmissive nature of GTAs' learning of pedagogy.

Furthermore, what the chemistry education literature fails to recognize is the inherent ambiguity in GTAs' roles and the resultant effects on undergraduate learning experiences within the chemistry laboratory. GTAs occupy unclear spaces in academia, a testament to the multiplicity and fluidity of their perceived and self-perceived roles and responsibilities (Muzuka, 2009). First, GTAs are employees who often view their teaching appointment as a fulfillment of a departmental requirement or a financial solution towards paying tuition (Austin, 2002). Such perspectives are further supported by chemistry departments' increasing reliance on GTAs as an inexpensive work force that can produce high-quality research and attend to large student populations (Chadha, 2013; Gillon & Hoad, 2001). Second, GTAs are graduate students who must allocate time for courses and research in order to successfully complete and submit their degree (Park, 2002). Unsurprisingly, there exists an air of disenchantment where GTAs and their department may see teaching appointments at best a secondary or tertiary option to research or at worst an inevitable interference to doctoral activities (Harland & Plangger, 2004; Jordan & Howe, 2018). As Muzuka (2009) contends, it is imperative that researchers seek to understand the contextual complexities of GTA experiences in order to better develop GTA provisions.

CHAPTER 3. PHASE ONE OF THE GTA PROJECT

Recently, there have been efforts to improve undergraduate chemistry laboratory learning by reforming how graduate teaching assistant (GTA) learn to teach. However, the literature has not fully foregrounded GTAs' identities, leaving their perspectives underexplored. Specifically, researchers have limited understanding on how GTAs understand and negotiate their pedagogy given contextual circumstances present within their staff meeting and instructional laboratories. To address this gap, this chapter introduces Phase One of the GTA Project. We investigate the underexplored experiences of general chemistry GTAs (Stains, 2019) through semi-structured interviews with 11 participants. Drawing on Wenger's (1998) theory of *Communities of Practice*, we elect to better understand GTAs' identities-in-practice and how they navigate between different communities of practice. Methodologically, we employ Gee's (1999) capital "D" Discourse analysis to ascertain the situated meaning of participants' words with regards to communal contexts. Based on the analysis of participating GTAs' interviews, we argue that their resultant identities-in-practice are a dynamic culmination of boundary objects and brokering that are informed by the interactions of different communities. In other words, GTAs negotiate existing circumstances and author new actions that, although may not align with what is recommended in the literature, are effective in fulfilling their teaching responsibilities. Exploring the situatedness of these actions highlights *how* GTAs learn about teaching chemistry. Accordingly, we assert that understanding GTAs' pedagogy should not solely focus on their shortcomings but also incorporate pedagogical affordances and limitations given their training and teaching contexts. By drawing more attention to the circumstances with which GTAs must negotiate, we as a larger chemistry community can better support GTAs' teaching and broaden the possibilities of undergraduate learning in general chemistry laboratories.

3.1 Communities of Practice as a Theoretical Framework

We posit that the learning is a sociocultural endeavor grounded in the interactions with others (Vygotsky, 1978). Such interactions have contextualized meanings which presuppose certain ways of knowing and doing (Gee, 2008). This emphasis on context enforces that knowledge is situated where learning can be the result of progressive involvement in professionally authentic activities

(Brown, Collins, & Duguid, 1989). Graduate students, for instance, learn by embodying the values, goals, and practices of a specific discipline by joining a research group, taking classes, and demonstrating expertise in front of a committee (Bulpin & Molyneaux-Hodson, 2013). To understand this melding of learning and context, we use Communities of Practice (CoP) as our theoretical framework. Like other researchers, we are interested in applying the theory of CoP to understand the resultant learning between newcomers (i.e., individuals who start at the periphery of communal participation) and old-timers (i.e., individuals who are already ingrained and recognized as authentic members) within a particular community of practice (e.g., Akerson, Cullen, & Hanson, 2009; Olitsky, 2007)

A community is a social configuration in which one's *actions* are socially legitimized by others (Wenger, 1998, p. 5). *Practice* is doing in historical and social context, giving structure and meaning to enacted actions (p. 43). Together, a community of practice is the context in which individuals make sense of their experiences, negotiate ways-of-being, and enact actions that establishes an *identity-in-practice* (p. 149). Identity is conceptualized as the layering of participative experience and reificative projections (p. 150). In other words, identity is conceptualized not just in what people think or say about themselves (e.g., Kelly, 2006; Zotos, Moon, & Shultz, 2020). Instead, Wenger defines an identity-in-practice as the way people live day to day by doing, becoming, experiencing, and belonging. Such practices interweave and interconnect, forming a complex process that constitutes as learning within a CoP. As newcomers enter a community, they learn to construct "their own future" by interacting with old-timers who are "living examples of possible trajectories" (p. 156). This relationship between communal members and their co-construction of knowledge are intrinsic for newcomers' development of a legitimate identity-in-practice in a given CoP (Lave & Wenger, 1991).

Wenger (1998, p. 73) shows that a CoP is comprised of three components: mutual engagement between members, pursuit of joint enterprises, and the utilization of shared repertoire. Wenger (p. 73) defines *mutual engagement* as newcomers and old-timers enacting "actions whose meanings they negotiate with one another," thereby establishing coherence for resultant actions. For example, Davidson and Hughes (2018) showed how K-12 science teachers learn within a professional development program. Working alongside with scientists and engineers (old-timers) led participating teachers' (newcomers) to better understand authentic research practices. In the context of general chemistry teaching laboratories, Dood, Johnson, and Shorb (2016) incorporated more realistic activities in their curricular revisions. Experiments such as the analysis of sugar in urine and nutritional chemistry were adapted from activities typical of professional nurses to better induct undergraduate nursing majors. Mutual engagement thus functions as the channel for newcomers to emulate old-timers and enact actions befitting of their respective CoP.

Wenger (1998, p. 77) conveys *joint enterprise* as members' "negotiated response to their situation." Joint enterprise is both the stated intention and the implicit responsibility that delineates the very practice of the community. For example, Kisiel (2010) explored schools working with aquariums for informal learning. While teachers valued student achievement given their test-driven curriculum, aquarium instructors prioritized communicating positive attitudes about science and the environment. The two CoPs, although sharing a teaching-related identity-in-practice, varied in how their respective members negotiated salient goals due to different communal norms. The community can also hinder newcomers' participation in joint enterprise (González-Howard & McNeill, 2016). Classroom activities like regularly moving English language learners (newcomers) into classes that better cater their proficiency levels can impede their goals of learning scientific argumentation. From these examples, joint enterprise can both characterize a community's practice and determine the extent to which members are supported by the CoP itself.

Wenger (1998, p. 82) defines the third communal characteristic as a *shared repertoire*, consisting of artifacts, concepts, and "the discourse by which members create meaningful statements." These resources gain meaning through members' ongoing mutual engagement and joint enterprises. For instance, jargon, spatial and temporal scales, and models of one discipline have different or no meaning in another (Morse, Nielsen-Pincus, Force, & Wulfhorst, 2007). A shared repertoire also informs how newcomers develop their identities-in-practice as fully-fledged members. Holland, Lachicotte Jr., Skinner, and Cain (1998) demonstrate how a plastic poker chip within an Alcoholics Anonymous (AA) meeting becomes an emblem for maintaining sobriety. AA old-timers use poker chips to view themselves as non-drinking alcoholics and to engage in emotionally connecting with fellow members. As newcomers develop their AA membership, they model old-timers' usage of shared resources to sustain communal unity. Therefore, shared repertoire acts as the source which dictates how newcomers should negotiate their identities-in-practice in tandem with their CoP's ongoing history.

Finally, the theory is not limited to conceptualizing individuals as belonging to only one CoP. As Wenger (1998) notes:

> “..we all belong to many communities of practice: some past, some current, some as full members, some in more peripheral ways. Some may be central to our identities while others are more incidental. Whatever their nature, all these various forms of participation contribute in some ways to the production of our identities.” (p. 158)

Wenger refers to an individual belonging to multiple CoPs as the *nexus of multimembership*. As a member to multiple CoPs, one must constantly negotiate their respective expectation in order to maintain an identity across boundaries (p. 158). Investigating how individuals cross communal boundaries requires understanding *boundary objects* and *brokering*. As noted earlier, participation and reification form an individual’s identity-in-practice. From a macro-perspective, participation and reification also contribute to both the continuity and discontinuity of communal boundaries. Boundary objects, the products of reification, can enter different CoPs to coordinate disjoint forms of participation (p. 107). For example, a book is a boundary object where multiple constituencies exert partial control. The author can determine what is written but readers dictate their interpretation. Brokering is participation through translating, coordinating, and aligning perspectives from different CoPs (p. 109). Just as how chemists may integrate their understanding of safety from their workplace into their household, brokering consists of linking aspects of one practice to another by facilitating transactions between CoPs. Boundary objects and brokering collectively serve as the underpinnings that enable individuals to maintain coexistence of their multimembership as summarized in Figure 3.1 (adapted from Wenger, 1998, p. 105).

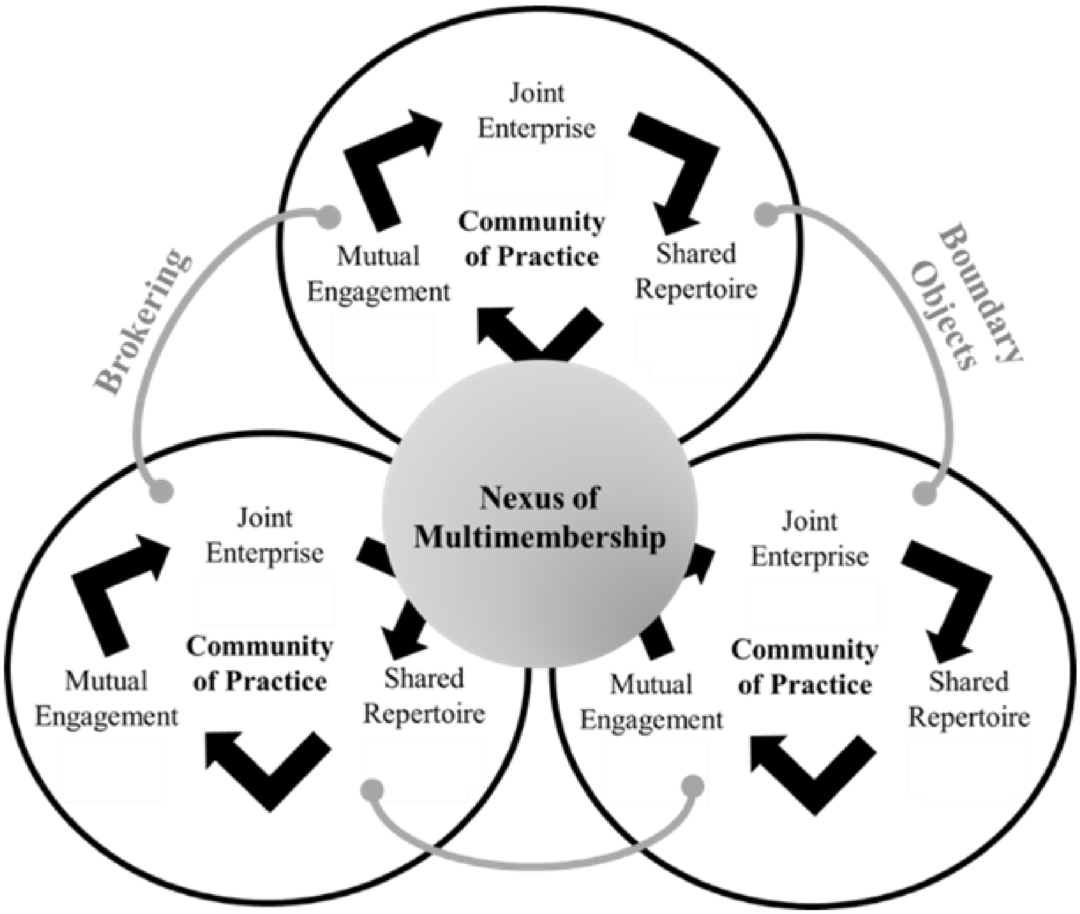


Figure 3.1. A model of the Nexus of Multimembership. Adapted from Wenger (1998).

We recognize that educational research on general chemistry laboratory GTAs has not addressed how the GTA as a nexus of multimembership reconciles multiple CoPs as evidenced by boundary objects and brokering. Research has implicitly positioned GTAs as newcomers during their training (e.g., Dragisich et al., 2016) and as old-timers during their teaching (e.g., Wheeler, Maeng, & Whitworth, 2015). To elaborate, GTAs are newcomers in training contexts when they learn from old-timers such as course instructors, staff meeting coordinators, preparatory personnel to teach chemistry. GTAs must abide by the logistical and social norms set forth by the chemistry department, pursue goals of fulfilling their responsibilities, and use resources such as grading rubrics and laboratory manuals (Park & Ramos, 2002). GTAs are also old-timers within contexts where they must teach students. While both GTAs and students are both learning chemistry in such contexts, the former is nevertheless more experienced and advanced, having more knowledge on the content, culture, and norms to legitimately participate in the larger chemistry community. Given their stronger chemistry identities, GTAs must inculcate norms appropriate to proper laboratory conduct and facilitate their students' chemistry learning (Bond-Robinson & Rodriques, 2006). Regardless of other CoPs that are possibly inhabited, GTAs must at least switch between newcomer and old-timer identities-in-practice due to their teaching appointment.

In our study, we use CoP as a theoretical construct to investigate identities-in-practice from the perspective of our participating GTAs themselves. More specifically, we posit that a chemistry GTA is a nexus of multimembership who belongs to at least two distinct communities. GTAs belong to a CoP of Teaching Chemistry (CoP-TC) in the context of their training and to a CoP of Learning Chemistry (CoP-LC) in the context of their teaching (Figure 3.2).

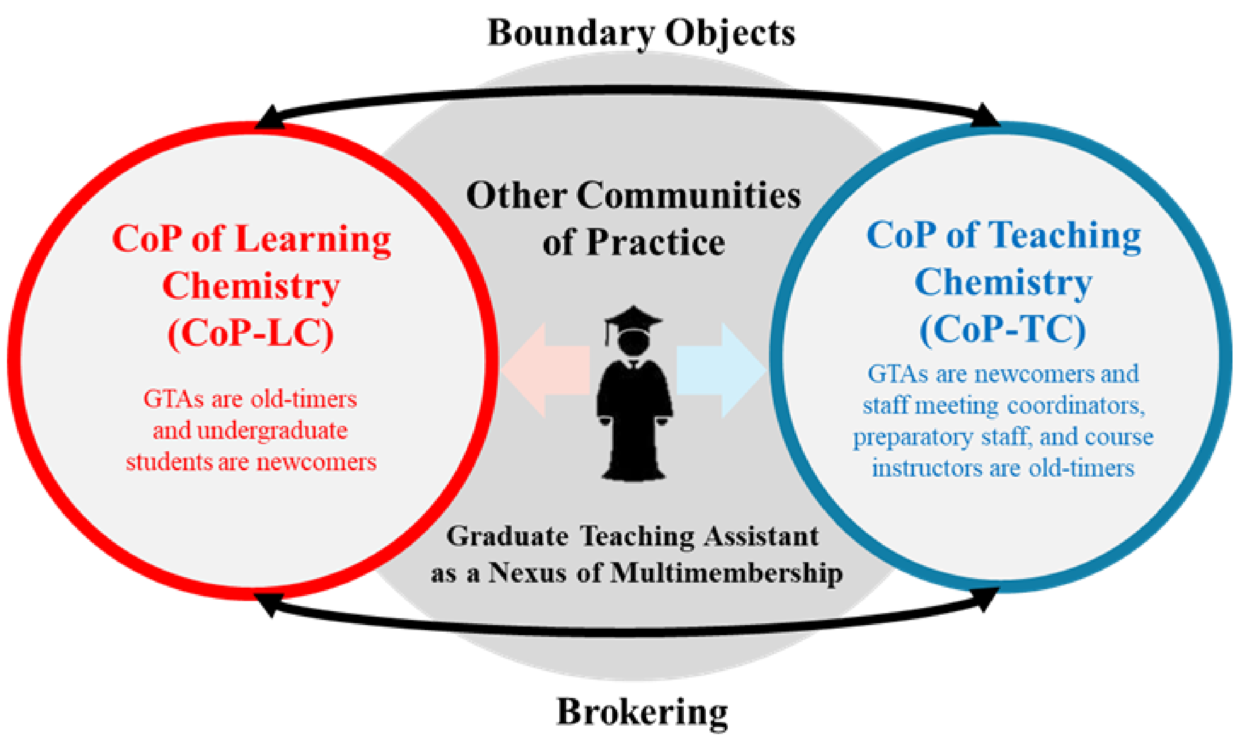


Figure 3.2. A graduate teaching assistant with dual-memberships in CoP-LC and CoP-TC

We focus on the crosstalk between these two CoPs to bound GTAs' experiences so we can explore how GTAs negotiate their newcomer and old-timer memberships, evidenced by their boundary objects and brokering. We also recognize that GTAs belong to other different CoPs beyond our scope (e.g., research, gender, race, culture, etc.). For the purposes of our study, we will not explicitly address these different CoPs in detail. However, we will acknowledge effects of different CoPs on GTAs' reconciliation of multimembership between CoP-TC and CoP-LC when appropriately relevant. Accordingly, we pose the following research questions.

> RQ1: What are GTAs' identities-in-practice, as constituted by their self-recognized actions, relative to CoP-TC and CoP-LC?
>
> RQ2: How do GTAs negotiate their multimemberships between CoP-TC and CoP-LC through boundary objects and brokering?

3.2 Discourse Analysis as a Methodology

Discourse analysis is a broad umbrella term that encompasses a variety of qualitative approaches for understanding language and its connection to social practice (Lester, Lochmiller, & Gabriel, 2016; Potter, 2004). Language is a system of forms and meanings that goes beyond the passive representation of reality (Hammond, Converse, & Grass, 1995). Language is action-oriented: the performative and transformative medium which people negotiate and enact their practices (Lester, Lochmiller, & Gabriel, 2017). Researchers use discourse analysis as a fine-grained, micro-analytical approach to investigate individuals' utterances in sociocultural contexts (Tang, 2017). Discourse analysis thereby functions as the method to understand how phrases are distributed along a text, the interactions between speaker and listener, and the expression of human experiences (Halliday & Hasan, 1985).

Researchers often use discourse analysis to explore the development of scientific literacy, namely how learners situated within a classroom environment communicate science and construct their memberships within scientific communities (Lemke, 1990). For example, Dohrn and Dohn (2018) investigated the nature of teacher questioning within a chemistry classroom, highlighting the various affordances for resultant student talk. They show that because the questions were closed in nature, students were limited in their conceptual agency as their utterances were more frequently characterized as recall and less as meaningful reflection. Criswell (2011) similarly uses discourse analysis to understand how high school teachers can support students' conceptualizations of chemistry such as stoichiometry and periodic trends. Their analysis suggests that teachers relying on the cognitive conflict strategy often defaulted to specific pedagogical practices and discursive moves, consequently reducing opportunities for teachers to understand the multiple pathways of students' conceptual reasoning.

These studies highlight a certain trend used in science and chemistry education research. On one hand, researchers use discourse analysis to understand the nature of classroom talk and how it orchestrates learners' thinking and participation (e.g., Current & Grunert Kowalske, 2016; Kulatunga & Lewis, 2013). On the other hand, discourse analysis can target thematic content and knowledge development as a result of teacher-student interactions (e.g., Kapanadze, 2018; Warfa, Roehrig, Schneider, & Nyachwaya, 2014). Studies using discourse analysis have concluded with typologies of pedagogical moves such as initiate-respond-evaluate (Mehan, 1979) or advocated for improved teacher training programs (Farré & Lorenzo, 2009). However, what science educational researchers less frequently do is use discourse analysis to understand experiences within and outside of classroom contexts. We specifically look beyond the confines of classroom talk and use discourse analysis as a means of investigating the multiple contexts situating language usage and how they interconnect with identity formation (Wodak & Meyer, 2009; Olitsky, 2006). For our study, we specifically leverage Gee's (1999) capital "D" Discourse analysis as our methodological tool.

Capital "D" Discourse is the combination and integration of "language, actions, interactions, ways of thinking, believing, valuing, and using various symbols, tools, and objects" (p. 21). In other words, Discourse analysis involves investigating how language, in a specific time and place, is used to construct context and how details of said context reflexively gives meaning to that language. This melding of context and language distinguishes Gee's Discourse analysis apart from other discourse methodologies in that the former moves beyond language as form and function and instead uses language to understand significant identities within social and historical structures (Hickey & Zuicker, 2012). For example, Gee (1999) employs Discourse analysis to describe how upper-middle-class teens use language to cloak their personal interests and fears while working-class teens personalize their narrative with their values and interests. Strieker, Adams, Lim, and Wright (2017) similarly used Discourse analysis to create a working model of their pre-service co-teaching program by examining their participants' descriptions (e.g., voice, reciprocity, and equality) of their teaching and relationships. By foregrounding the dialectic between context and language, researchers can better investigate the hidden patterns of practices, feelings, and norms embedded in one (MacKay, 2003).

Drawing from Gee's capital "D" Discourse analysis, we seek to understand how GTAs self-recognize their identities-in-practice as both newcomers and old-timers. Specifically, we use Discourse analysis to understand how people use language as a tool to participate in communities of practice (Carlsen, 2007). We posit that the specific social situations GTAs experience (micro-level) result in a thickening of an identity-in-practice trajectory (macro-level) (Wortham, 2006). Additionally, we use Discourse analysis to ascertain how GTAs broker their practices as they describe the practices they deem fitting for their roles. How GTAs are positioned (newcomer vs. old-timer) and how they navigate this interface therefore results in complex and varied identities-in-practice that otherwise may not be elucidated (Wood, 2013). We then use the language GTAs use to reflexively describe the network permeating the general chemistry CoP that may give rise to such GTA self-recognitions, creating implications for GTA training, curriculum revisions, and future research avenues. Accordingly, our usage of Discourse analysis answers Gee's (1999, p. 96) call to "organize the thinking and social practices of sociocultural groups" and "create bigger and bigger storylines." Below I present the research context and methods of data collection and analysis.

3.3 Research Context

The work shown in this study is a subset of a larger research endeavor. We had conducted our data collection at a large, Midwestern public R1-university in the spring semester of 2018. At the time, there were approximately 5,000 UGs enrolled in general chemistry courses with approximately 120 presiding GTAs. We had solicited graduate teaching assistants during their staff meetings and those who were interested had volunteered to be a part of this study. Specifically, we targeted the CHM 101/102 and CHM 105/106 (assigned pseudonyms) general chemistry sequences from which to sample our GTA population. Both sequences have a 50-minute lecture (twice a week) and a three-hour laboratory session (once a week). The CHM 101/102 sequence is designed for agricultural, health, and social science majors while CHM 105/106 is designed for agricultural and engineering science majors. A vast majority of general chemistry students are enrolled in either one of these two sequences. Accordingly, these courses have the largest pools of GTAs, offering the greatest variety of experiences our research aimed to explore.

There is a total of eleven GTAs (eight women) who voluntarily participated in our study as shown in Table 3.1 (listed names are pseudonyms, reflective of their self-identified gender and ethnicities). Participants varied with regards to their year in the program and the courses they are currently teaching/previously taught. Specifically, we had one participant in CHM 101 and four in CHM 102. We also had one participant in CHM 105 and three in CHM 106. The reason for this distribution is that off-sequence courses in the spring semester (CHM 101 and 105) typically have fewer students and consequently, fewer assigned GTAs. Thus, our distribution of GTAs is somewhat representative of how GTAs were distributed across the various chemistry courses available during the spring semester, with more participants coming from CHM 102 and 106 respectively.

Table 3.1. Phase one demographics

Participants	Self-Identified Gender	Self-Identified Ethnicity	Status	Program	Year in Program	Chemistry Course
Linda	Female	Asian	International	PhD	3rd	105
Ashley	Female	Asian	International	PhD	1st	106
Selina	Female	Latina	Domestic	PhD	2nd	106
Beatrice	Female	Latina	International	PhD	1st	106
John	Male	White	Domestic	MS	1st	102
Dani	Female	African	Domestic	PhD	2nd	101
Helga	Female	Polish	Domestic	PhD	1st	106
Esther	Female	Asian	Domestic	PhD	1st	102
Richard	Male	White	Domestic	PhD	2nd	102
Beverely	Female	White	Domestic	PhD	3rd	102
Isiah	Male	White	Domestic	PhD	3rd	102

3.4 Methods

We had conducted and transcribed semi-structured interviews with GTAs that were approximately an hour to an hour and a half long. Our interview protocol prompted participants to discuss salient actions throughout their teaching assignment. The interview protocol can be found in Appendix A. We operationalize actions are behaviors which are tightly connected to the emergent meaning of said behaviors and the development of identity (Harré & Moghaddam, 2003). We furthermore note that data drawn from interviews cannot provide any conclusion about public behaviors. The analysis of interview data instead foregrounds "*recognition* (of self and by others) as a key component" of identity formation (Carlone & Johnson, 2007, p. 1197, emphasis in original). In other words, we address RQ1 by analyzing GTAs' self-recognition of what they do (their actions) to interpret the meaning of relevant CoP-TC and CoP-LC identities-in-practice.

The interview explored how participants self-recognize their enacted actions in different contexts that require their attendance such as the laboratory, recitation, office hours, staff meetings, lecture, and others that emerged during the interview. The interviewer (first or second author) initially asked participants what they do in their laboratories (e.g., "Imagine a typical day. Can you briefly walk me through what you do from the beginning until the end of lab?"). The interviewer then addressed what participants would do in different contexts such as recitation, staff meeting, lecture, and office hours (e.g., "Describe what typically happens during staff meetings"). Finally, the interviewer prompted participants to discuss ways in which they felt supported or unsupported (e.g., "What are some currently available resources provided to you that support your learning how to teach?") and their perspectives on balancing their teaching appointment with other responsibilities (e.g., "How do you negotiate all of your GTA responsibilities with other aspects of graduate school life?"). What participants had stated with regards to their laboratory section and staff meeting was far richer in terms of the diversity of their actions than other contexts (e.g., office hours, recitation, and lecture). We thus designated the laboratory and staff meeting as the primary foci of this study. On one hand, staff meeting represents CoP-TC where GTAs enter as newcomers to learn how to teach chemistry. On the other, the laboratory represents CoP-LC where GTAs enter as old-timers to teach their students chemistry.

Our data analysis for RQ1 predominantly leveraged qualitative approaches where we coded the transcripts, generated themes, reiteratively compared them against findings from the literature, and subsequently revised and reorganized our analysis (van Manen, 1990). Using Nvivo software (ver. 12) for the coding process, the research team designated actions that GTAs described during staff meeting or the laboratory as belonging to CoP-TC and CoP-LC respectively. Members of the research team had first independently coded actions for several participants and met together to discuss discrepancies and disagreements with the coding. After several rounds of revisions, the research team had created agreed upon codes to document the self-recognized actions for the remaining participants.

Using the agreed-upon codes, we relied on analytic coding (Richards, 2015) to interpret and reflect on the meaning of our codes and axial coding (Charmaz, 2014) to interconnect and compile codes into bigger categories. Specifically, we analyzed participants' actions and explored similarities and differences in their participative experience and reificative projections. We assumed that actions are layers of their communal membership that describe not only what participants do in and of itself but also how participants recognized the meaning of their doing in social and historical contexts. A collection of interrelated actions thereby culminates into a larger practice, understood as the source of coherence for a community. Because our theory designates identity as an integration of what individuals say and what they do, we understand identity to be the lived and negotiated experience embedded within the practice itself, literally an identity-in-practice. Thus, our coding process involved using participants' experiences, as evidenced by the actions themselves and their corresponding meaning, to inform our perspectives of the CoPs and generate befitting identities-in-practice that encapsulate a collection of actions.

To address RQ2, we selected three focal participants that had the most detailed narratives about their reconciliation of CoP-TC and CoP-LC memberships. Furthermore, during the preliminary stages of our analysis, we noted the non-straightforward nature of all three of our focal participants' pedagogy. On one hand, these three participants would have potentially scored well on observation protocols that gauge laboratory instructional practice (Velasco et al., 2016). On the other hand, how focal participants self-recognized the rationale for their actions hints at deeper implications that may not be as clearly elucidated using observation protocols.

To better investigate the embedded meaning within these three participants' words, we leverage capital D Discourse analysis. Discourse analysis is a methodology that seeks to understand the reflexivity between language and a social situation at a specific time and place. As Gee (1999, p. 97) notes, reflexivity is conceptualized as two mirrors, language and context, facing one another and endlessly reflecting. Using Discourse analysis thereby entails asking questions about how language construes aspects of the social context and how the context provides meaning to the language itself. Because this methodology assumes both language and context are in constant reciprocity, it provides a suitable means to connect participants' self-recognition of their actions to the larger CoP that may inform such perspectives (Carlsen, 2007).

We used Discourse analysis for our study in several stages. First, we analyzed the transcripts of our focal participants to establish a meaningful relationship between their self-recognized actions (language) and the characterization of both CoP-TC and CoP-LC (context) for each person. Specifically, we identified excerpts that typify instances of mutual engagement, joint enterprise, and shared repertoire to construct their perspectives of their multimemberships. Second, we analyzed how focal participants navigated between CoP-TC and CoP-LC. This process involved understanding the meaning of brokering and boundary object (as verbalized by participants' language) as it crosses boundaries between each focal participant's constructed perspective of CoP-TC and CoP-LC (context). Our analysis of participants' brokering and boundary objects further refined our interpretations of their perspectives of CoP-TC and CoP-LC. Finally, we weaved salient excerpts together to form overarching storylines for each focal participant. With each narrative, we portray how different communal features interconnect to form participant's nuanced identities-in-practice as situated by their CoP-TC and CoP-LC multimemberships.

3.5 Findings

In this section I present my findings. The first part conveys themes, with respect to CoP-LC and CoP-TC, inductively generated from the coding of participants' interviews. The second party involves our usage of Discourse analysis in which we analyze excerpts of transcripts to ascertain how participants view their memberships within CoP-TC and CoP-LC.

3.5.1 RQ1: What are GTAs' identities-in-practice, as constituted by their self-recognized actions, relative to CoP-TC and CoP-LC?

Table 3.2 summarizes coding of the interview data with respect to identities-in-practices in CoP-TC and CoP-LC. The Sources column refers to the number of participants who had described the corresponding action while the Number of References column refers to the frequency of every unique action participants had self-recognized. Actions that participants discussed in relation to their staff meeting were coded under CoP-TC whereas the actions participants discussed in relation to their laboratory teaching were coded under CoP-LC. Below, we discuss the details of actions in each of these two Communities of Practice.

Table 3.2. Themes related to CoP-LC and CoP-TC

Context	Identities-in-Practice	Total # of References	Actions	Sources (11 total)	# of References
Laboratory (CoP-LC)	Conducting the Laboratory	353	Sustaining Efficiency	11	116
			Getting Students to Think and Do like Chemists	11	93
			Asking or Responding to Questions	11	34
			Providing Experimental Orientation to Students	10	52
			Encouraging Good Student Interactions	10	42
			Connecting to Different Ideas	7	16
	Attending to Affects	165	Sympathizing	11	69
			Upholding Responsibility	9	37
			Developing Rapport	8	20
			Addressing Negative Stress	7	31
			Negotiating with Fear	4	8
	Drawing on Prior Experience	87	Leveraging Prior Teaching Appointments	10	29
			Incorporating Their Undergraduate Experiences	9	29
			Utilizing Previous Sections for the Same Course	2	6
			Using Different Student Groups of Same Section	2	2
	Following the Rules			11	87

Context	Identities-in-Practice	Sources (11 total)	# of References
Staff Meeting (CoP-TC)	Being Obligated to Follow the Rules	11	110
	Being Oriented to the Experiment	11	65
	Being Instructed on how to Teach	10	16

Communities of Practice of Teaching Chemistry (CoP-TC)

We identified three identities-in-practice related to Cop-TC: *Being Obligated to Follow the Rules*, *Being Oriented to the Experiment*, and *Being Instructed on how to Teach*. As shown in Table 3.2, all participants described actions related to *Being Obligated to Follow the Rules* (# of References: 116) and *Being Oriented to the Experiment* (# of References: 65) whereas ten participants mentioned actions related to *Being Instructed on How to Teach* (# of References 16). *Being Obligated to Follow the Rules* refers to participants' concern with logistical duties expected of all chemistry GTAs. Participants discussed mandatory tasks established during staff meeting, largely consisting of fulfilling clerical tasks (e.g., checking out equipment), maintaining the laboratory facilities (e.g., getting students to lock their drawers and clean their benches), and enforcing safety per the general chemistry guidelines (e.g., checking for goggles and clothing violations). *Being Oriented to the Experiment* comprised of instances where participants would reread the laboratory manual to familiarize themselves, enact strategies to complete the experiment more efficiently, and use provided slides as exposition to the laboratory for themselves and for their students. Being Instructed on How to Teach refers to recommended pedagogical moves (e.g., using post-it notes) to facilitate discussion, confidence in one's teaching, and methods to connect submicroscopic concepts to macroscopic phenomena.

Although most participants discussed all three identities-in-practice, the details of constituting actions differ. *Being Instructed on How to Teach* had fewer number of references and lacked the same degree of breadth compared to that of the other two identities-in-practice. Participants typically cited what they had learned in their teaching seminar, a compulsory course for first-year graduate students that is disparate from their teaching appointment. Because participants had integrated what they learned from a separate course into their current pedagogy, we suspect that staff meeting itself does not provide as many opportunities for GTAs to learn how to teach. As a result, this discrepancy suggests that participants strongly associate their CoP-TC newcomer membership with following the rules. We note this compliance furthermore necessitates knowing the experiment so that participants can fulfill their logistical duties. This obligation to follow the rules appears to be the most common characteristic all participants share.
Community of Practice of Learning Chemistry (CoP-LC).

Communities of Practice of Learning Chemistry (CoP-LC)

We identified four identities-in-practice related to CoP-LC: *Conducting the Laboratory* (# of References: 353), *Attending to Affects* (# of References: 165), *Drawing on the Past* (# of References: 66), and *Following the Rules* (# of References: 87). Compared to that of CoP-TC, what GTAs had described in CoP-LC was far more diverse, resulting in more saturated action codes that were categorized in broader identities-in-practice.

Conducting the Laboratory is constituted of GTAs' attending to the cognitive and social aspect of experimental work. We note that all participants described actions related to *Sustaining Efficiency*, *Getting Students to Think and Do like Chemists*, and *Asking or Responding to Questions*. These actions referred to facilitating students' laboratory experiences via fixing experimental errors, reinforcing proper chemistry techniques, and clarifying ambiguities within the protocol respectively. With surface-level interpretations, it appears that GTA-student engagement in the laboratory is quite prominent. However, upon deeper inspection, we note that the meaning of such interactions is predominantly based on the premise of correcting and troubleshooting. We note that actions related to facilitating students' chemistry sensemaking with the experiment are largely absent from participants' narratives. As a result, participants may feel more obligated ensuring the successful completion of students' experimentation while guiding students' chemistry understanding takes lower priority.

The identities-in-practice *Attending to Affects* and *Drawing on Prior Experience* showcase how teaching in the CoP-LC is complex. Attending to Affects refers to bringing in emotionality to teaching that guide or justify participants' interactions with students. All participants described *Sympathizing* within *Attending to Affects*. Here, *Sympathizing* means when participants would imagine themselves as their students. Participants talked about having empathy for the exhaustive nature of chemistry laboratories or anticipating moments where students may be confused with the experimental protocol. Together with *Upholding Responsibility* (e.g., holding oneself accountable for students' laboratory performance), *Developing Rapport* (e.g., building solidarity with students), *Addressing Negative Stress* (e.g., creating a more pleasant laboratory environment), and *Negotiating with Fear* (e.g., being concerned with the daunting nature of teaching), participants understand CoP-LC to be a challenging environment where they feel compelled to create a more positive and respectful ambiance for themselves and their students. In addition, participants appear to recognize teaching in CoP-LC to be more than a cognitive process, demanding attention to affects as well. The nuanced strategies participants self-recognize reinforce that each laboratory teaching context is unique and requires careful navigation to effectively sustain ideal student engagement in the laboratory.

Drawing on Prior Experience consists of participants utilizing previous teaching and learning experiences (e.g., past semesters, prior laboratory sections, their own undergraduate experiences) to inform their teaching. Almost all participants mentioned *Leveraging Prior Teaching Appointments* to guide their current teaching. Participants would evaluate what approaches worked in the past and reconsider alternative routes for more efficient implementation of the experiment. In conjunction with *Incorporating their Undergraduate Experiences* (e.g., modeling previous GTAs or instructors' pedagogy), *Utilizing Previous Sections for the Same Course* (e.g., relying on prior experience of the same experiment), and *Using Different Student Groups of Same Section* (e.g., using students' performance and data to gauge progress of other students), we interpret that participants are actively making sense and customizing their teaching to better fit their students. Participants' learning to teach appears to be an ongoing process that involves constant negotiation of new actions to address the emergent and complex demands of teaching within their laboratories.

The last identity-in-practice *Following the Rules* (# of References: 87) was mentioned by all eleven participants. We note that actions which constitute *Following the Rules* were so homogeneous that the research team could not meaningfully distinguish and categorize these actions like those of other CoP-LC identities-in-practice. As a result, *Following the Rules*, like CoP-TC identities-in-practice, does not have an explicit list of coded actions. There appears to be correspondence between *Following the Rules* and *Being Obligated to Follow the Rules* in terms of both the number of participants and references. Both identities-in-practice share analogous actions, a sensible connection given that the rules GTAs abide by in CoP-LC are intrinsically transferred from CoP-TC. What this shows is that despite the vast differences in actions and identities-in-practice between CoP-TC and CoP-LC, the two CoPs nevertheless overlap. Specifically, how GTAs negotiate their CoP-LC membership requires CoP-TC features (e.g., rules) as an initial template. We recognize that how participants learn to teach is an integrative process that begins with their obligation to abide by expectations established in staff meeting and is later adjusted by their desire to help students succeed in the laboratory.

In summary, our analysis shows that participants' membership as CoP-TC newcomers is more limited and uniform. Participants discussed following the rules as the dominant identity-in-practice for CoP-TC, indicating a passive experience that lacks opportunities to explore the learning of teaching in conjunction with the experiment. However, participants' experiences as CoP-LC old-timers were far more diverse in actions and identities-in-practice. Our analysis conveys that there are numerous ways in which participants negotiate their teaching, showcasing the complex and unique experiences within each laboratory section. In CoP-LC, GTAs are active sensemakers of their pedagogy as they draw upon multiple resources from to address the various demands of laboratory teaching. For the second half of our findings, we will portray in detail how GTAs reconcile their multimembership, mitigating the limited identities-in-practice enabled in CoP-TC and authoring more expansive identities-in-practice in CoP-LC. Our analysis demonstrates how CoP-TC transforms GTAs' interpretations of CoP-LC teaching, creating various meanings and consequences that the literature has yet to explore.

3.5.2 RQ2: How do GTAs negotiate their multimemberships between CoP-TC and CoP-LC through boundary objects and brokering?

To answer RQ2, we use capital D Discourse analysis to better understand how GTAs negotiate their multimemberships between CoP-TC and CoP-LC via brokering and boundary objects. Accordingly, we organized our interview transcripts into excerpts framed within the three communal components: mutual engagement, joint enterprise, and shared repertoire. This level of analysis will better elucidate how these contextual meanings fit together as a broader storyline to characterize not only the GTA's identity-in-practice but also the communal interactions between CoP-TC and CoP-LC, from the perspective of focal participants. Below, we present three participants: Selina, Richard, and Dani.

Selina

Selina is a Latina female in her second year of her PhD program. Selina has a background in education research which provides her with more experience in research-based instructional strategies that may inform her enacted actions within the CoP-LC. We note Selina's identities-in-practice to primarily consist of *Being Oriented to the Experiment* (CoP-TC) and *Conducting the Laboratory* (CoP-LC). With these two identities-in-practice, we show how Selina negotiates her teaching to ensure that students get a good grade on the laboratory report but at the potential expense of their chemistry understanding.

First, Selina brokers between CoP-TC and CoP-LC by translating practice via her usage of slides, laboratory manual, and students' laboratory grades.

> "They provide us the slides you know? … This is what we're gonna do. This is the data you're gonna get. How you're gonna analyze it…so that's how I prepare. I take the slides…and fill like important information like by me reading the lab manual. And then I present it to them"

This quote demonstrates how Selina (as a newcomer) is oriented to the experiment in CoP-TC. Using shared repertoire, such as laboratory manual and slides, old-timers in CoP-TC inform GTAs of teaching preparation. As shown in her statement "they provide us the slides," old-timers in CoP-TC ("they") create and sustain such shared repertoire without much input from GTAs while GTAs ("us") are obligated to meet expectations established by old-timers. Selina's description of slides ("this is what we're gonna do. This is the data you're gonna get. How you're gonna analyze it.") indicates that joint enterprise in CoP-TC encourages her to methodically attend to laboratory experiment. Selina's meticulous recounting of information in the slides and lab manual reinforces that what she deems important in CoP-TC is the mechanics of the experiment, not its relevance to chemistry understanding.

Her exclusive focus on the mechanics of the experiment is shown in the following quote as well:

> "I'm there to guide them throughout the experiment but then again that's what they follow like step-by-step in the manual. … [If a student says] 'I have a question about this particular step or whatever is I'm doing' then I'm there to help them out."

This quote conveys that Selina is mutually engaged with her students in the lab by giving information and responding to their questions. This action represents how Selina orients her undergraduate students to the experiment. Selina sees her role in the CoP-LC as someone who guides undergraduate students by telling students exactly what to do step-by-step. Selina's assisting of students when they "have a question about this particular step" supports that her actions in CoP-LC center around completing the experiment and potentially preventing mistakes more so than teaching underlying chemistry.

She further mentioned,

> "You [interviewer] brought up a good point like connecting the chemistry to the whatever they're doing in lab…I don't think I do it explicitly…I don't think we do it explicitly."

Although her statement, "I don't think I do it explicitly" might mean that her teaching of chemistry concepts is inherently implicit, her previous emphasis of helping students stepwise like a manual rather suggests she does not connect the chemistry to the experiment. Her choice of "we" in "I don't think we do it explicitly" shows that conceptual teaching may not be a form of mutual engagement in the laboratory in many other GTAs' labs as well. As shown in these interview quotes, Selina uses the laboratory manual and slides as boundary objects in brokering between the two communities. While these resources are supposed to help undergraduate students' learning, in both CoP-TC and CoP-LC they are actually used as a strict guideline for doing experiments. As Selina was oriented to completing the experiment in CoP-TC, she orients her students to the completion in CoP-LC.

Another important way that Selina brokers between the two communities is through grading:

> "I would literally just straight up tell them like in your observations everything you see just write it down. … Like if there's a section on the report that says observations, I tell them like write everything. … I don't know what I have to grade so you just put everything there and that way we would be like safe"

In this quote, Selina describes that she asks students to record everything to avoid point losses on their laboratory reports. By telling students to record everything, Selina sympathizes with her students and shows her intention to have her students' performance properly recognized. Selina's usage of the word "we" in "that way we would be like safe" signifies that both she and her students share the goal of scoring well on the report. We note that a student's grade is another important boundary object that moves between the two communities. Because Selina, as a newcomer in CoP-TC, is not involved in designing the grading key, she cannot anticipate how her students will be assessed. In this context, she assumes her role in brokering between the two communities as someone who encourages students to hunt for right answers by recording everything. Consequently, students who record everything may not understand how experimental phenomena relate to broader chemistry concepts. Selina's grading responsibilities incentivizes her teaching to hedge students' performance, resulting in students who potentially get a good laboratory report grade without the chemistry understanding that the experiment was prescribed to facilitate.

Richard

Richard is a White male in his second year of the PhD program. Considering Richard's intentions to pursue careers in industry after his program, his perspectives on teaching during the interview were unenthused, often describing teaching as an interference to his biochemistry research. Throughout his interview, Richard's identities-in-practice prominently resembled *Being Obligated to Follow the Rules* (CoP-TC) as well as *Conducting the Laboratory and Attending to Affects* (CoP-LC). Accordingly, we portray a narrative in which Richard's emergent pedagogy motivates students to complete the experiment efficiently but at the cost of constraining their sensemaking with their experiment.

How Richard reconciles his multimembership first requires understanding his grading experiences in CoP-TC. Responding to the question of what resources would be beneficial for his teaching, Richard elaborates by suggesting specific changes to the design of the laboratory report:

> “Instead of the lab notebook pages, you just have tables and stuff formatted so it's ready to take the data…you could even create software where you can just take a picture of [the report] and then get something where you have all the answers like right or wrong. I'd feel like that be a great tool for us to cut down on the TA's time on doing tedious, meaningless or seemingly meaningless work.”

Richard dislikes the CoP-TC joint enterprise of grading, describing it as “tedious, meaningless or seemingly meaningless work.” By suggesting software that can automatically grade answers either right or wrong, Richard clearly wants grading to be more convenient. As a newcomer in CoP-TC, Richard is not involved in designing shared repertoire such as student assessments. What old-timers in CoP-TC have provided appears more impractical, evident from Richard’s envisioning of a more streamlined laboratory report (“tables and stuff formatted so it’s ready to take the data”). Furthermore, Richard’s desire for time-efficiency may not be his alone. His statements “the TA’s time” instead of his time and “us” in “a great tool for us” suggest that Richard recognizes fellow GTAs who are also disgruntled with their CoP-TC time commitments. Newcomers like Richard may feel unsupported by CoP-TC where extant shared repertoire and its lack of feasibility for GTAs make joint enterprises like grading harder to fulfill.

Richard further states:

> “And have the TA focus more time with like the students or like you know going over the conceptual types of things and giving feedback on like the long paragraph answer instead of just ticking away the numbers or the set-in-stone answers.”

Richard recognizes grading to be either providing feedback on students’ conceptual sensemaking or checking the correctness for more straightforward responses. Richard’s words “ticking away,” “numbers,” and “set-in-stone answers” suggest that the latter is more monotonous in which students’ answers are less substantial. Despite such perspectives, Richard defaults to this verification-style of grading. Richard claims that designing the laboratory report differently would allow more time for “going over the conceptual types of things and giving feedback.” Richard wants the checking task to be more time-efficient so that he can spend more time giving students conceptual feedback. Richard’s assertion conveys that CoP-TC obligates newcomers like himself to spend more time attending to non-conceptual questions within the laboratory report. Because Richard’s ideas of assessment remain unincorporated, CoP-TC old-timers have inadvertently contributed to Richard’s trivialization of his duties and the compromising of his membership development.

Richard’s frustrations extend beyond his CoP-TC responsibilities and into his actions situated within CoP-LC. When prompted to describe the challenges Richard faces in his laboratory teaching, he emphasizes his students’ lack of enthusiasm:

> “I feel like I'm being negative, and the students just pick up on it and just kind of mimic that. I also try to bring in cool little tidbits or facts or things. And when I first introduce myself and stuff, I talk a little bit about my research. It's challenging to keep them enthused but I think some of those things help, just trying to be positive…have a little fun”

Richard mutually engages with his students by creating an enjoyable laboratory environment. The words “cool,” “enthused,” “positive,” and “fun” represent the foregrounding of positive affects in his pedagogy. We recognize that Richard’s affect-centered pedagogy is a result of brokering. Because Richard is discontent (“being negative” and “trying to be positive”) with CoP-TC responsibilities like grading and facilitating the laboratory, he mirrors similar sentiments onto his students. As a CoP-LC old-timer, Richard attends to his students’ motivation as a response to how GTAs like himself remain unsupported in CoP-TC. Richard also relies on his membership to a research group to facilitate his mutual engagement with students. Richard’s research, originally meant for publication or the pursuit of his doctoral degree, becomes a boundary object that is simplified (“a little bit about my research”) to generate more laboratory appeal. Richards’ statements altogether convey that the joint enterprise of being positively motivated is his precedent for students’ CoP-LC participation.

How Richard handles students’ experimental errors is another application of his brokering:

> “I tell [students], ‘Sorry you have to restart and you're going to be here for an extra hour’ when everyone else is getting out of the lab. They're basically kind of like, ‘Oh dang we messed up.’ I hope that consequence of the extra time that they're spending is an ‘alright maybe next time I will know what's going on.’”

Richard’s instructing students to restart suggests that CoP-TC necessitates successful completion of an experiment for a good laboratory report score. In addition, Richard’s sympathy with “Sorry” and his statements juxtaposing “be here for an extra hour” with “everyone else is getting out” reinforce that students, like himself, do not enjoy spending extra time in the laboratory. Because Richard wishes CoP-TC old-timers would provide newcomers more time-efficient tasks, he brokers between two communities by incorporating early completion of the experiment as a reward for students. By hoping “that consequence of the extra time” will encourage students to responsibly “know what’s going on,” Richard incentivizes students’ success by attending to and leveraging their desire to leave. However, Richard's teaching may implicitly encourage rote experimentation. Students who quickly and correctly complete the laboratory may not understand the connections to broader chemistry concepts. The laboratory would be less purposeful as students would enact experimental mechanics without realizing the underpinning rationale.

Dani

Finally, Dani is an African female who is in her second year of the PhD program. She neither described teaching as a benefit nor a detriment to her own graduate student schedule, but we do recognize her ambition to fulfill her teaching appointment appropriately. Dani's identities-in-practice are most related to *Being Oriented to the Experiment* (CoP-TC) as well as *Conducting the Laboratory* and *Drawing on Prior Experience* (CoP-LC). How Dani incorporates these identities-in-practice becomes a laudable teaching approach that connects chemistry with more relevant topics grounded in students' interests. However, Dani's consequential portrayal of the laboratory becomes problematic as she inherently minimizes its relevance to students.

We begin with Dani's experiences as a CoP-TC newcomer that serves as the impetus guiding her multimembership negotiation. When asked what Dani finds to be helpful and unhelpful, she specifically recounts her experiences attending staff meeting:

> "I feel like staff meeting could be an email sent out and that sometimes it feels like no reason to meet like someone's just reading to you the same PowerPoint that you're going to get a copy of, the same prep-lab notes … staff meeting could be like, 'Are there any questions? Is there anything you want to bring up about the previous week's lab that you noticed, so that it could help next semester's lab?'"

Dani's statement, "sometimes it feels like no reason to meet" conveys her dissatisfaction with staff meeting. This is likely due to the interactions between GTAs and staff meeting coordinators. CoP-TC mutual engagement consists of newcomers listening to old-timers' reading of resources ("the same PowerPoint" and "the same prep-lab notes") the latter will still receive. Dani's suggestion that "staff meeting could be an email sent out" indicates in-person staff meetings do not substantially contribute more insight than if she were to read the materials herself. As a response, Dani wishes that staff meeting could involve more of GTAs' input ("any questions," "anything you want to bring up," and "you noticed"). Dani wants to create more opportunities for newcomers like herself to actively participate in the discussion of teaching. In doing so, Dani hopes to reposition her identity as an important CoP-TC member who can contribute, an action that is currently limited to CoP-TC old-timers.

Dani further elaborates her actions during a typical staff meeting to negotiate her circumstances:

> "So, I always try to read over the lab [manual] before staff meeting, so at least when we are going over it, I already have an idea and I've already written some questions that I may be confused about, so I can get it out of the way."

Dani prepares for her laboratory teaching meticulously, shown by her statements "always try to read," "already have an idea," and "already written some questions." Specifically, Dani uses her CoP-LC old-timer insight to find ambiguities within the laboratory manual ("I may be confused about"). These ambiguities, whether related to the protocol or chemistry concepts, risk inciting confusion among her students. We thus interpret Dani's preparations as her brokering to prioritize her students' experimental success. Dani leverages her CoP-LC old-timer role to actively ask questions ("get it out of the way") instead of passively listening during staff meeting, making the otherwise unproductive CoP-TC mutual engagement more beneficial. In her brokering, the laboratory manual is an important boundary object. What facilitates CoP-LC newcomers to learn chemistry in the laboratory becomes a tool for Dani to improve her teaching. Altogether, Dani's brokering conveys that although she may dislike current CoP-TC mutual engagement, she nevertheless endeavors to fulfill the joint enterprise of successfully teaching.

Despite her preparations, Dani still recounts her difficult experiences as a CoP-LC old-timer, reiterating that the support CoP-TC old-timers currently provide is insufficient. When asked to describe a representative day of the laboratory, Dani talks about struggling to address the overwhelming demands of the students. Dani mitigates this issue by implementing her question rule: Students must ask their benchmates first if they have a question. If no one at the bench has the answer, then students must ask their peers at a different bench for help before consulting Dani. She later adds:

> "I wasn't able to notice what was going on because I was too busy going around, so that's when I was just like, 'You guys, you need to ask each other because you need to be able to communicate. No matter what job you do when you leave here, if you can't find out information and if you can't communicate with your colleagues, you're going to have a difficult time.'"

Dani's rule of encouraging student collaboration serves dual purposes. First, Dani mutually engages with students by monitoring what they do in the laboratory and answering their questions in order to maximize their success. We note that these two actions are prescribed by CoP-TC old-timers as recommended pedagogical moves. However, due to the volume of questions ("always running around" and "too busy"), Dani cannot effectively oversee her students' experimentation to prevent potential errors. Dani negotiates by enforcing her question rule to make these actions obligated by CoP-TC more feasible. Second, Dani's question rule reflects an emergent CoP-LC joint enterprise. The statement, "No matter what job you do when you leave here" indicates Dani's recognition that communication skills students develop in CoP-LC can be relevant for future, non-chemistry contexts. Dani, unlike CoP-TC old-timers, invites students to engage with and contribute to each other's sensemaking, thereby encouraging newcomer participation and strengthening their membership development.

Dani further elaborates on the interconnections between CoP-LC and future contexts outside of chemistry.

> "When I was teaching the nursing majors, I was trying to give them examples like you have to read your procedure, you have to know what's on there because if you can't read a procedure, how will you read a patient's chart? It's not just we are making you do cook-book labs and you know, there is a reason that you need this skill when you leave."

By paralleling CoP-LC shared repertoire ("procedures") to that of nurses ("patient's chart"), Dani contends that students learn CoP-LC skills that are applicable in nursing careers. Dani's pedagogy may stem from her desire for more meaningful experiments. Using the term "cookbook labs," Dani assumes the laboratory does not intellectually and authentically engage with students. Dani responds by advertising CoP-LC to be more student-relevant ("there is a reason"), an action which we recognize to be a nuance of her brokering between CoP-TC and CoP-LC. Whether making staff meeting more productive by asking questions or connecting the laboratory to non-chemistry contexts, Dani brokers actions that foreground newcomer benefit. Dani's brokering reconciles CoP-TC or CoP-LC contexts that may otherwise bar either her or her students' newcomer membership formation.

However, it is problematic that Dani's pedagogy demonstrates that CoP-LC, without her advertising, does not fully support newcomers' participation. We note that Dani teaches a chemistry course for non-chemistry majors. Dani may assume that her students are intrinsically demotivated because neither the experiment can meaningfully support their chemistry learning nor is the chemistry content related to their interests. Dani's emphasis of nursing in lieu of chemistry, although an effective hook, may consequently disregard the experiments' inherent value. In other words, it is likely that Dani less frequently capitalizes on the connections between the experiment and students' chemistry sensemaking due to her lackluster opinion of the laboratory itself. What Dani deems to be beneficial for her students consequently detracts from the chemistry understanding CoP-LC was intended to facilitate.

3.6 Discussion

As Stains (2019) has noted, researchers must investigate the processes of learning situated in the laboratory to better understand the underexplored experiences of general chemistry GTAs. We have responded to these calls by foregrounding GTAs' perspectives as essential components for understanding what transpires in the laboratory. Addressing RQ1, our data analysis had shown emergent identities-in-practice that both reiterate and expand previous findings in the literature. In CoP-TC, emergent GTAs' actions were more uniform and limited than those in CoP-LC. Such CoP-TC actions culminated into identities-in-practice that primarily consisted of following rules and facilitating the experiment more so than learning to teach. This finding is unsurprising considering how laboratory training often prioritizes familiarizing GTAs to the conducting of the experiment (e.g., Dragisich et al., 2016). GTAs may feel more obligated as CoP-TC newcomers to understand laboratory teaching and learning to be more confirmatory and high-throughput where fostering students' understanding of chemistry is eclipsed by the need to maximize experimental efficiency.

Our findings for RQ1, however, convey that GTAs' teaching experiences are nuanced, even within the obligations set forth by CoP-TC. Participants' descriptions of how they would conduct their laboratory, attend to affects, and draw on their prior experience demonstrates that GTAs are active sensemakers of their pedagogy. Considering how participants leveraged their insights, experience, and knowledge, we forward that conceptions of GTA's chemistry teaching in existing literature are limited. Our data analysis shows that GTAs author intricate pedagogies to effectively address various factors and meet a variety of demands. Such insight would not have been possible if GTAs' chemistry pedagogy were decontextualized in terms of the affordances and limitations inherent within GTAs' membership to CoP-TC and CoP-LC. In other words, the nature of GTAs' teaching is everything but straightforward when accounting for how salient context informs emergent meaning.

First, we offer a counterpoint against the typical claim that general chemistry GTAs lack sophisticated pedagogical knowledge (Bond-Robinson & Rodriques, 2006), becoming barriers to undergraduate learning (Addy & Blanchard, 2010). Our analysis shows that GTAs negotiate pedagogies that, although may be unaligned with what is recommended in the literature, might have been their best choice within the context of CoP-TC and CoP-LC. In other words, the focus should not primarily be on GTAs' limited pedagogical knowledge and skills, but include the absence of appropriate support to encourage GTAs to enact more meaningful pedagogy. Second, the implied notion that GTAs' prior experiences are unproductive for their learning to teach (Roehrig, Luft, Kurdziel, & Turner, 2003) is in itself unproductive. Instead, we agree with Fairbrother (2012) who notes that GTAs do possess rich resources to inspire and transform their teaching. As shown with our participants, GTAs utilize available materials, their research, and their students to create sophisticated teaching methods that may unfortunately go unnoticed due to this pervasive deficit model. We forward that better recognizing the resources GTAs possess is the first step towards encouraging and legitimizing their learning to teach.

Addressing RQ2, our three focal participants showcase that their teaching may have problematic side effects despite good intentions. For instance, due to CoP-TC shared repertoire of slides and laboratory manual, Selina's teaching overly ensures her students' CoP-LC success such that a good laboratory report score can be procured without understanding the experimental phenomena itself. Because of Richard's discontent with CoP-TC's joint enterprise of grading, his teaching similarly mirrors the need for efficiency where CoP-LC learning is reinterpreted as completing the experiment both timely and perfectly. Finally, Dani's dissatisfaction with CoP-TC mutual engagement in which newcomer benefit is sparse shapes a CoP-LC pedagogy that motivates students at the expense of minimizing the value of the experiments themselves. Based on our findings, we show the necessity with involving context to understand GTAs' teaching that other studies (e.g., Velasco et al., 2016) have yet to do. Addressing GTAs' emergent pedagogy must first begin with its conceptualization as a cumulative process that accounts for both inputs (e.g., CoP-TC and CoP-LC features) and outputs (e.g., influence on students' chemistry sensemaking).

Our RQ2 findings more finely elucidate the intricacies between CoP-TC and CoP-LC. Just as how curriculum can affect GTAs' emergent pedagogy (Current & Grunert Kowalske, 2016), the social context of a presiding CoP influences GTAs' negotiation of what they learn and what they do. In conjunction with our RQ1 findings, our focal participants' narratives convey that newcomer GTAs may understand the CoP-TC identity-in-practice to be less related to teaching chemistry. Instead, GTAs as CoP-TC newcomers likely view their training to become better chemists as opposed to better teachers. More specifically, GTAs are pushed to develop an identity of someone who can conduct and troubleshoot an experiment for students as opposed to someone who can teach with the experiment. Both CoP-TC and CoP-LC expectations appear to be misaligned, creating a vague space in which GTAs are left to their own devices to negotiate potential solutions. Like Muzuka's (2009) work, our study exemplifies that GTAs' identities, especially considering their training and teaching, are largely unacknowledged in existing literature. Analysis restricted to CoP-TC and CoP-LC already offers new insight that otherwise may have been lost with more surface-level observations.

We reinforce that the purpose of this study is not to assign fault to our participants. Our study instead forwards the perceived lack of support, motivation, and incentive for GTAs to leverage the chemistry experiment to foster their students' sensemaking. Such perspectives may be traced to the initial assumption that GTAs lack any productive knowledge about teaching. We speculate that there are few systems in place that invite GTAs to share their experiences to improve both CoP-TC and CoP-LC. In addition, the professional culture in which research is valued over teaching may dissuade doctoral students from developing and pursuing their interests in teaching (Lane, Hardison, Simon, & Andrews, 2018). Given such contexts, it becomes sensible for our participants to perceive their training as information dissemination to become better chemists as opposed to reflective discussion to become better teachers. These institutional structures sustain an alarming divide between the learner-centric, collaborative, and inquiry-based nature of undergraduate learning in CoP-LC (e.g., Budner & Simpson, 2018; Hein, 2012) and, as described by our participants, the non-pedagogical nature of CoP-TC. If GTAs are expected to facilitate these types of environments for learning chemistry, then GTAs must similarly have opportunities for learning how to teach.

CHAPTER 4. SUCCESS-BASED VS. FAILURE-BASED LEARNING THEORIES

Based on the findings of Chapter Three, revisiting how researchers have conceptualized failure and success became a necessary task before progressing further with the overall research project. I specifically aimed to explore how the literature has previously utilized failures productively, the benefits or lack thereof, and the theories that situate the corresponding rationales. For this chapter, I present a literature review that introduces theories of learning from failure. I delve deeper into the historical context, comparing not only how learners' successes and failures are operationalized but also how such definitions have shaped the resultant curricula design. Finally, to narrow my attention towards design principles, I use a more relevant example of video games to explore similarities with the chemistry laboratory. I discuss how certain video game design principles can transform the laboratory context, creating a space more suitable for productively learning from failure.

4.1 Theories of Learning from Failure

Failure has harshly negative connotations that are difficult to separate. For instance, failure within learning environments has undesirable implications of being unable to obtain an expected grade (Bidjerano, 2010), dropping out of school (Khan, Ahamad, & Koursar, 2013), and negative emotional states (Cetin, Ilhan, & Yilmaz, 2014). Failure also conveys a social identity that alludes to character flaws, moral shortcomings, and worthlessness (Sandage, 2005). With all of these associations, it is sensible that learners are hesitant to use their failures to ask questions, be open to ideas, and develop appropriate skepticism for conceptual development (Stein & Muzzin, 2018). In order to efficaciously rebrand failure, there needs to be a strong theory that informs practice such that social norms around failure can be renegotiated for productive and meaningful sensemaking.

Failure has been incorporated into a variety of cognitive frameworks, all of which overlap in their conceptualizations about learning. For instance, impasse-driven learning argues that opportunities for sensemaking strictly occur when learners experience a temporary mental block in their problem-solving activities (VanLehn, 1988). When progress can no longer be made, the learner would leverage different resources (e.g., the instructor, peers, and the textbook) to generate the canonical solution (VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003). Another perspective is Problem Solving before Instruction (PS-I) which foregrounds learners' production of hypothesis and their modeling of unfamiliar topics before explicit instruction (Loibl, Roll, & Rummel, 2017). Brand and colleagues (2019) show that although students struggle producing a comprehensive model throughout this inquiry activity, PS-I may promote learners' awareness of conceptual gaps to restructure their understanding. Finally, productive failure (PF) is a theory that explains how design principles can capitalize on their failures to sustain their future learning (Kapur, 2016). Similar to the aforementioned theories, PF consists of two phases in which students explore oftentimes incorrect ideas and later consolidate their reasoning (Kapur & Bielaczyc, 2012). Studies that use PF have reported positive learning outcomes such as improved problem-solving skills, greater depth of conceptual understanding, and better preparation for future learning (Steenhof, Woods, Van Gerven, & Mylopoulos, 2019).

These perspectives altogether convey that delaying instruction and encouraging learners to produce conceptions regardless of the correctness can be beneficial (diSessa, Hammer, Sherin, & Kolpakowski, 1991). Learning from failure becomes an exploratory, non-linear process with frequent changes in direction, sudden dead ends, and unanticipated outcomes (Brown, 2009). Instead of being perceived as a singular event of insight, understanding becomes a continuum of brief failures that progresses towards eventual success. It is important to note that learning from failure is not an advocacy for a paradigmatic shift in how learning and teaching should be conceived. Instead, advocates for meaningfully utilizing failures highlight the new affordances in which learners can invent epistemic resources for tinkering with context-specific problems (Hammer, Elby, Scherr, & Redish, 2005). Developing a stronger repertoire that consists of these resources may be a more productive approach for both advancing and sustaining learners' performances and experiences.

4.2 Successes and Failures in Learning

Introducing PF first requires describing how researchers have historically conceptualized successes and failures throughout the learning process. Indubitably, the topic of instructional design which underpins problem-solving activities has been thoroughly explored in the fields of education and the learning sciences (Tobias & Duffy, 2010). Eventually, a large body of research began to reach consensus: instruction must be paired with heavy guidance in the beginning because in the latter's absence, learning will not occur (Kirschner, Sweller, & Clark, 2006). A commonly cited rationale to support this claim is cognitive load theory. It predicts that new concepts with a large amount of interrelated details would overload learners' working memory and lead to little retention (Sweller, Ayres, & Kalyuga, 2011). Providing instruction first before the problem-solving activity has grown to become a popular standard of orchestrating the learning context. Typically, instructors would first provide guidance that remove degrees of freedom such that learners are more likely to succeed in their later activities (Wood, Bruner, & Ross, 1976). Instructors would over-time gradually remove these "sensemaking training wheels" once learners develop a more comprehensive understanding (Puntambekar & Hübscher, 2005).

This initial approach to prioritizing success via guidance is what Kapur (2016) defines as *productive success*, in which the goal is help learners achieve "both improved performance on problem-solving and sustainable learning" (p. 289). This entails instructors creating a learning context that maximizes short-term performance which enables long-term learning. For example, Puntambekar and Kolodner (2005) conducted a study that showcased the benefits of utilizing problem-based learning activities in an eighth grade classroom exploring erosion management. Their findings claim that learners need multiple forms of support, facilitated by different tools or agents, to enable successful problem solving (i.e., short-term gains) and learning (i.e., long-term gains). However, researchers have begun to problematize the learning context when guidance becomes too heavy-handed. Explicit guidance may actually be detrimental to learning, restricting attention to procedures as opposed to contextual features in which the procedures become relevant (Reber, 1989, Schwartz, Lindgren, & Lewis, 2009). Instruction with a deluge of scaffolding, despite leading learners to produce correct solutions, may discourage learners from developing the ability to generate novel solutions in the future (Kapur, 2014). Learners who superficially accept the canonical answer may not fully grasp the nuanced features of the problem (Chowira, Smith, Dubois, & Roll, 2019). Such conditions that maximize short-term performance without maximizing long-term learning is what Kapur (2016) defines as *unproductive success*.

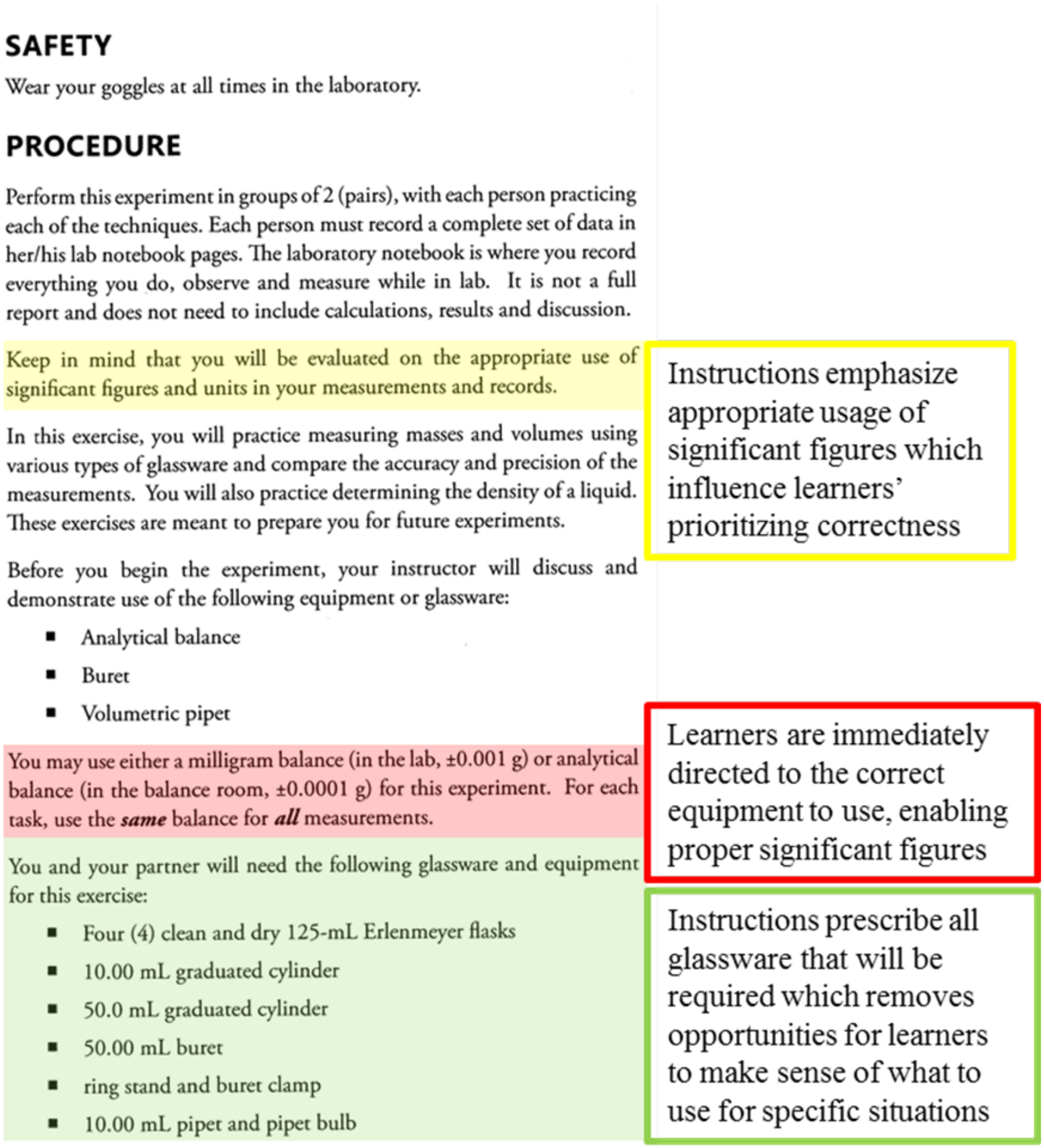
Kapur provides an alternative solution to counter the conundrum of guidance potentially hindering learners' future experiences. Known as *productive failure*, this perspective foregrounds learners' failures as an essential component to their sensemaking process. Kapur (2008) defines failure as the inability to independently create the canonical solution. Productive failure starts with a novel, complex problem for which learners must "generate and explore the affordances and constraints of multiple solutions" (Kapur, 2016, p. 292). Once learners have created a repertoire of approaches, many of which may be suboptimal or incorrect, they transition into the consolidation phase. Instruction here involves creating "opportunities for comparing and contrasting, organizing, and assembling" learners' previous ideas into a mutually-agreed upon solutions (p. 292). By switching the order and foregrounding problem-solving as the primary activity, productive failure aims to maximize long-term learning, even at the expense of short-term performance. Thus, acquiring the solution is no longer the foremost goal of problem-solving (Schwartz & Martin, 2004). Instead, educators guide learners to attend to the problem's context and develop understanding of what is both known and not known. Recent studies have begun to show the efficacy of productive failure, accumulating more evidence that suggests learners who undergo failure first can more effectively learn from instruction later (e.g., Sinha et al., 2019).

Whether instruction comes before or after the problem-solving activity establishes a divide between those who support cognitive load theory and those for PF. On one side, researchers have shown that success-driven templates of the learning activity (i.e., instruction first) characteristically comprises of pro-active error elimination and immediate feedback (e.g., Chin, Chi, & Schwartz, 2016). In doing so, instructors enable better performance and more effective learning among novice learners (e.g., Mayer, 2004; Schwonke et al., 2009). These instructors who prevent errors are inherently minimizing the scenario of *unproductive failure*, a context that neither maximizes short-term performance nor long-term learning (Kapur, 2016). On the other side, Kapur notes that if unguided problem solving were an issue, the solution should not involve overindulging on guidance. Kapur instead argues that it is more efficacious to attend to how learners' failures are incorporated in later instruction. Namely, instructors who adopt a failure-driven perspective (i.e., problem-solving first) recognize that the mistakes others strive to prevent actually do not harm learning (e.g., Roelle & Berthold, 2016). Withholding guidance and creating a space of initial failure may have more benefits relating to learners' curiosity, motivation, and their agency to make sense of and generate solutions (Kapur & Bielaczyc, 2012). By priming learners to invent first, instructors can then capitalize on the formers' sensemaking to ensure more comprehensive understanding (Roll, Aleven, & Koedinger, 2011).

Both sides have ample evidence to justify their claims, so the question should not be which of the two is superior. Instead, the resolution to this debate should be directed at the context of the problem as opposed to the approach itself. Ashman, Kalyuga, and Sweller (2020) show instruction first is superior when the problem is overly complex and learners' proficiency is low. However, their findings also convey that as learners develop expertise and problems become less complex, problem-solving first then becomes more effective for conceptual understanding. Furthermore, Ashman and colleagues' study indirectly supports an additional proposition: aspects of productive success and productive failure can co-exist. As Kapur (2016, p. 296) notes:

> "…we need to abandon the dichotomy between unguided problem solving and heavily guided direct instruction. There is a large design space in between the two extremes that can be exploited to achieve optimal learning."

Kapur shows that it is potentially more problematic to completely side with just one end of the argument. Consequently, I turn my attention to the chemistry laboratory which I suspect is overly success-driven. Although the chemistry laboratory is designed to be an inquiry-based learning space, there may exist tensions due to the predilection to minimize *unproductive failure*. Namely, researchers respond by bounding or guiding the inquiry process such that short-term success is more probable which inadvertently devalue learners' failures throughout their sensemaking process (Chan & Yang, 2018). There may exist so much guidance in written laboratory curricula that it transforms learning into a linear and uniform process (Duffy & Raymer, 2010). For example, one can observe the implication for avoiding unproductive failure in a laboratory manual excerpt taken from an authentic general chemistry curriculum in Figure 4.1.



SAFETY

Wear your goggles at all times in the laboratory.

PROCEDURE

Perform this experiment in groups of 2 (pairs), with each person practicing each of the techniques. Each person must record a complete set of data in her/his lab notebook pages. The laboratory notebook is where you record everything you do, observe and measure while in lab. It is not a full report and does not need to include calculations, results and discussion.

Keep in mind that you will be evaluated on the appropriate use of significant figures and units in your measurements and records.

In this exercise, you will practice measuring masses and volumes using various types of glassware and compare the accuracy and precision of the measurements. You will also practice determining the density of a liquid. These exercises are meant to prepare you for future experiments.

Before you begin the experiment, your instructor will discuss and demonstrate use of the following equipment or glassware:

- Analytical balance
- Buret
- Volumetric pipet

You may use either a milligram balance (in the lab, ±0.001 g) or analytical balance (in the balance room, ±0.0001 g) for this experiment. For each task, use the ***same*** balance for ***all*** measurements.

You and your partner will need the following glassware and equipment for this exercise:

- Four (4) clean and dry 125-mL Erlenmeyer flasks
- 10.00 mL graduated cylinder
- 50.0 mL graduated cylinder
- 50.00 mL buret
- ring stand and buret clamp
- 10.00 mL pipet and pipet bulb

Figure 4.1 An excerpt of a general chemistry protocol

This overt emphasis on correctness in terms of data analysis, laboratory technique, and equipment usage, highlights that the design of the chemistry laboratory is implicitly success driven. Although these scaffolds may push learners to perfectly complete the experiment, this degree of explicit guidance may also potentially detract from learners' understanding of the rationale for and consequences of their approaches. In other words, learners may not understand how or why their mistakes influenced their experimentation given that opportunities to encounter and engage with mistakes are sparse. Thus, general chemistry laboratories may risk promoting unproductive success if learners' failures continue to be prevented so extremely.

4.3 How Video Game Design Can Create Learning Opportunities from Failure

To ground the theoretical conceptions of PF in a more tangible example, I turn my attention to video games, a genre which has a rich and well-developed history of research. Since the release of Atari's 2600 Video Computer System in the late 1970s, the industry of video games has rapidly dispersed and etched its place in financial, social, and technological histories (Lastowka, 2009; Skolnik & Conway, 2017; Spires, 2015). Such proliferation has also sparked academic interest such as the usage of virtual reality for stroke rehabilitation (Saposnik et al., 2010) and the modeling of SARS and avian influenza outbreaks via virtual pandemics (Balicer, 2007). Similarly, the field of educational research has adjusted their approaches to curricula design by modeling design principles of video games. Video games can be a conducive space for learning due to their clearly defined goals and feedback such that players have an objective means of measuring their performance and optimizing their strategies (Juul, 2013). When appropriately implemented in more formal learning settings, benefits from incorporating game design principles include more effective activation of learners' in-game knowledge resources to make sense of non-game contexts (Holbert & Wilensky, 2014) and improved learning outcomes through situated learning (Lacasa, 2013). Video game design principles therefore serves as an effective means of transfer, promoting long-term learning as theorized by productive failure.

It is important to note that good games have design principles that fosters good learning, of which I emphasize the engendering of players to persist through failure (Gee, 2007). Failure in this context is theorized as the simultaneous realization of a player's inadequacy and the drive to compel players to search for learning opportunities in order to overcome (Juul, 2013). As the author continues to describe: "Failure connects us personally to the events in the game; it proves that we matter, that the world does not simply continue regardless of our actions" (p. 122, emphasis in original). This melding of both failure and learning is a very common practice that reiteratively comes up in researchers' analysis of good games. For example, Chen (2009) describe his learning experiences in his World of Warcraft dungeon raids where he and his teammates would consistently die in-game, resulting in a complete party wipe which inconveniently entails a loss of time and money. However, through consistently failing to effectively strategize and survive, Chen and his team eventually learned to develop methods of attacking, coordinated communication among the team, and the optimization of their digital avatars.

Parker (2013) also describes failure in terms of the quintessential "boss fight," common throughout video games, as the barrier for players to overcome by applying all their gained skills and knowledge. Farber (2017) accordingly contributes the following to the notion of boss fights: "When I reach a boss level in a video game, I expect to fail. If the challenge is too easy, I assume that the rest of the game will be that way" (p. 113, emphasis in original). Failure is thus is an integral element of good video games when designed appropriately. Failure not only becomes a lens for players to better understand the complexity of a problem but also a metric of improvement when players discover the answer (Juul, 2013). Others have forwarded that failure should not just be an unideal result of assessment but instead the opportunity for developing creativity and innovation (Wagner, 2012).

4.4 Comparing Video Game Design Principles to Chemistry Laboratory Curricula Design

Video game design provides a wealth of theoretical underpinnings that melds problem-solving activities with playful attitudes (Schell, 2008). Unlike formal learning settings that involve reading books or listening to lectures, good video game design provides embodied meanings where players mindfully know what they are doing and can customize their understanding for novel situations of actual practice (Gee, 2007). Within recent years, there have been several research endeavors that integrate game design principles with chemistry education. For example, digital badging has been implemented to more effectively improve undergraduates' knowledge, confidence, and experience in laboratory practices (Towns, Harwood, Robertshaw, Fish, & O'Shea, 2015). Digital badging models the achievement system one would expect in video games that rewards players for successfully progressing through their gameplay. Researchers have also developed Chairs!, a mobile game for organic chemistry students to better visualize the ring flip of cyclohexane (Winter, Wentzel, & Alhluwalia, 2016). Like other mobile games, Chairs! highlights the accessibility and interactivity that video games can offer to promote student understanding of molecular structure.

Although there exists a compatibility between chemical education research and video games, these studies focus mostly on the front-end of design. Although digital badging and Chairs! have the appearance and aspects of video games, these applications lack the theoretical considerations that explore how learners can specifically use their failures as part of their sensemaking process. Upon reviewing existent chemistry education literature, I notice a persistent gap that compares the design of good games and laboratory curricula. For the remainder of this chapter, I respond by exploring the theories explaining how certain video game design principles can enable learning from failure in the chemistry laboratory context. Furthermore, I showcase that in chemistry education research, researchers can incorporate video games more than solely creating a game for students to use. Instead, researchers can delve more into the theory of good game design, gaining new micro-perspectives on how the learning of chemistry within the laboratory occurs within-the-moment. Below, I present three major design principles that inform written curricula and learners' practices to maximize productive failure: play as freedom of choice, ownership by leveraging learners' experiences, and reflection to understand the metagame.

4.4.1 Play as Freedom of Choice

Play is a multifaceted concept that has a wide diversity of definitions. In the context of video games, play has been described as autotelic, spontaneous, and an indispensable element of learning (Kalmpourtzis, 2019). Klopfer, Osterweil, & Salen (2009) have explained play as the freedom of effort and of interpretation where one can experiment, fashion identities, and fail. Play is also player interactions with a system, the freedom of expression framed within the space of possibility (Salen & Zimmerman, 2004). Accordingly, I distill many of these definitions to narrow my operationalization of play as a video game providing players the freedom of choice. This suggests that good games must be designed as a space for players to discover both successes and failures through play using actions they choose to enact. For example, the popular multiplayer game League of Legends offers endless choices for team strategies, lineup compositions, and lane assignment during competitive play (Donaldson, 2017). This study also noted the protean nature of choice, showcasing how players elected tactics that were not only optimal but also dependent on their opponents' play style for maximum effectiveness. This conceptualization of play prompts players to position failure as a channel for feedback instead of a detrimental outcome. Feedback in this case is the game-player interaction where in-game experiences ascribe significance to player's choices (Kalmpourtzis, 2019). As players encounter failures, they adjust and reformulate their choices of play in order to better achieve in-game success. Freedom of choice thus consists of player agency where players genuinely matter as they resolve decisions that can meaningfully change their world (Gibbs, 2011).

For extant general chemistry curriculum, there lacks the same degree of choice (i.e., play) as one might expect in a good video game. Buck, Bretz, and Towns (2008) had shown that most of their reviewed laboratory curricula had prescribed a great deal of information for learners to use for experimental navigation. Such prescriptions include providing the problems, the theory, the procedure, and the methods to analyze results. While providing the scaffolding is important, having so much initial structure from the top-down limits what a learner can actually. If framed from the perspective of video game design, there should be greater flexibility via alternative solutions to a problem that allow room for user interpretation and challenge user thinking (Hiwiller, 2015; Kalmpourtzis, 2019). By embedding greater degrees of choice and minimizing overt information dumping, learners can be more engaged in genuine inquiry: the freedom to fail and discover as one would in a good game (Gee, 2007; Salen & Zimmerman, 2004). The written curriculum must be designed to include more opportunities for learners to be agentive in how they play with their experiment instead of restricting them to rigid protocols.

4.4.2 Ownership by Leveraging Experiences

This design principle involves sustaining a space that leverages players' experience to promote their ownership. Users, not the designers, create and communicate meaning when interacting with the game's designed structure (Dourish, 2001). This setting thus shifts away from understanding how a game is played to how players engage with a game (Hung, 2011). Such meaning-making is emergent when players negotiate what success means by utilizing their expectations derived from their lived experiences. By capitalizing on these experiences, good games can promote users to "find personal connections that motivate engagement with a specific context for long-term change" (Nicholson, 2014, p. 1). Such elicitation of players' experiences generates greater impact on the ownership of their decisions during gameplay, thereby transforming failure into their failure and consequently success into their success. For instance, Gee and Hayes (2010) demonstrate how The Sims leveraged a young girl's interests in art and aspirations to become a designer by enabling modding options where she experimented with taking photos of real clothes, transforming and redesigning them per her desires, and exporting them into her game. In addition, other competitive games such as EVE Online and Counter Strike: Global Offensive (CS:GO) have platforms for players to leverage personal experiences, referencing broader and evocative references to Internet popular culture and enacting player-determined, unsportsmanlike practices respectively to boost team morale and demoralize opponents (Carter, 2015; Irwin & Naweed, 2018). To productively incorporate failure, the design should invite players invited to use their existing knowledge and concepts in any situation, thereby becoming more invested as they realize that they do possess more stake in their outcomes (Chan & Yang, 2018).

Similarly, capitalizing on learners' available resources has been thoroughly developed in the context of scientific inquiry. Moll, Amanti, Neff, and Gonzalez (1992) show that legitimizing students' household knowledge can result in a participatory pedagogy that reduces the insularity nature of classrooms. Similarly, diSessa and Sherin (2000) show that students possess rich constructive resources that teachers can draw upon to develop external representation competency. It is necessary to contextualize the starting point of learning within learners' interests, perspectives, and needs for a more authentic learning experiences (Buxton, 2006). In general chemistry laboratories however, the content may feel so removed with few personal connections that motivation and engagement would be difficult to cultivate. Accordingly, learners may not attribute the same degree of ownership to their experiment, wanting to simply finish instead of more deeply understanding the contextual and consequential meaning of their experimental inquiry. Written curriculum should build learners' investment such that they avoid passively waiting for the instructor to reveal the answer and instead seek additional information, ideas, and concepts. By providing avenues that facilitate learners connecting activities to their experiences, curriculum design can reposition failure as a more personal undertaking such that it can push learners to search for new opportunities of personal and professional growth (Lottero-Perdue, 2016).

4.4.3 Reflection to Understand the Metagame

The last design principle involves maintaining a space in which players can engage in reflection to understand the metagame. First, the notion of a metagame has a diverse range of academic and practical definitions. One common interpretation is "the game beyond the game" where play is redefined not from the rules but from the surrounding contexts permeating within and outside digital structures (Salen & Zimmerman, 2004, p. 481). For example, theorycrafting is a metagame which involves World of Warcraft players using mathematics and logical analyses to probe the game mechanics in order to optimize the concerted activities of forty party members (Paul, 2011). Apolyton University is yet another type of metagame: an online strategy school for Civilization III where members investigate new war strategies and constructively evaluate each other's gameplay (Squire, 2012). As the author elaborates, members of Apolyton University significantly value the practices of sharing and gaining knowledge, even at the expense of failing to achieve a high score or failing to win the game. Both examples illustrate that players should not be limited to what they do in-game; to overcome failure, they must engage in sensemaking within and outside of the game context for their future learning.

The metagame is consequently a product of reflection, a process which instigates players to draw from their experiences to better understand the game's rules to gain some type of favorable advantage (Gee, 2007; Hayes & King, 2009). Such reflection on the complex interactions between the player and the game pushes users to adopt a designer epistemology such that they can be better equipped with critical and systems-level thinking skills. (Gee, 2007; Shaffer, 2006; Zimmerman, 2007). The issue that I identify in general chemistry laboratories is that learners are frequently positioned as novices instead of genuine designers of their experiment. The rules of the chemistry laboratory such as restrictions on time and rigidity in protocol create a space where UGs are obligated to prioritize efficiency and perfect execution. As a result, UGs potentially lack opportunities of reflection to understand the relevance of the protocol, the consequences of their actions, and foremost the learning from failure. The metagame of the instructional laboratory should not be avoiding failure to leave early or getting correct answers but rather embracing failure as a lens for learners to reformulate their chemistry inquiry as a function of improvement.

4.5 Summary of Design Principles and their Interconnections

Play as freedom of choice, ownership by leveraging experiences, and reflection to understand the metagame are the three interconnected design principles that foregrounds productive failure within good video games. In such digital spaces, players often use their failures to learn and become more proficient at obtaining what they define to be success within the game. Play as freedom of choice enables players to experiment with different options in order to formulate new approaches to a problem at hand. Ownership by leveraging experiences provides immersion such that players are not dissuaded by their failures and instead endeavor to overcome. Reflection to understand the metagame is the process which players productively use their failures to inform and plan the next set of actions that can better guarantee success on the next playthrough.

Accordingly, I use these design principles to inform my reinterpretation of learning from failure in the chemistry laboratory. Imagining the laboratory as a good video game, written curricula would invite learners to use their experiences to play and reflect throughout the chemistry laboratory. These themes not only are well-developed in their respective fields of research but also overlaps with learning outcomes found in current laboratory reform efforts. By encouraging learners to play as a means of freely choosing and resolving their laboratory practices, the laboratory context can facilitate student-centric inquiry similar to other studies (e.g., Cooper & Klymkowsky, 2013). Leveraging learners' experiences as authentic resources in the construction of their understanding aims to boost engagement, motivation, and ownership which other studies have identified to be lacking in the chemistry laboratory (McGill et al., 2019). Finally, reflection to understand the metagame would provide learners legitimate affordances to understand the whys and hows of their laboratory practices, a crucial skill for learning chemistry (Galloway & Bretz, 2016). These design principles serve as a foundation to which I will build upon in the following chapter. Although currently incomplete, I will use these theoretical constructs to assemble a pedagogy that, instead of positions failure as an avoidable consequence, uses failure as a stepping stone for more meaningful learning (Bolinger & Brown, 2015). While assuming the laboratory as a good video game can be beneficial, it may be more practical for Phase Two of the GTA project to draw parallels between a good video game and the graduate teaching assistant instead.

CHAPTER 5. PHASE TWO OF THE GTA PROJECT

This chapter introduces Phase Two of the GTA project. For this study, only nine of the original eleven GTAs continued their voluntarily participation. The research team had video-recorded one laboratory session from each of the nine participants. We had also conducted video-stimulated recall (VSR) interviews afterwards to better understand the GTA perspective of teaching. Accordingly, I begin this chapter with an overview of how I assembled my conceptual framework *Play First, Reflect Later* (*PFRL*) to deductively explore the laboratory learning context with a failure-inspired research lens. I then discuss methodologies of video analysis and VSR interviews before transitioning to methods of data collection and analysis. Based on my analysis, I argue for theoretical reconsiderations to better align failure-driven learning theories with the laboratory context. Namely, the nature of explicit guidance and errors may need to be reconsidered. At the same time, I also recommend specific pedagogical moves for GTAs to enact. Encouraging transfer to sustain learners' long-term learning as well as maintaining a space of learner agency are all crucial for failure-driven learning. From my analysis, I recommend implications to GTA training as well as written curriculum design. By foregrounding both successes and failures throughout the learning process, we as a chemistry education community can generate more opportunities for learners to explore the various dimensions of a given problem.

5.1 PFRL as Conceptual Framework

Due to its inclusive bulk of prior failure-related learning theories, I will mainly use PF in my conceptual framework in several ways. First, researchers typically conceptualize PF as a means to understand students' mathematics learning in activities when problem-solving comes before instruction (e.g., Granberg, 2016; Song & Kapur, 2017). In other words, PF is largely employed from the perspective of the design of the curriculum to understand student performance. Even Kapur (2016) describes the intent of his work to "theoretically and empirically interrogate" the "possibilities for design" (p. 289). However, my conceptual framework will distill the literature, its epicenter being PF, into a catalog of pedagogical practices. Instead of using PF from the perspective of the curriculum itself, I establish my theoretical vantage from the instructor-side to observe the resultant effects on learners' sensemaking. Although differentiating between design of curriculum versus of pedagogy can also be a matter of semantics, I nevertheless underscore my conceptual framework as a toolkit for what instructors can pragmatically do. Second, theories related to learning from failure are largely based in cognitive research. Although I will be citing these works, my conceptual framework will take a different stance and posit that learning is a sociocultural process that entails interactions with others (Vygotsky, 1986). Specifically, I leverage threads of situated learning to sustain a dynamic relationship between my theoretical assumptions of learning and the social context in which they are applied (Lave & Wenger, 1991). Lastly, my conceptual framework will leverage theories of failure from the video game context (as described in Chapter Four) due to inherent similarities. Instead of comparing the design of video games and that of written laboratory curriculum, I suggest that modeling the instructor's pedagogy as if it were a good video game may have useful insights. Using video game literature as an auxiliary will support my conceptual framework on reimagining failures, learning, and teaching within the laboratory context and open new avenues for potential theoretical refinement.

As previously described, the chemistry laboratory appears to be overly success-driven despite being conducive for failure-driven conditions. The design of the laboratory involves learners needing to solve a problem first (i.e., experimentation) before consolidating their understanding (i.e., writing the laboratory report). However, the pedagogy GTAs' enact more closely resembles that of productive success than productive failure. This incongruity is not particularly surprising. As outlined in Chapter Two, the popular reformed-based models of laboratory curricula (POGIL, PLTL, and PBL) assume aspects of success-based learning. For example, the curriculum expects students to correctly progress through the provided scaffolding and accurately and precisely enact scientific practices. These models inherently sustain a high-stakes environment where the appeal of failure is quickly diminished. Within such contexts, it becomes sensible that GTAs would enact more success-based pedagogy. Investigating GTAs' teaching practices using a PF-informed framework may lead to key insights on how learners' failures can be better utilized for their sensemaking. By pushing the PF perspective, I can better theorize ways to improve the current state of teaching and learning within the chemistry laboratory such that these processes can be maximized to their potential. I now present a reorganization of PF and related literature in terms of my conceptual framework, *Play First, Reflect Later* (*PFRL*). For each theoretical construct, I discuss its purpose for my subsequent analysis and its corresponding limitations with regards to the laboratory context. Finally, I conclude summarizing the interconnections of all four theoretical constructs and their related pedagogical practices.

5.1.1 Play

I designate the initial activity in which students encounter an impasse as *Play*. Here, the instructor must ensure that learners are confronting a complex problem (Kapur & Bielaczyc, 2012). The rationale is that complexity entails multiple dimensions that can enable a proliferation of various ideas. For learners to consider different options, instructors should draw their attention to the different contextual features of the problem. Doing so may generate more opportunities to investigate interconnected facets that may have been otherwise obscured by explicit scaffolding and problem simplification (Jonassen, 2000). This problem-solving phase frequently results in learners' failures (Kapur, 2012). However, the pay-off is that processes of generating a variety of novel solutions based on learners' intuitive ideas may be more beneficial for long-term learning (Kapur & Bielaczyc, 2012). The goal of this phase is to productively make errors and to push learners to engage with a problem beyond its superficial features.

As learners undergo this period of problem-solving, it is imperative that the instructor emulates a good video game. Instructors need to carefully mediate a context in which uncertainty and familiarity are balanced for learners to remain engaged with reasoning (Rowe, Shores, Mott, & Lester, 2011). Learners, like players, should have a space in which they can freely navigate inquiries, interpret feedback, and experiment with different solutions (Garris, Ahlers, & Driskell, 2002; Kiili, 2007). Along this note, instructors during Play need to redefine the norm of failure. As Juul (2013) notes, video games enable players to use their consecutive failures as tools to pursue success. Similarly, instructors during Play need to invite, not prevent, errors. Instructors must facilitate a context in which failures are productively accepted as part of the sensemaking process (Ramirez, Seyler, Squire, & Berland, 2014). Overall, instructors must draw on three major pedagogical practices related to the theoretical construct of *Play*: *Encouraging Exploration of Different Options*, *Fostering Various Sensemaking of Observations*, and *Allowing for Errors*.

From the chemistry perspective, *Play* serves to frame the first portion of the laboratory in which learners conduct their experiment. From my personal experiences, I recognize that *Play* has aspects that are both compatible and incompatible with the chemistry laboratory setting. On one hand, problems of high complexity are abounding. Learners must confront not only their experimental protocol but also the finer details of chemistry practices. These include but are not limited to knowing what glassware to use, how to set-up experiments, and what their observations mean in terms of their experimental progress. There are many opportunities in which instructors can instigate learners to observe and produce ideas about their experiment. On the other hand, how learners are incentivized to make usage of their observations to create different solutions is another issue altogether. Learners in the laboratory may be obligated to the social norm of strictly adhering to their protocol, potentially preventing instructors from leveraging errors. What this means is that instructors have great potential to foster learners' exploration and various sensemaking, but within the limitations of not fully committing to an error. Similar to Litts and Ramirez (2014) discussion, it may be extremely challenging for the chemistry laboratory instructor to discern when failure to achieve a particular activity can actually further the learner's understanding of the subject. Thus, my utilization of *Play* serves two main functions. First, I can better explore what GTAs are doing and their rationales as a means to gauge the feasibility of *PFRL* during learners' experimentation. I can then use *Play* to conceptualize compromises in which GTAs can enact pedagogical practices that are both pragmatic for the chemistry laboratory and related to *PFRL*.

5.1.2 Reflect

I designate the latter activity in which learners consolidate their previous ideas with the canonical answer as *Reflect*. It is during this phase that learners' previous failures during *Play* are utilized, exploring specifically what went wrong. Instructors must direct learners to discern the context of the problem, unveiling the advantages and disadvantages of one solution versus another (Kapur & Bielaczyc, 2012). For example, instructors can compare learner-generated answers, provide contrary hypotheticals for learners to make predictions, and elicit learners' contribution to the problem-solving path (Chowira et al., 2019; Kapur, 2010; Roll, Holmes, Day, & Bonn, 2012). Getting learners to realize why their sensemaking was initially incongruous with the standard answer is intrinsic to the later revisions of their solutions. Chi (2000) showcases that learners can more effectively repair their mental models of a target concept when they recognize the inherent flaws. Thus, instructors are tasked with facilitating learners to create new solutions as informed by their prior mistakes as well as pinpointing conceptual features that may still conflict with the learners' own understanding. By better recognizing how to address the contextual features of the current problem and its related errors, learners can better adapt to different problems in the future (Belenky & Schalk, 2014).

This stance of instigating learners to reconstruct their understanding in new ways parallels the tenets of a well-designed video game. Game mechanics productive for learning push learners to reconsider their actions, self-correct their actions, and refine their mastery (Gee, 2007; Juul, 2013). Just like a video game, instructors must provide different forms of feedback to help learners calibrate towards the correct reasoning. Instructors must also orchestrate this phase to be conducive for transfer, defined as the ability to adapt and apply a learned concept into a different context (Loibl, Roll, & Rummel, 2017). Because the goal of *Reflect* is long-term learning, instructors' actions should utilize learners' previous inventions during *Play* as a means to facilitate better retention for the future (Schwartz, Chase, Oppezzo, & Chin, 2011). Overall, instructors must draw upon five major pedagogical practices related to the theoretical construct of *Reflect*: *Getting Learners to Understand the Context of Errors*, *Urging Learners to Revise*, *Identifying Learners' Knowledge Gaps*, *Providing Feedback for Learners to Consolidate Canonical Answers*, and *Preparing Learners for Transfer*.

Reflect designates the portion of the laboratory session in which students finish their experimentation and work on their reports until they leave, ideally with the canonical understanding. During this period, learners are often prompted by the assessment (post-laboratory reports) to calculate relevant equations, evaluate their observations, and make claims that connect macroscopic phoneme with submicroscopic processes. The advantage that these reports have in terms of Reflect is a design conducive for directly connecting learners' experimentation with their resultant sensemaking. At the superficial level, there does not appear to be a component of *Reflect* that is as potentially incompatible as *Allowing for Errors* is during *Play*. However, I fear that the design of the current laboratory report itself may be problematic. These assessments, like other traditional educational tools, may have higher stakes connoted with failures, consequently favoring conformity and standardization (Plucker & Makel, 2010). How GTAs help their learners with the report may be different than what is envisioned in *Reflect*. With this assumption, I incorporate *Reflect* as a means to explore the context of GTAs' interactions with their students during the laboratory report-completion phase. Investigating which pedagogical practices are leveraged, prevented, or ignored can then help me identify what actions are more feasible for GTAs and formulate a discussion of whether other features of the laboratory needs revision.

5.1.3 Experiences and Concepts

Described originally as core interdependent mechanisms present throughout both phases of exploration and consolidation, *Experiences and Concepts* encapsulates learners' prior knowledge in conjunction with features of the target concept (Kapur & Bielaczyc, 2012). In other words, I posit that in order for *Play* and *Reflect* to have their intended effect, instructors must ensure that learners productively compare their past experiences to the present concept. Previous research has asserted that learners have rich constructive resources crucial for sensemaking (diSessa & Sherin, 2000). Brand and colleagues (2019) show that when these resources are activated, learners can look past surface-level characteristics and more deeply engage with the underlying structure of the target concept. This mechanism is fundamental for both *Play* and *Reflect*. The more learners can draw upon their prior experiences, the more ideas they can generate which improves their learning during *Play* (Kapur, 2013). Furthermore, leveraging these experiences may help learners become aware of the limits in their understanding which becomes crucial when later resolving incongruities about the target concept during *Reflect* (Kapur & Rummel, 2012).

Another component to *Experiences and Concepts* is how knowledge is co-constructed within the social context. For example, collaboration among learners is important for ensuring the meaningful utilization of their prior experiences to address the target concept (Sears, 2006). As a prominent feature in the video game literature, Gee (2007) describes how collaborating within an affinity space can enable players to contribute, debate, and reformulate information. Working together in this fashion also strengthens involvement, legitimizing players' contributions in affirming or debunking hypothesis in their gameplay (Squire, 2011). Within the context of learning from failure, collaborative discourse has been shown to have a positive effect: encouraging learners to not only share information but become peer instructors as they collectively engage more comprehensively with the target concepts (Anderson, Dalsen, Kumar, Berland, & Steinkuehler, 2018). In order to sustain collaboration, instructors must facilitate a space in which learners feel comfortable to share, critique, and negotiate their shared work with one another (Scardamalia & Bereiter, 2003). On that note, how instructors themselves interact with learners is also crucial. If instructors provide explicit guidance by directly giving the answer, this may hinder leaners' implicit learning (Reber, 1989). Instructors who unreservedly disseminate instructions may establish a norm in which learners ignore the situational structures of a problem and attend to the procedural aspects instead (Schwartz, Lindgren, & Lewis, 2009). As summarized by Sawyer (2019), how instructors provide feedback to learn from failure and the nature of the feedback itself require further investigation. Overall, instructors must draw upon four major pedagogical practices related to the theoretical construct of *Experiences and Concepts*: *Leveraging Learners' Prior Experiences/Understanding*, *Directing Learners to Target Concepts*, *Enabling Learners to be Collaborative*, and *Avoiding Direct Instruction*.

With regards to the chemistry laboratory, *Experiences and Concepts* incorporates aspects of learners' sensemaking with their experiment, the chemistry, and chemistry-related practices. Learners for instance may need to understand how to properly use a pipet, justifying their techniques with percent error calculations. Correct pipetting also requires understanding the significance of rinsing, differentiating between the waste and source container, and knowing the more efficient protocol for volume calibration. Afterwards, learners could leverage this prior understanding of pipetting to determine an unknown solution based on its density. Learners would explore the chemistry concept of density as an intensive property which is made possible only if their pipetting were accurate enough to have justifiable data. As shown by these examples, there are many instances in which GTAs can facilitate learners' past experiences to better address new topics. Furthermore, laboratory experiments are inherently collaborative. Learners are often tasked to work together on an in which they need to discuss and produce a mutually agreed-upon answer. GTAs consequently have the option of attending to how learners work together, ensuring that the discourse matches with what the theoretical construct recommends. The only potential complication is Avoiding Direct Instruction. The laboratory may have an embedded culture in which GTAs feel obligated to give answers as opposed to encourage learners to produce answers. In other words, both GTAs and learners may be uncomfortable with uncertainty within the learning context (Clifford, 1988). I thus use *Experiences and Concepts* as a lens to understand how GTAs mediate the co-construction of ideas among their learners throughout *Play* and *Reflect*. Having this perspective can lead to insights on the influence GTAs have on their learners' reasoning and discern avenues of improving GTAs' current pedagogy in terms of the chemistry content.

5.1.4 Motivation

The last theoretical component of *PFRL* is *Motivation* which delves into the affective domain of learning from failure throughout Play and Reflect. As mentioned previously, there are very undesirable implications associated with failure, one of the foremost being negative emotional states (Cetin, Ilhan, & Hilmaz, 2014). Kapur and Bielaczyc (2012) address this by describing the importance of Play and Reflect activities to be affectively appealing. Specifically, boosting learners' motivation has been shown to be a dimension that increases the effectiveness of learning from failure, especially during the problem-solving phase (Glogger-Frey, Fleischer, Grüny, Kappich, & Renkl, 2015). Instructors consequently must facilitate a space in which negative affects remain minimized and curiosity, the need to seek resolution, can grow (Grossnickle, 2016). Curiosity throughout learning has generally been noted as a prerequisite for knowledge construction (Piaget, 1952). By attending to this component, instructors can capitalize on brief moments of uncertainty during Play to beget motivated learners who can more effectively engage with Reflect later (Lamnina & Chase, 2019).

Motivation is highly relevant within video game literature such that drawing connections between the instructor and a good video game yields insightful pedagogical practices. First, games need to be what Gee (2007) described to be pleasantly frustrating. Players need to feel that the game-based problem is challenging but reasonably doable. The rationale is that when players achieve a task that is situated at the edge of their abilities, it creates a sense of competence and empowerment (Przybylski, Rigby, & Ryan, 2010). In order to dynamically match a game-based problem with the player's ability, good video game design entails proper monitoring and adjustment when appropriate (Hunicke, 2005). Such feedback systems should provide more advantages when players are struggling and less when players are doing well (Wark, 2015). Like a good video game, instructors need to continually tailor the learning context by attending to the learner within-the-moment (Anderson et al., 2018). When providing feedback, instructors also need to be aware of the agency that is contextually being negotiated. Here, agency is operationalized as the freedom of effort and of interpretation, a contextual feature one would expect a good video game to sustain for players (Klopfer, Osterweil, & Salen, 2009). Instructors must be wary not to override a learners' agency when correcting mistakes (Kapur & Bielaczyc, 2012). Instead, social norms must be established in which ideas are neither assessed as correct or incorrect but deemed valuable for overall sensemaking (Thomas & Brown, 2007). Instructors inherently tread a thin line that involves balancing complexity and uncertainty with learners' familiarity and control (Ke, Xie, & Xie, 2016). The default option for instructors should be promoting rather than compromising learner agency in order to improve the benefits of learning from failure (Belenky & Nokes-Malach, 2012). Overall, instructors must draw upon three major pedagogical practices related to the theoretical construct of *Motivation*: *Reducing Negative Affects*, *Adjusting the Difficulty*, and *Promoting Learner Agency*.

Motivation functions to understand the negotiation of affects throughout both the experimentation and the laboratory report phase, similar to Experiences and Concepts. As reported previously in the literature, the laboratory may not be an ideal space conducive for learners' positive affects. DeKorver and Towns (2015) for instance show that learners feel more accomplished when quickly completing the experiment while still acquiring an acceptable grade, implying how reluctant learners are in terms of staying longer within the laboratory. From my personal experience, the laboratory context can be daunting for learners. There can be an overwhelming amount of information that learners must understand, both in terms of the experimental protocol and the available equipment. The prescribed tasks can also be tiresome for both learners and GTAs considering the duration and the time of day when the laboratory starts. As a result, affects may be a significant dimension influencing learners' laboratory experiences. It is also sensible that establishing positive report among learners and between learners and their GTAs is also desirable. I recognize that the laboratory is a highly interactive space that necessitates 21st century skills throughout *Play* and *Reflect* (Binkley et al., 2014). Given this context, the pedagogical practices of *Reducing Negative Affects* and *Adjusting the Difficulty* appear to appropriately coincide. However, *Promoting Learner Agency* is potentially a theoretical limitation. Based on my experience, GTAs may feel more inclined to momentarily assume control. GTAs may complete aspects of the experiment and sensemaking for learners for the sake of guaranteeing a correct answer. Thus, to better understand the social interactions between GTAs and learners, I use *Motivation* to investigate what GTAs do to manage their learners' affects. This theoretical lens will specifically inform my recommendations of how GTAs should adjust problems associated with chemistry concepts within the periphery of what learners can achieve without compromising the latter's agency.

5.2 Summary of *PFRL*

A summary of the four theoretical constructs and their relationships respective to each other is summarized in Figure 5.1. *Play* and *Reflect* are indicated by the blue and red arrows respectively. These two represent the experiment and laboratory report phases, highlighting how both inherently feed into each other. In other words, the process of *Play* informing *Reflect* and *Reflect* informing the subsequent period of *Play* are continually recursive. *Play* and *Reflect* are not necessarily far apart conceptually. One can also infer that the two are intertwined and that related processes may occur more dynamically and simultaneously. From a pedagogical perspective, it is reasonable that GTAs must enact actions that not only facilitate learners during *Play* and *Reflect* but also interconnect both phases such that one is not without the other. The reason for the distinction between *Play* and *Reflect* is established more out of pragmatics, namely to adhere to the structure of the chemistry laboratory. Because students experiment first and then do their reports later, these separate phases fundamentally change the discourse between GTAs and students. Towards the middle is *Experiences and Concepts* which underpins both *Play* and *Reflect*. What learners do during periods of exploration and consolidation inherently requires leveraging their prior experiences and the target chemistry concepts. Placing *Experiences and Concepts* within the center foregrounds the relative importance of learners' sensemaking within the laboratory. Finally, towards the periphery is *Motivation* which also encompasses *Play* and *Reflect*. Just as how it is crucial for GTAs to orchestrate learners' sensemaking, GTAs must also attend to learners' engagement. GTAs must constantly regulate their pedagogy in response to the context, providing assistance when appropriate while maintaining a space for learners to agentively come to their own decisions.

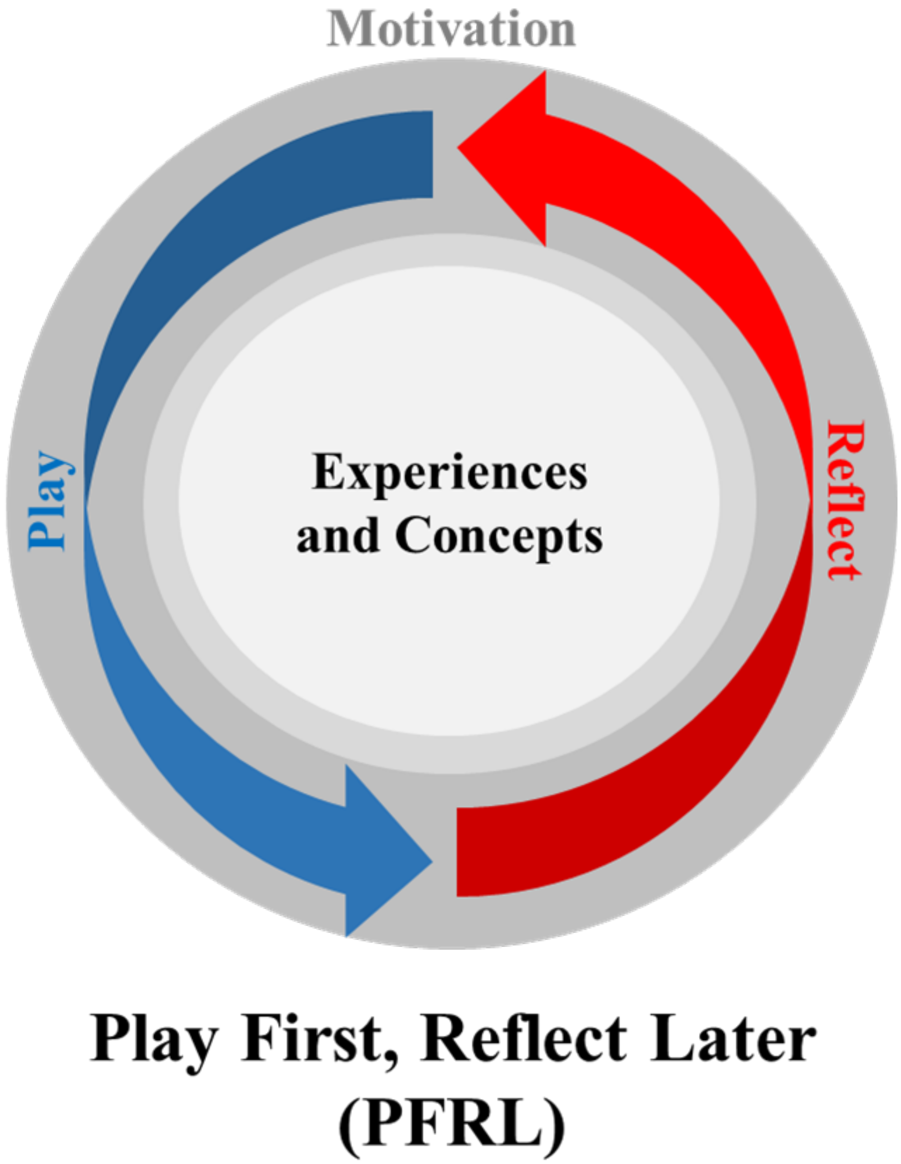


Figure 5.1. A model of *Play First, Reflect Later*

As an ensemble, all four theoretical constructs serve to explicitly define associated pedagogical practices, as summarized in Table 5.1.

Table 5.1. A list of pedagogical practices identified by *PFRL*

PFRL Pedagogical Practices
Play
Encouraging Exploration of Different Options
Fostering Various Sensemaking of Observations
Allowing for Errors
Reflect
Getting Learners to Understand the Context of Errors
Urging Learners to Revise
Identifying Learners' Knowledge Gaps
Providing Feedback to Consolidate Canonical Answers
Preparing Learners for Transfer
Experiences and Concepts
Leveraging Learners' Prior Experiences/Understanding
Directing Learners to Target Concepts
Enabling Learners to be Collaborative
Avoiding Direct Instruction
Motivation
Reducing Negative Affects
Adjusting the Difficulty
Promoting Learner Agency

These identified pedagogical practices are what the PF and video-game related literature suggest are most conducive for learning from failure. Leveraging material from Chapter Two, one can the similarities between video game and PF literature as well as ways the former augmented the latter. For example, freedom of choice is aligned with *Play*, suggesting that learners should not only have the options of making choices but also that their choices should be meaningful, to have a genuine consequence that becomes an opportunity for learning. The metagame has parallels with *Reflect*, encouraging learners to make sense of their previous choices to develop a sustainable understanding for future *Play*. Finally, ownership functions as the auxiliary that helped me articulate *Experiences and Concepts* and *Motivation*. The PF literature does not explicitly distinguish between these two theoretical constructs, but such distinction is more apparent in video game literature. Because participants in Phase One had expressed the difficulties of the laboratory and the importance of GTA-student discourse, it was necessary to create two theoretical constructs to incorporate both learners' sensemaking and affects to establish a more comprehensive analysis of GTA practice. Thus, this conceptual framework serves as a baseline to later reconceptualize what GTAs can do to better integrate PFRL within a chemistry laboratory context. I accordingly pose the follow researching questions for this study:

> RQ1: What do graduate teaching assistants do in the chemistry laboratory that support or fail to support PFRL?
>
> RQ2: Why do graduate teaching assistants enact actions that support or fail to support PFRL?

5.3 Video Analysis and Video-stimulated Recall Interviews as a Methodology

Researchers who seek to understand interactions assume that knowledge and action are not confined in strictly one's head. Instead, cognition is socially constructed where learning and understanding are situated within the everyday interactions of a particular time and place (Jordan & Henderson, 1995). Because of the plurality inherent within the social world, there are a variety of approaches to investigate how people interact and the effects on distal and proximal outcomes (Enyedy & Stevens, 2014). One popular and well-studied methodology is video analysis. Hadfield and Haw (2012) showcase how videos can be a powerfully flexible resource to generate new understanding. Videos have a distinct advantage of providing a "slowing-down" effect such that researchers can understand what transpired orally and visually through continuous replay (Rosaen et al., 2008). By using video footage, researchers can immerse themselves within the rich contexts and nuances of interactions that otherwise may have gone unnoticed (Brophy, 2004; Miller & Zhou, 2007). Videos ultimately provide a high quality data corpus by recording minute interactional moments associated with expressions, non-verbal cues, spatial arrangements, and body positions *in vivo* (Clarke, 2011; LeBaron, 2008).

Video analysis as a methodology has established itself as a prominent feature across various bodies of literature. For example, Hopper and Quiñones (2012) describe their experiences as a Deaf, White, bilingual female researcher and a Latina researcher respectively engaging in collaborative video data analysis. They highlight Deaf epistemology in which they carefully attended to visual cues, expressions, movements, gestures, and body language within video records. González, Deal, and Skultety (2016) on the other hand utilize video analysis in a professional development context. Here, the researchers pinpointed what facilitator moves sustained an inquiry stance among teachers, noting the importance of instigating a discussion to elicit teachers' agreements or disagreements. Finally, Kahn (2020) uses video analysis to understand middle school participants' story-telling experiences and their modeling of their family geobiography. The researcher's analysis focused on multimodal talk-in-interaction, conveying that family is a significant intersection of self and society and a site for racial contestations. Video analysis indubitably affords great depth and breadth of insight. Nevertheless, Hadfield and Haw (2012) warn that researchers need to carefully deliberate the usage and integration of video analysis in research design. As outlined by Derry and colleagues (2010), there is an extensive list of principles, three of which I will address in this methodology: selection, analysis, and the limitations of technology. Later, I describe the usage of video-stimulated recall interviews as a way to overcome the technological limitation.

5.3.1 Selection

Selection is the process in which the researcher distills a complex event and identifies specific parts to further evaluate (Goldman-Segall, 1998). Typically chunked into something smaller known as an event, this focus of analysis represents "a bounded series of actions and reactions that people make in response to each other at the level of face-to-face interaction" (Bloome, Carter, Christian, Otto, & Shuart-Faris., 2005, p. 6). To isolate an event, the researcher must attend to what emerges as important boundaries, considering the starting-up and winding-down processes (Bamberger & Shon, 1991) as well as changes in spatial orientation (Kendon, 1985). Whether the approach is deductive or inductive also affects selection. Although both presuppose an exhaustively reiterative watching of the video in its entirety (Erickson, 2006), a deductive method requires a robust theory and clearly delineated research questions to inform how the researcher selects events from the data corpus and identifies patterns (Alibali & Nathan, 2007). Finally, the selection criteria can include whether the ensemble of events can generate a thick description of the setting that is rich with details (Geertz, 1973). As Derry and colleagues (2010) note, the goal is not to theoretically reduce the data but rather make the complex more digestible for understanding. Regardless of how events may be selected (e.g., representing consistent patterns, supporting an evolving narrative, or any blend of the two), researchers must nevertheless be transparent about their choices and deliberate with their intentions.

5.3.2 Analysis

Analysis involves researchers using videos to excavate interactions from one context into another, to reflect on a given phenomenon, to instigate critical examination, or to challenge power structures (Hadfield & Haw, 2012). Viewing the video itself is also complicated as researchers need to consider playing at faster or slower speeds, listening to just the audio, and watching the video without audio (Erickson, 1982). Whichever approach fundamentally requires iteration, the researcher's evolving interpretations and hypotheses, and shuttling between video clips for further sensemaking (Derry et al., 2010). To distill these protocols, Jordan and Henderson (1995) leverage their ethnographic training to produce a general list to follow: content logs, group work, the researcher's individual work, and transcription. Content logs serve to efficiently summarize the data corpus, which can include descriptive notes, the timings of specific moments, and initial thematic categorizations (Glaser, 1965; McNaughton, 2009). Video analysis necessitates group work during multiple viewings and discussions. Similar to Hopper and Quiñones' (2012) study, collaboration helps reduce idiosyncratic biases and encourage the manifestation of different hypotheses. In terms of individual researcher's work, video excerpts that are typical or atypical of a larger theme must be presented (Erickson, 2006). For instance, Scherr and Hammer (2009) used a systematic observational protocol to identify patterns of student behavior that they could designate as being representative of all student behavior throughout their data corpus. Finally, researchers need to carefully deliberate what to transcribe. As Rostvall (2005, p. 93) notes, transcribing that "represents solely verbal communication is not adequate" when analyzing interactions. Verbal and nonverbal behaviors such as proxemics, gesture, gaze, and object manipulation need to be appropriately considered given the type of analysis the researcher intends to do (Jordan & Henderson, 1995).

5.3.3 Limitations of Technology

With recent advancements in technology, the usage of video-taping has overcome obstacles such as cost, complexity, and lack of familiarity with salient equipment (Shrum, Duque, & Brown, 2005). Videos having greater utility, convenience, and durability substantially increases their potential as a researcher's tool (Pink, 2007). However, while videos currently can provide viewers with a visually-rich and almost vicarious experience of a different setting (Schuck & Kearney, 2006), there are still limitations inherent within the technology. Video recordings only represent a particular frame of a given setting (Smets, Burke, Jarzabokowski, & Spee, 2014). Thus, researchers must consider the location of the camera (e.g., hidden or in-view) and the type of lens (e.g., wide or close-up) (Ratcliff, 2003). Jordan and Henderson (1995) further note the video's inability to produce a record of smell or heat detection, the decision-making of the operator when determining what is being audio and video recorded, and how the presence of a camera may influence behavior. It is simply not possible to exhaustively record every aspect of a given setting no matter the employed data collection method (Erickson, 1992).

5.3.4 Video-stimulated Recall

To establish a more holistic understanding of what had transpired in the collected data, Fitzgerald and colleagues (2013) note the importance of researchers to converse and negotiate with participants and to draw upon other related artifacts (e.g., field notes and photographs). Otherwise, researchers risk maintaining an outsider perspective stance in which they are insensitive to the emergent meaning that is socially-embedded and culturally-framed. One approach to triangulating analysis is through video-stimulated recall (VSR) interviews. Here, the researcher selects and presents events of the previous recording to the participant in order to facilitate reflection and the revelation (Muir, 2010). VSR can enable participants to more effectively articulate their thoughts and feelings by framing an explicit space through showing and interrupting the playback of previously recorded practices (Powell, 2005). Thus, VSR serves as an avenue for participants to relive their experiences such that they may share their thought processes as if they were encountering the situation for the first time again (Pirie, 1996). This methodological design allows for participants to discuss their unique, insider perspectives while simultaneously raising new ideas to address (Rowe, 2009).

5.3.5 Summary

I use video analysis to explore the interactions between GTAs and their learners within the general chemistry laboratory setting. By foregrounding these interactions, I aim to better understand how social norms of what is considered appropriate sensemaking activities are negotiated and currently reinforced (Cobb, 2002). I employ a deductive approach, using the distilled pedagogical practices of *PFRL* to inform how I will view, select events, and code the highlighted events of participants' laboratory observations. I will foreground gestures, gaze, and proxemics alongside with the emergent verbal discourse emergent within each event. In addition, I utilize participants' perspectives via the usage of VSR interviews to more holistically develop an understanding of the experiment, learners' laboratory reports, and participants' pedagogical decision-making. The combination of video analysis and VSR interviews aims to ascertain specifically where are the gaps between participants' current pedagogy and recommended pedagogy to facilitate learning from failure. Identifying the specific areas in which GTAs are leveraging, preventing, or neglecting *PFRL*-related practices can enable more effective reconceptualization of laboratory learning from failure. Below, I discuss further details on the research context and methods of data collection and analysis that were utilized for this portion of the study.

5.4 Research Context

This analysis and findings of this study is part of a larger research endeavor that was introduced in Chapter Three. The research team has collected data at a large, Midwestern public R1-university in the spring semester of 2018. Unlike the first half of the study in which there were eleven participants (eight women), only nine of these participants (seven women) continued their voluntary participation. Table 5.2 shows a list of the participants, their assigned pseudonyms (reflective of their self-identified gender and ethnicities), the year in the program, and the courses they were appointed with during the time of data collection. For continuity purposes, we use the same pseudonyms that were previously assigned to both the participants and the courses in which they had taught. As a reminder, the CHM 101/102 sequence is for agricultural, health, and social science majors while the CHM 105/106 sequence is for agricultural and engineering science majors. These courses all consisted of a 50-minute lecture (twice a week) and a three-hour laboratory (once a week). In total, we had one participant who taught CHM 101 and three participatns who taught CHM 102. We also had one participant who taught CHM 105 and four participants who taught CHM 106. The reason for this distribution is that data collection had taken place during the spring semester which typically has fewer students in the off-sequence courses (CHM 101 and 105) which require fewer GTAs. Our distribution of GTAs for this study is somewhat representative of all the GTAs that were employed throughout the various chemistry courses available during the spring semester, with more participants teaching CHM 102 and 106.

Table 5.2. Phase two demographics

Participants	Self-Identified Gender	Self-Identified Ethnicity	Status	Program	Year in Program	Chemistry Course
Linda	Female	Asian	International	PhD	3rd	105
Ashley	Female	Asian	International	PhD	1st	106
Selina	Female	Latina	Domestic	PhD	2nd	106
Beatrice	Female	Latina	International	PhD	1st	106
John	Male	White	Domestic	MS	1st	102
Dani	Female	African	Domestic	PhD	2nd	101
Helga	Female	Polish	Domestic	PhD	1st	106
Esther	Female	Asian	Domestic	PhD	1st	102
Isiah	Male	White	Domestic	PhD	3rd	102

5.5 Methods

Due to strict hours allotted for the laboratory sessions at the research site, the research team reached out to each of the participants and coordinated a mutually-agreed upon time for video recording. As a result, each video highlights a different experiment from a different course as coordinating among different laboratories simultaneously was too infeasible. At the beginning of the laboratory session, the research member would instruct the participant to affix a Sony ECMAW4 Bluetooth wireless microphone to the lapel of her or his laboratory coat. Next, the participant would introduce the researcher to the learners. The researcher stated that the laboratory will be recorded but the focus will be on the GTA. In addition, the researcher will remain in the laboratory, recording field notes of what occurs within the laboratory. The camera the research team used was a Canon VIXIA HF R80 HD Camcorder, equipped with a wide angle lens. Due to safety concerns, the research team agreed to mount the camera on a tripod, placed atop the GTA bench at the front of the laboratory as shown in Figure 5.2. This location was the most unobstructed location that minimized any risk towards the participants and learners. However, this position comes with significant drawbacks as indicated by the yellow triangle representing what the limitations of the camera angle. First, it is difficult to observe what learners are doing on their benchtops because of the obstructed view with the laboratory bench in front. Second, interactions occurring at the peripheries of the laboratory or at the first row would be difficult to record. To circumvent these challenges, the present research member would at times adjust the camera to track the participant throughout the laboratory to better frame GTA-learner interactions throughout the laboratory.

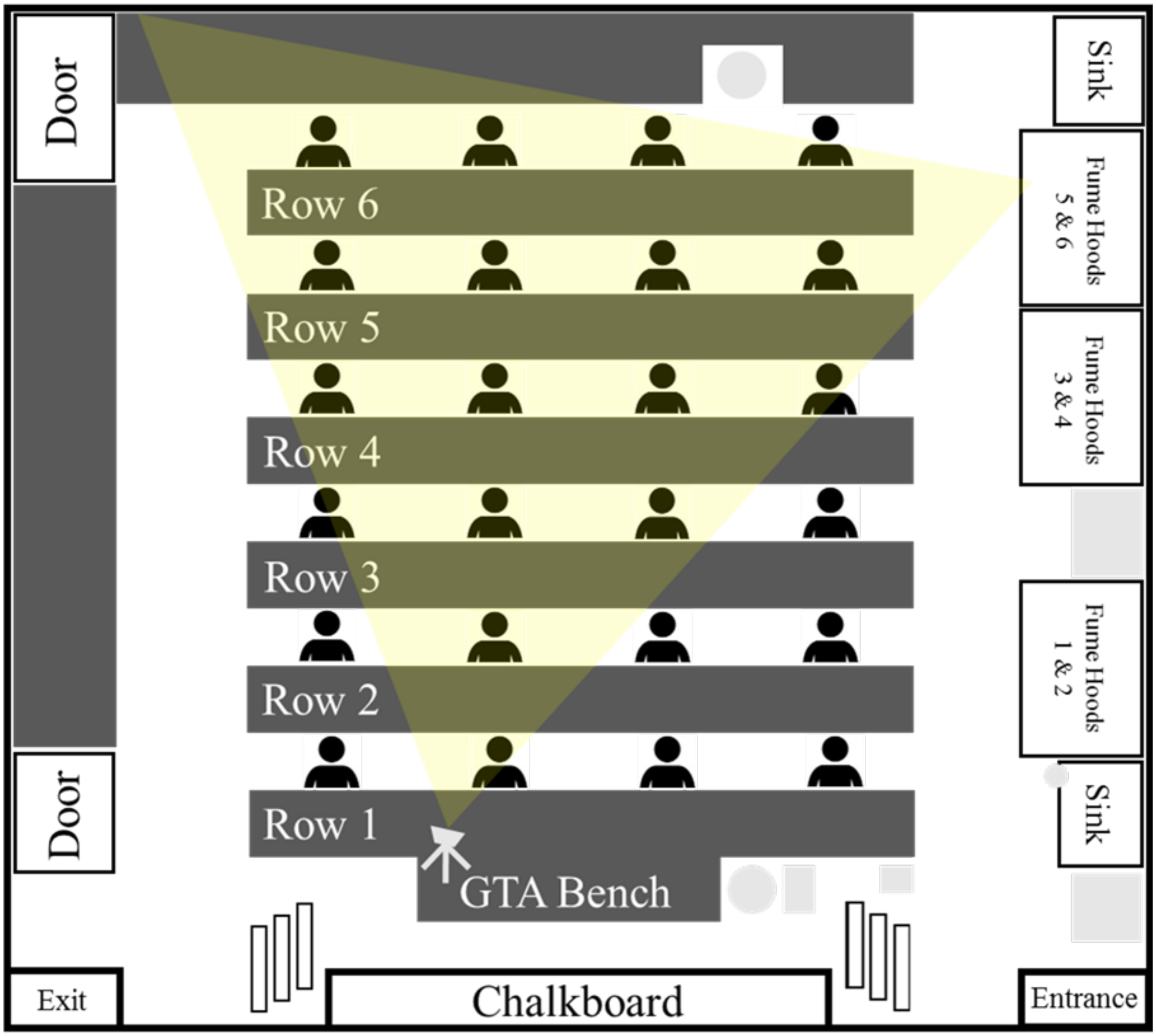


Figure 5.2. Camera placement in a general chemistry laboratory

When the data was in the process of being collected, the research team had the initial goal of documenting what GTAs were actually doing in the laboratory to promote learners' sensemaking within-the-moment. Field notes thus consisted of the present researcher noting particular moments of GTA-learner interaction. For instance, the researcher would write descriptive details when a learner had a question for the participant, when the learner was experience difficulties with the experiment or the laboratory report, and when there were any other interactions that appeared to be relevant given what was happening during that particular setting of the laboratory. These descriptions included the time that the interaction had occurred, chemistry-related information to provide more context, and whether the participant had done something that the researcher would have done differently if the latter were the presiding GTA. Once the laboratory had finished, members of the research team reviewed the videos in their entirety recursively. This process consisted of research members using their field notes to inform how the video would be viewed and how events would be segmented. In total, the research team had selected four to six events (each several minutes long) for participants' subsequent VSR interview. Each event began with a GTA or a learner initiating the interaction and would end once the GTA walked away to address something else in the laboratory.

The research team had conducted semi-structured VSR interviews with the participants that were approximately an hour long. An example of the interview protocol can be found in Appendix B. The interview protocol consisted of a distinct pattern. First, the interviewer would ask the participant what she or he had remembered from the recorded laboratory (i.e., "Can you briefly describe the purpose of that day's experiment?"). For the rest of the duration, the interviewer would show events on the television screen within the room (i.e., "So what I'm going to do now is I'm going to show you a couple of clips") and ask the participant to provide more context on the interaction, their corresponding rationale, and any other details that would provide more in-depth understanding of what had transpired. For example, the interview would ask the participant the degree to which the participant felt that the problem was resolved, the extent to which the participant recognized their learners' canonical understanding, and alternative pedagogical options that could be considered. The research team had followed typical protocols of VSR interviews (e.g., Nguyen & Tangren, 2017), but also recognized the importance of participants being able to select events on their accord (Busse & Borromeo Ferri, 2003). Consequently, the interviewer provided opportunities for participants to select events (i.e., "Is there another moment in mind that you would like to talk about?"), to which all but one participant declined. In the case of the exception, the participant would find a salient event and resultant discussion would follow. The interview would ask the participant to summarize the event, explain why it was selected, and explore the participant's perspective of her or his student's sensemaking. The interviewer would then conclude by asking participants how they perceive their GTA responsibilities (i.e., "What is your role as a GTA in this laboratory?) and follow up by exploring how participants negotiated their statements.

Because VSR interviews affords the advantage of researchers to better understand how and why participants enacted their actions within the laboratory, subsequent coding predominantly centered on themes of participants' rationales. Using Nvivo software (ver. 12), I had inductively coded the transcripts, generated emergent themes, compared the themes against findings from the literature as well as the video recordings, and revised and reorganized my analysis (van Manen, 1990). I relied specifically on analytic coding (Richards, 2015) to reflect and interpret the meaning of the established codes and axial coding (Charmaz, 2014) to interconnect and compile codes into bigger categories. Upon several rounds of analysis, I noticed that participants prominently discussed ideas about their learners' successes and failures within the laboratory which also aligned with the findings from Chapter Three. However, what participants had discussed during this research phase was far more nuanced and actually grounded in their enacted actions. As a response to Derry and colleagues' (2010, p. 16) reminder to "remain open to discovering new phenomena," I began to further investigate how the literature conceptualizes successes and failures (as shown in Chapter Four). Eventually, I generated the *PFRL* conceptual framework, based on PF and video game design literature, centered around pedagogy to inform how I will reanalyze participants' video recordings.

Reanalyzing the video data using the *PFRL* conceptual framework involved several key steps. First, I had watched the video recursively, paying closer attention to events that were utilized during the VSR interview. Eventually, I had selected four events per participant, two of which representing *Play* (i.e., the experimental phase of the laboratory) and the other two representing *Reflect* (i.e., the report writing phase of the laboratory). Almost all of the events selected for this deductive analysis were the same events for the VSR interviews. However, several events had to be replaced due to length, obscured camera angles, and/or distorted audio. In case an event had to be substituted, I had selected a similar event that mirrored the interactions between learners and the participant. Because the video recording was situated in a laboratory context in which all learners are doing the same experiment and have the same laboratory report, switching an event for another was straightforward considering how learners typically have the same types of questions for their GTAs.

Second, once the events had been determined, I had transcribed the events in terms of what was verbally said and what was non-verbally done (e.g., gestures, gaze, and proxemics). Transcribing involved focusing my attention on one actor in the interaction at a time, attending first to what was verbally said. These verbal interactions provided the most insight on details regarding learners' experimentation and chemistry sensemaking. Additional playbacks were required in which I attended to that actor's non-verbal features (with audio both on and off). This process would be repeated for the rest of the involved actors in the interaction as well. I chose to analyze the non-verbal gestures because of how there are many features in the laboratory that are interactive (glassware, equipment, laboratory manuals, etc.). Because experiments were typically conducted in groups of two or four learners, it was also important to explore how gaze, gestures, and proxemics framed how participants directed learners' attention, encouraged collaboration, and sustained a space for learners to speak. Accordingly, non-verbal features of the transcripts were italicized. Furthermore, I chose not to explore the finer verbal details such as prosody of speech and pitch contours (Garfinkel, 1996; Schegloff, 2006). I realized that this additional level of analysis was not productive for answering my research questions but may be a productive avenue of exploration for the future.

Finally, analysis of these events consisted of determining whether the participant had enacted an action that leveraged, prevented, or was entirely unrelated to the *PFRL* pedagogical practice. The first two events would only have codes corresponding with *Play*, *Experiences and Concepts*, and *Motivation*. The last two events would only have codes corresponding with *Reflect*, *Experiences and Concepts*, and *Motivation*. Participants' actions were coded to support and/or prevent the *PFRL* pedagogical practice. There is also the possibility that participants' actions were left uncoded there was no relation at all with respect to the *PFRL* pedagogical practice. Because the video analysis was conducted by myself despite the literature recommending a collaborative group effort among researchers, the work below largely assumes an interpretive stance. Consequently, I make no claims towards interrater reliability. Furthermore, because I employ this coding scheme, I must declare that the goal of this coding is neither to generalize what participants do nor the event itself. In other words, how I code an event is not an encompassing summary of how the participant conducts all of her or his laboratories. Rather, the coding highlights participants' actions enacted specifically to that particular moment. Because this study had participants sampled from different chemistry courses which has separate experiments, it would also be impractical to claim that my analysis befits all GTAs' pedagogy at this research site. Instead, the purpose of my deductive coding is more exploratory in which I develop an ongoing perspective of what GTAs at this research site may potentially be doing as well as the social context that situates their pedagogy. I accordingly incorporate various events from participants to create a more cohesive narrative of how pedagogy that enables learning from failure is currently conceptualized and how it can be reconceptualized. The developed codebook that attributes specific events to the codes of *PFRL* can be found in the Appendix B under Table B.2.

5.6 Findings

Below, I present my findings, corresponding figures, and related information that provides context on the notation and rationale of my coding scheme. Specifically, I use the deductive coding of the video recordings to answer RQ1 and the inductive VSR-interview coding to answer RQ2. For RQ1, my findings are organized into four themes, each corresponding with a theoretical construct of *PFRL*. For RQ2, my findings are organized into four rationales, each of which correspond with the four aforementioned themes respectively.

5.6.1 RQ1: What do GTAs do in the chemistry laboratory that support or fail to support *PFRL?*

Table 5.3 summarizes the coding of the video data in terms of enacted GTAs' actions in the chemistry laboratory and the alignment with the pedagogical practices related to the four theoretical constructs (e.g., *Play*, *Reflect*, *Experiences and Concepts*, and *Motivation*) underpinning *PFRL*. Each major column is designated as a participant and is divided into sub-columns. These sub-columns refer to the four corresponding events (E1 and E2 correspond with *Play*, E3 and E4 correspond with *Reflect*) of the participant's recorded laboratory session. If a participant enacted an action in the laboratory that was reminiscent of a *PFRL* pedagogy, she or he would receive a "O." This designation serves to better understand specifically what GTAs do that support *PFRL* in the chemistry laboratory setting. Furthermore, if a participant had enacted an action in the laboratory that conflicted with a *PFRL* pedagogy, she or he would receive an "X." This designation investigates what actions GTAs enact that reduce the intended effect of *PFRL* in the chemistry laboratory setting. There can also be instances where within a given event, participants enact actions that both support and fail to support *PFRL* in a given event which results in a "XO" coding. Finally, spaces would be left uncoded if the corresponding *PFRL* practice was not observed at all within the event. Having an uncoded dimension functions to better understand in what areas can GTAs introduce more *PFRL* pedagogical practices and whether such practices would be feasible in a chemistry context. With this coding convention, I am not counting specifically how many times GTAs enacted a particular action. Instead, I am strictly designating whether a *PFRL* pedagogical practice was present in a given event.

Table 5.3. Coding scheme for video analysis

PFRL Pedagogical Practices	Linda				Ashley				Selina			
Play	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**
Encouraging Exploration of Different Options	O	X			O	O			X	X		
Fostering Various Sensemaking of Observations	O	X				O				O		
Allowing for Errors	X	X				X			X			
Reflect												
Getting Learners to Understand the Context of Errors			X				O	O				
Urging Learners to Revise			O				O	O				
Identifying Learners' Knowledge Gaps			O				O	O				O
Providing Feedback to Consolidate Canonical Answers			O				O	O				
Preparing Learners for Transfer												
Experiences and Concepts												
Leveraging Learners' Prior Experiences/Understanding		X	O	O		O	O	O	O	O		O
Directing Learners to Target Concepts	O	O	O	O		O	O	O		O	O	O
Enabling Learners to be Collaborative	O	O	X	O				O	O			O
Avoiding Direct Instruction	X	X	X	X	X	X	X	X	X	X	X	X
Motivation												
Reducing Negative Affects		O		O	O			O	O	O	O	
Adjusting the Difficulty		O	O	O	O					O		
Promoting Learner Agency	O	XO	XO	X	O	O	O	O	O	O	O	O

Table 5.3 continued

	Beatrice				John				Dani			
Play	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**
Encouraging Exploration of Different Options	O				O	X			O	O		
Fostering Various Sensemaking of Observations	O				X	X			X	O		
Allowing for Errors	X	X			X	X			O	X		
Reflect												
Getting Learners to Understand the Context of Errors			O	O								
Urging Learners to Revise			O	O				O			O	
Identifying Learners' Knowledge Gaps			O	O								
Providing Feedback to Consolidate Canonical Answers			O	O								O
Preparing Learners for Transfer												
Experiences and Concepts												
Leveraging Learners' Prior Experiences/Understanding	O	O	O	O		O	O	O	O			O
Directing Learners to Target Concepts	O	O	O	O		O	O	O		O	O	O
Enabling Learners to be Collaborative				O		X			O			
Avoiding Direct Instruction	X	XO	O	O	X	X	X	X	O	X	X	X
Motivation												
Reducing Negative Affects					O			O	O			
Adjusting the Difficulty							O	O				
Promoting Learner Agency	XO	O	O	O	X	X	X	XO	O	XO	O	XO

Table 5.3 continued

	Helga				Esther				Isiah			
Play	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**
Encouraging Exploration of Different Options	X	X			O	X			O	OX		
Fostering Various Sensemaking of Observations	O	X			O							
Allowing for Errors	X	X			X	X			X	X		
Reflect												
Getting Learners to Understand the Context of Errors			X	O			X	O			O	
Urging Learners to Revise			O	O				O			O	
Identifying Learners' Knowledge Gaps							O				O	
Providing Feedback to Consolidate Canonical Answers											O	O
Preparing Learners for Transfer												
Experiences and Concepts												
Leveraging Learners' Prior Experiences/Understanding				O		O	O	O	O	O	O	O
Directing Learners to Target Concepts	O	O	O	O	O	O	O	O		O	O	O
Enabling Learners to be Collaborative				XO							O	O
Avoiding Direct Instruction	X	X	X	X	X	X	X	X	X	X	XO	XO
Motivation												
Reducing Negative Affects					O	O		O	O		O	O
Adjusting the Difficulty					O						O	
Promoting Learner Agency	XO	O	XO	XO	X	O	O	X	XO	XO	O	O

Table 5.4 compiles the coding of Table 5.3 into a more numerical presentation that organizes GTAs' enacted actions that were characteristic of, counterproductive towards, and unrelated to PRFL pedagogy. Each column is attributed to every participant where there are three sub-columns underneath each name. The "O" column refers to the number of *PFRL* pedagogical practices that aligned with GTAs' enacted actions. For example, Linda's designation of 9 for Experiences and Concepts conveys that across all four events, there were nine instances of *PFRL* pedagogy that utilizes learners' experiences and target chemistry concepts. The "X" column refers to the number of enacted actions that had an opposite effect. For example, Linda who has scored a 6 under Experiences and Concepts means that her enacted actions had six characteristics that were observed to be contrary to what *PFRL* recommends for Experiences and Concepts. Finally, the "Uncoded" column refers to the number of *PRFL* actions that were not observed at all, meaning that the participant's enacted actions neither supported nor prevented *PRFL* pedagogy. To reiterate, this coding is not conducive to exploring the frequency of GTAs' enacted actions that support or fail to support *PFRL* pedagogy. Instead, this coding scheme specifically investigates what *PFRL* actions were emergent and/or absent in the events to better conceptualize the theory of *PFRL* in the chemistry setting.

Table 5.4. Compilation of participants' actions with respect to *PFRL*

	Linda			Ashley			Selina		
	O	X	Uncoded	O	X	Uncoded	O	X	Uncoded
Play	2	4	0	3	1	2	1	3	2
Reflect	3	1	6	8	0	2	1	0	9
Experiences and Concepts	9	6	1	7	4	5	8	4	4
Motivation	8	3	3	7	0	5	8	0	4
	Beatrice			**John**			**Dani**		
	O	X	Uncoded	O	X	Uncoded	O	X	Uncoded
Play	2	2	2	1	5	0	4	2	0
Reflect	8	0	2	1	0	9	2	0	8
Experiences and Concepts	12	2	3	6	5	5	7	3	6
Motivation	4	1	8	5	4	4	5	2	7
	Helga			**Esther**			**Isiah**		
	O	X	Uncoded	O	X	Uncoded	O	X	Uncoded
Play	1	5	0	2	3	1	2	3	2
Reflect	3	1	6	3	1	6	5	0	5
Experiences and Concepts	6	5	6	7	4	5	11	4	3
Motivation	4	3	8	6	2	4	8	2	4

To guide my exploration, I started constructing a macro-perspective by distilling the above information into more insightful configurations. Specifically, Tables 5.5 and 5.6 highlight the interconnections among participants' actions that support, fail to support, and are not reminiscent of *PFRL*. Table 5.5 foregrounds whether there are more emergent *PFRL*-related pedagogical practices compared to participants' actions that were analyzed to have an opposite effect. Each participant was coded with either a "Yes" or "No" if the number of "O" designations were greater than the number of "X" designations. All participants that were coded as "No" are highlighted in red. In this table, seven of the nine participants enact more actions that do not support Play, meaning that there were more instances of *PFRL* pedagogies coded as "X" compared to "O." Investigating specifically what about *Play* is unachievable in the laboratory context requires delving deeper into the specifics of its pedagogical practices. For the other theoretical constructs (e.g., *Reflect, Experiences and Concepts,* and *Motivation*) it appears that a majority, if not all, GTAs do enact actions that align with more *PFRL* pedagogies. In other words, how participants interact with their learners appear to be more productive than counterproductive for *PFRL*.

Table 5.5. Exploring if there are more *PFRL*-related pedagogical practices

Is O > X ?	Linda	Ashley	Selina	Beatrice	John	Dani	Helga	Esther	Isiah
Play	No	Yes	No	No	No	Yes	No	No	No
Reflect	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Experiences and Concepts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Motivation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5.6 takes a different approach by comparing participants' actions which had no semblance to PFRL to the total amount of actions that either support or fail to support *PFRL*. In other words, this table investigates what areas are "Uncoded" greater than "X" and "O" combined. Similar to Table 5.5, each participant was coded with either a "Yes" or a "No" if the number of "Uncoded" designations were greater than the sum of "O" and "X" designations. All participants that were coded as "No" are highlighted in red. Here, the data suggests another thread to this evolving narrative. Seven of the nine participants appear to enact actions that were unrelated to the five pedagogical practices *PFRL* recommends for *Reflect*. This interpretation suggests that even though GTAs are doing more to potentially facilitate, as opposed to discourage, *Reflect* in the chemistry laboratory, there are *PFRL*-related pedagogical practices that can still be incorporated. Similar to the earlier inference with Play, understanding specifically what aspects of *Reflect*-enabling pedagogy can be integrated in GTAs' laboratory teaching requires a more micro-perspective. In terms of the other dimensions of *PFRL*, the comparisons for *Play* and *Experiences and Concepts* suggest that there is not as noticeable of an absence of recommended *PFRL*-related pedagogical practices compared to *Reflect*. This means that participants are somewhat locked into either support or failing to support *Play* and *Experiences and Concepts* with little room for adopting new *PFRL* pedagogies. In terms of *Motivation*, three of the nine participants suggest that there can still be more Motivation-related pedagogies integrated within GTA-student interactions. In what areas specifically can this be improved again necessitates a closer investigation.

Table 5.6. Exploring if enacted actions have any semblance to *PFRL*

Is O + X > Uncoded?	Linda	Ashley	Selina	Beatrice	John	Dani	Helga	Esther	Isiah
Play	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reflect	No	Yes	No	Yes	No	No	No	No	No
Experiences and Concepts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Motivation	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes

With the information provided in Tables 5.4, 5.5, and 5.6, I now have more definable coordinates to direct my analysis, namely which *PFRL* pedagogical practices require additional attention. To facilitate this process, Table 5.7 provides a different perspective of what *PFRL* pedagogical practices are present by combining all of the data per participant into three categories. Here, all participants' enacted actions are compiled and organized based on the relevance to *PFRL* (i.e., if the action was related, contrary, or completely unrelated). Each column is designated as "# of O," "# of X," and "# of Uncoded." The number underneath each column represents how many instances each *PFRL* pedagogical practice was coded throughout all the participants respectively. For example, *Encouraging Exploration of Different Options* has 10 underneath "# of O" which means that there were 10 instances for all participants that had exhibited an action that resembled this pedagogical practice.

Table 5.7. Compilation of all participants' actions with respect to *PFRL*

PFRL Pedagogical Practices	# of O	# of X	# of Uncoded
Play			
Encouraging Exploration of Different Options	10	8	1
Fostering Various Sensemaking of Observations	8	5	6
Allowing for Errors	1	15	2
Reflect			
Getting Learners to Understand the Context of Errors	7	3	8
Urging Learners to Revise	11	0	7
Identifying Learners' Knowledge Gaps	8	0	10
Providing Feedback to Consolidate Canonical Answers	8	0	10
Preparing Learners for Transfer	0	0	18
Experiences and Concepts			
Leveraging Learners' Prior Experiences/Understanding	25	1	10
Directing Learners to Target Concepts	31	0	5
Enabling Learners to be Collaborative	11	3	23
Avoiding Direct Instruction	6	33	0
Motivation			
Reducing Negative Affects	16	0	20
Adjusting the Difficulty	9	0	27
Promoting Learner Agency	30	17	0

Using the data provided in Table 5.7, I present four major themes of my results: 1. GTAs enable sensemaking of observations and different options but do not allow for errors. 2. GTAs' actions do not explicitly prevent *Reflect,* but they can still do more to facilitate related pedagogical practices. 3. GTAs enact actions related to learners' experiences and target concepts, but there is a fundamental issue in the manner of their implementation. 4. GTAs enact actions that foster positive affects and adjust the difficulty but potentially at the expense of learners' agency. Each theme will be supported with corresponding evidence from the video analysis, namely captured frames from the laboratory observation video and transcripts that detail key interactions between the participants and their learners. By foregrounding specifically what participants do in the chemistry laboratory, this first half of the findings creates the context of GTAs' current pedagogy. Later, in the second half of the findings where I present the key findings from their VSR interviews, I will integrate their rationale and their enacted practices. Combining the two then enables me to further instigate discussion on and draw implications for reconfiguring *PFRL* within a chemistry setting.

Theme One: GTAs enable sensemaking of observations and different options but do not allow for errors.

With regards to *Play*, a cursory analysis of the coding in Table 5.7 shows that participants incorporated more instances that facilitated instead of impeded *Encouraging Exploration of Different Options* and *Fostering Various Sensemaking of Observations*. This appears sensible in the laboratory as participants would often advise students to try different routes of experimentation in situations of troubleshooting, thereby increasing the different options available to students. Along that note, participants would direct student's attention to key aspects of the experiment and connect it back to the underlying chemistry concepts. For example, Beatrice engages with B1 about an experiment involving vacuuming nitric gas away from a system shown in Figure 5.3.

a b c

Figure 5.3. Beatrice interacting with B1 in the fumehood

Beatrice: This is yours? *((Faces B1 and points at experiment in fume hood))*

B1: *((Turns to face Beatrice and turns again to look at experiment))* Yes

Beatrice: Yours is the okay *((Takes a step closer to fume hood and reaches in to swirl the glassware containing the reaction))*

B1: It's at the end?

Beatrice: *((Takes hand out and faces P1))* I will wait a little bit more

B1: Okay *((Turns to face Beatrice and back to the experiment))*

Beatrice: But it's almost done

Beatrice first engages with B1 by asking about the progress of the experiment. Within this interaction as shown in Figure 5.3a, Beatrice intervenes momentarily by reaching into the fume hood and swirling the glassware containing the reaction (indicated by the red circle). The rationale is that providing some mechanical energy via mixing would potentially evolve more nitric gas which B1 is trying to completely remove. As demonstrated by B1's question, "It's at the end?" it appears that B1 understands Beatrice's swirling as a contextualization cue. Depending on what B1 and Beatrice observes after the mixing, it may potentially signal the end of the experiment. In other words, B1 is likely connecting the observation that no additional nitric gas means that the reaction is complete. Beatrice responds by telling B1 that the experiment still needs to continue, indicating that there may have been some nitric gas present. At the end, Beatrice assures B1 that the experiment is almost done which legitimizes B1's initial hypothesis that the reaction was nearing its end.

Later in this interaction, Beatrice creates an opportunity for B1 to explore a different option as shown in Figure 5.3b.

Beatrice: It should be like this you see *((Points to an adjacent experiment in same fume hood))*

B1: *((Bends down to view what Beatrice is pointing at))*

Beatrice: This one is ready for sample

Beatrice utilizes *Encouraging Exploration of Different Options* in this interaction with B1. Specifically, Beatrice introduces an alternative approach by comparing one's experimental progress to an adjacent experiment that is also running in parallel. By pointing to the adjacent experiment (indicated by red circle), she draws B1's attention to the point that B1 actually crouches down and peeks through the gap of the fume hood sash. Beatrice explicitly creates a space where B1 can now utilize another student's experiment to facilitate B1's experimental success. It is likely that B1 now has different options to explore, namely attending to other features of an experiment deemed "ready for sample." Beatrice's actions have likely encouraged B1 to look beyond one's own experiment (i.e., whether nitric gas is present) and instead incorporate other points of references to gauge a reaction's completion.

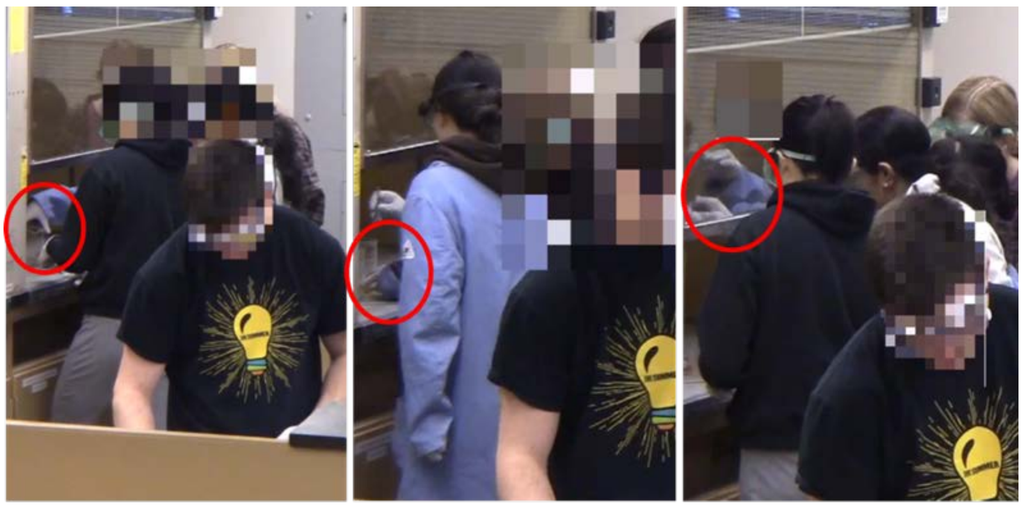
Immediately after this suggestion, B1 asserts a different observation than what Beatrice had stated as shown in Figure 5.3c.

> B1: There's still gas going out *((While still bent over, moves closer to adjacent experiment))*
>
> Beatrice: Really?
>
> B1: Yeah from the bottom
>
> Beatrice: *((Bends down to view experiment through gap of fume hood sash))*
>
> Beatrice: *((Stands up))* Yeah okay

This excerpt highlights *Fostering Various Sensemaking of Observations* because of Beatrice responds to B1's input. Despite what Beatrice had said earlier, B1 still takes the initiative to look at the adjacent experiment to confirm whether it passed B1's conceptions of the reaction being complete. By noting the presence of the gas "going out" and "from the bottom," B1 is voicing key observations that directly contend with what Beatrice had confirmed earlier. And yet, Beatrice does not reprimand the student or reinforce her previous statement. Instead, she also bends down to view the experiment through the gap of the fume hood sash, similar to how B1 is doing. Upon confirming what B1 had observed, Beatrice retracts her previous statement by affirming B1's statement. Within this interaction, Beatrice's vocal agreement further legitimizes B1's sensemaking of observations. Beatrice's response sustains a space where students in the laboratory can disagree with their GTAs by noting observations that could warrant different conclusions.

However, it is important to note that for *Encouraging Exploration of Different Options*, the number of instances that supported this pedagogical practice is still somewhat close to the number of times that GTAs would actually limit the options available to students. Such a case would still be understandable in the chemistry context considering that there is a protocol from which GTAs and students should not widely deviate. This segues into the following observation from Table 5.7: there is a noticeable discrepancy in *Allowing for Errors*. Specifically, GTAs tend to enact actions that prevent experimental errors as a means to strictly adhere to the experimental protocol.

The following event for Figure 5.4 shows Linda's interactions with students and how she creates a context that minimizes the chances for experimental error.



a b c

Figure 5.4. Linda heling students with nylon synthesis

Linda: So the rest of you can do by yourself. So now, you are the one to pull. Okay. *((Reaches hand into fume hood and moves a beaker to the side))*

Linda: Beaker with the water *((Moves a 500 mL beaker close to L1))*

Linda: And here's the scissors *((Moves scissors in back closer to the front and points at it))*

Linda: I would remove this guy because the chemical it's actually it's a little bit not very gentle *((Takes a step backwards))*

L2 and L3: *((Moves respective laboratory manual from fume hood to adjacent bench))*

Linda: Some of them toxic, some of them corrosive so

Starting with Figure 5.4a, Linda initiates the interaction by noting "so the rest of you can do by yourself." This statement refers to the protocol necessitating students to pull the synthesized nylon thread out of the interface within the solution. Although Linda's verbal and physical gestures signal to students that she will not be involved in the nylon pulling, it is evident that Linda is doing other things within the fume hood that can still facilitate said process. For example, Linda explicitly moves a large 500 mL beaker with water (indicated by red circle) closer to the students. This action may be to safeguard them from inappropriately disposing of the nylon. As shown in Figure 5.4b, Linda also directs students' attention to the location of the scissors. Doing so may prevent a scenario where students have nothing to cut the thread with which may result in some kind of error that Linda seemingly prefers to avoid. Finally, Linda instructs students to move their laboratory manuals out of the way as a safety precaution due to the chemicals being toxic and corrosive. Altogether, Linda's instructions convey how she adheres to the experimental protocol by enacting actions that serve to prevent any potential experimental errors students may encounter.

Once students are ready to actually do the pulling, Linda gives one final instruction as shown in Figure 5.4c.

> Linda: Once you're ready, you can have yep, you can just pull *((Sways between moving close to fume hood and moving slightly away))*
>
> L2: Yes
>
> L1: Alright
>
> L3: And it immediately goes into the beaker *((Raises and puts arm in fume hood))*
>
> Linda: *((Puts hand into fumehood, levels hand, and raises it to a specific height within the fume hood for L1, L2, and L3 to see))* So you have to pull all the way up to probably 30 cm around this

Linda reiterates the student's agency in doing the experiment through her words, "Once you're ready" and "you can just pull." Again, this may be due to the experimental protocol requiring students to actually pull the nylon for the GTA to see. As a follow-up, Linda offers additional advice by suggesting the height to which students need to pull the nylon thread (i.e., "You need to pull all the way up to probably 30 cm"). Linda uses her hand as a contextualization cue, placing it against the fumehood window for her students to see (indicated by the red circle). In conjunction with her instructions in Figures 5a and 5b, the way Linda interacts with her students conveys how she optimizes what students need to do for their experiment. Linda enacts certain actions that inherently create a scenario in which students solely need to be concerned with the act of pulling the nylon thread. Doing so prevents *Allowing for Errors* as Linda's students now have fewer features of the experiment with which to be concerned.

However, such actions of removing any potential variable that may worsen or hinder students' performance come with the costs of limiting the options students have in experimentation and the resultant sensemaking. For example, going back to Figure 5.4b, Linda uses the words, "I would remove this guy." This excerpt suggests that it is what Linda would have done because she is aware of the complication of nearby chemicals and the consequences of spilling on the laboratory notebook. Rather than creating an opportunity for her students to potentially hypothesize what may go wrong, Linda opts to disseminate instructions. This enacted action is arguably more efficient but has less influence on her students' potential to anticipate and resolve this type of error in the future. Alongside with explicating the 30 cm height, Linda is distilling the purpose of the experiment into one particular moment in which students need to successfully pull the nylon thread. Such distillation may cause students to lose sight of other contextual features necessary to make sense of the broader experimentation process. Preventing errors to this extent ironically does a disservice to the experiment itself in that students are no longer flexibly experimenting in the sense of *Play*. Instead, students are linearly progressing through the instructions both the GTAs and protocol have established.

Theme Two: GTAs' actions do not explicitly prevent Reflect, but they can still do more to facilitate related pedagogical practices

In terms of *Reflect*, Table 5.7 shows a different distribution than that of *Play*. Specifically, for all of the five pedagogical practices related to Reflect, there were very few instances in which GTAs actually enacted contrary actions. However, for *Getting Learners to Understand the Context of Errors*, *Urging Learners to Revise*, *Identifying Learners' Knowledge Gaps*, and *Providing Feedback to Consolidate Canonical Answers*, there appears to be a somewhat equivalent distribution between participants' actions that either promote such practices or participants' actions that are completely unrelated. What this suggests is that within the events that were selected, some participants are incorporating actions related to *Reflect* pedagogies while others are not. Due to different teaching styles among participants, this divide is somewhat to be expected. Nonetheless, it is crucial to the types of interactions occurring within moments of *Reflect*. Doing so serves two functions: identifying what participants are specifically doing to enable *Reflect* and informing where GTAs can integrate *Reflect*-related pedagogy for future student interactions.

Shown in Figure 5.5, Ashley clarifies two students' confusion about their calculations.

a b c

Figure 5.5. Ashely troubleshooting students' laboratory report

Ashley: Still working on that? *((Walks towards A1 and A2, leans on bench top and gazes at the laboratory report))*

A2: I don't understand how he did this cuz I know the balanced equation is 2 H plus 2 NaOH *((Moves hand with pen and points at random spots on report))*

Ashley: *((Nods head))*

A2: So what I did was since we know the moles of or no we know the grams *((Moves right hand similarly like before in the air))*

A2: Um what's it called *((Taps bench twice with right hand))*

A2: The acid. What I did was. So NaOH, the concentration of NaOH

Ashley: Mmhmm

A2: Times the liters we added, that gives us moles

Ashley: *((Nods head))*

A2: And then I

A1: We did the mole ratio

A2: Yeah divided by 2 and what do I need to multiply by *((Leans forward and back))*

A2: It's concentration so I need to divide it by oh just divide it by 25 right?

Figure 5.5a introduces the context of the situation in which Ashley approaches A1 (in a dark blue shirt) and A2 (in a black shirt) who are working on the laboratory report. When A2 states, "I don't understand how he did this," A2 is referring to the other laboratory partners who had finished the calculations but had already left due the pretense of having completed all that was required of them. However, A1 and A2 appear to be stuck at an impasse because they do not appear to understand how their laboratory partners' calculations were done. A2 begins by explaining the calculations in context with what is known about the experiment. For example, A2 states details about the neutralization (i.e., "2 H plus 2 NaOH"), variables that are currently known (i.e., "the grams"), and the beginning stages of the calculation (i.e., "concentration of NaOH" and "Times the liters we added, that gives us moles"). Throughout these interactions, it is important to note that Ashley does not say much. She merely affirms and listens to the student. Although her actions may not explicitly instigate *Reflect*-related pedagogical practices, she still creates a space in which students feel invited to share their reasoning in the ways A2 had done. Furthermore, the way that A1 pitches in by stating, "We did the mole ratio" reinforces that within this moment, students feel comfortable interjecting and explaining their sensemaking to the GTA. This type of space between GTA and student within the laboratory is key for Ashely to set up the opportunities that incorporate *Reflect*-related pedagogical practices for A1 and A2.

After stating the rationale and the proposed calculation steps, A2 asks Ashley whether the explanation makes sense. This causes Ashley to physically lean very deeply towards the report as shown in Figure 5.5b, a type of proxemics that indicates that Ashley is now closely examining the students' calculations to assess its correctness.

A2: Would that not make sense?

Ashley: *((Adjust goggles))* I think which yeah I think it's correct. Let's see with your calculations

Ashley: *((Leans deeply forward, towards the laboratory report))* So this is

A2: Concentration of the OH *((Points to something in front of Ashley))*

Ashley: NaOH concentration

A2: Oh wait oh wait ignore that first one. Times 0.03 liters

Ashley: Yeah that is the volume

A2: That was our equivalence point

Ashley: Mmhmm *((Nods head))*

A2: Divide that by 2

Ashley: By 2 right

A2: To get the moles

Ashley: Of HNO2

A2: And divide that by 0.025 cuz that's how many uh

Ashley: Weak acid yeah

A2: Yeah

Ashley: Yeah your calculation is right.

The interactions between A2 and Ashley highlight a particular type of discursive exchange in which the co-construction of understanding is very evident. First, Ashley affirms that the A2's explanation sounds reasonable. However, her words, "I think" suggests some potential doubt in the sense that although the A2's words make sense, Ashley still needs to further corroborate the findings through the calculations themselves. As Ashley is going through the report, A2 provides somewhat of a commentary that orients Ashley to A2's sensemaking. For example, A2 points out the "Concentration of the OH," the "0.03 liters" being the volume, and relating "equivalence point" to "moles" of the acid with additional calculations. It is almost as if A2 and Ashley are completing each other's sentences, especially towards the latter end of this interaction. How the turns alternate between Ashley and A2 is crucial to facilitate Ashley's enacting of *Providing Feedback to Consolidate Canonical Answers*. Through revoicing the base concentration, affirming what A1 had said about the equivalence point and the volume, and responding to A1's sensemaking, Ashley is supporting the path that A2 had created to make sense of this particular problem. At the end, it appears that Ashley could not find any errors with the question despite the initial confusion in the earlier excerpt.

After approving of A1 and A2's proposal to do the calculations, Ashley leaves and then eventually returns after some time to follow-up on their progress as shown in Figure 5.5c. It is during this event in which Ashley's enacted pedagogies coalesce to generate an opportunity for *Reflect*.

A2: I understand what you meant like there should be *((Raises hand to indicate something on the laboratory report))*

A2: There should be divided by two cuz you're multiplying by two in the denominator but I think their calculations was flat out wrong because we found this

Ashley: Mmhmm

A2: *((Again emphatically points to something on the report))* The average was 0.0602

Ashley: *((Nods head))*

A2: So multiply it by the 0.025 *((Moves hand back and forth above report))*

Ashley: No? You can't multiply it by 0.025. Remember so the whole .7 gram is diluted to 100 mL *((Turns head to face A1 and turns back to face A2))*

A2: *((Begins typing some buttons on calculator))*

A2: Oh multiply it by 10?

Ashley: .1, .1 liter, right?

A2: *((Continues to type on calculator))*

A1: So you multiply that by 0.1 because to get moles

A2: Okay so 117? *((Shows Ashley the calculator value))*

Ashley: Yes mmhmm *((Nods head))*

A2 initiates conversation with Ashley by stating that A2 now "understand(s) what [Ashley] meant." This is indicative of Ashley's *Getting Learners to Understand the Context of Errors*. Due to the previous interactions, it appears that A2 now understands the miscalculation ("but I think their calculations was flat out wrong") that was previously introduced in Figure 5.5a. As A2 continues to describe the calculation, Ashley notes a new error in terms of A2 incorporating the incorrect volume. To address this, Ashley reminds A2 of what was done experimentally, namely that the grams of solid was diluted specifically to 100 mL. This type of feedback serves two purposes: *Identifying Learners' Knowledge Gaps* and *Urging Learners to Revise*. By reminding A2 of what was done experimentally, Ashley is drawing A2's attention ("Remember so the whole .7 gram is diluted to 100 mL") to the specifics of the equation. This instigates A2 realizing that using 0.025 is an incorrect approach because it is unrepresentative of the actual volume of the sample. A2's realization of the gap in understanding is reinforced when A2 suggests a different approach ("Oh multiply it by 10?") in response to what Ashley had said. Furthermore, this showcases that A2 has immediately revised the initial solution approach by incorporating Ashley's recommendation. It is important to note that A2 makes another mistake that Ashley immediately corrects, namely A2 makes an incorrect conversion between milliliters and liters. Ashley's direct response with the correct answer (".1 liter, right?") may signify she deems the target concept of converting between milliliters to liters to be not as crucial as other topics emergent within this conversation. Regardless, it seems likely that A1 and A2 have arrived to a canonical understanding of volume, concentration, and moles with which Ashley is satisfied.

To highlight areas in GTA-student interactions that could incorporate more *Reflect*-related pedagogical practices, I introduce an example of John who assists his students in understanding the difference between the sample concentration and a penny concentration shown in Figure 5.6. The transcript below represents Figure 5.6a-c unlike previous examples. It is imperative to state that John did not do a poor job of instructing and that the point of this analysis is not to showcase what went wrong. How John interacts with the students is both sensible and appropriate given the context of the chemistry laboratory. Rather, the point of this analysis is to strictly highlight areas in which GTAs could possibly leverage *Reflect* in their enacted pedagogy, similar to what Ashley had done.


a b c

Figure 5.6. John explains the experiment to students

J2: Okay so *((Points to something on paper with pen in hand))*

J2: I was reading something up here

John: Yes *((Adjusts hat))*

J2: I'm kind of confused as

John: Okay so the

J2: Concentration of the sample and then concentration of the penny solution *((Turns head to face John))*

John: *((Leans back on bench behind him and begins to slouch down))* So if you had to guess what the penny solution is, what would that be?

John: *((Turns to face J2 and then turns to face J1))*

J2: What?

John: Like what physically is the penny solution?

J1: Solution with the penny in it

John: *((Turns to face J1))* Yeah that you just dissolved the penny in

John: *((Nods head, shrugs and turns to face J2))* That's the penny solution but the absorbance that you measured was not that

John: *((Turns to face J1))* You diluted that, right?

J2: Yeah

John: Alright so you found the absorption for those three trials *((Holds up three fingers and faces J2))*

John: Use that absorption in your *((Points and looks at computer screen and lower arm))*

John: Trend line *((Scans between J1 and J2 several times))*

John: there to find the concentration *((Turns to face J2))*

J1: *((Points and looks at computer screen and then lowers arm to return gaze towards the right))*

John: And that's the concentration of that *((Points to something on J2's paper and retracts arm))*

John: In the sample but then you diluted it *((Points to something again on J2's paper))*

John: So you have to do a dilution calculation to get to the penny solution *((Turns to face J1))*

J2: Oh okay that makes sense

John: Okay *((Turns head to face J2))*

J1: Nope *((Moves hand quickly across hat as if gesturing the whoosh motion, like something just went over his head))*

J2: *((Points to computer screen in the middle))* So what should we put down?

John: *((Turns to face computer screen in front))*

J2: When we did the concentration cuz it needs another one to put the

John: Oh just type in a random number cuz all you need is the absorbance

J2: Okay *((Nods head and looks down at paper))*

At the beginning of this interaction shown in Figure 5.6a, J2 bids for John's attention by raising the paper and noting a specific issue in terms of making sense of what the numbers represent. John responds by asking J1 (wearing a blue hat) and J2 (in a black sweat shirt) what they imagine the penny solution to be. This type of question may be indicative of John trying to promote students connecting their results to their actual experimentation. In other words, John may assume that guiding students to what they had previously done may contextualize the otherwise abstract information in more concrete and relevant examples. However, this attempt to draw J1 and J2's attention to the experimental protocol does not seem to work as effectively as John had hoped. J1's response, "Solution with the penny in it" does not seem to contribute any more substantial details compared to John's initial statement of "the penny solution." As a result, John follows up with more details that the students themselves did not say. Keywords such as "dissolved," "absorbance," "measured," and "three trials" all provide essential information about the experiment. But John's explanation appears more like telling the students the context as opposed to guiding the students to explore the contexts on their own. Comparing the number of turns between John's interaction and Ashley's interaction, there is a distinct difference. There are fewer turns in which John's students speak while Ashley and her students' turns are more equally distributed. As a result, John appears to dominate the conversation more which may encourage J1 and J2 to adopt a role of a listener instead of a contributor.

Once John has provided the experimental context, he proceeds to disseminate instructions on how J1 and J2 should resolve the problem. By directing their attention to the computer screen shown in Figure 5.6b, John discloses not only the presence of the trend line but also the manner in which students need to utilize the trend line (i.e., "Use that absorption in your trend line there to find the concentration"). Essentially, John is creating a direct path to the canonical answer instead of providing the resources for students to reflect and create said path for themselves. Once John concludes with providing the approach to the answer, J2 confirms understanding but J1 does not. As indicated in Figure 5.6c with the red circle, J1 makes a gesture that suggests little understanding of the current situation, as if what John had said had gone over J1's head. However, such a contextualization cue went unaddressed. Perhaps John may have been distracted with what J2 had said or J1 may not have made the gesture obvious enough. By continuing to instruct J1 on what to do, John loses a ripe opportunity to capitalize on and enable *Getting Learners to Understand the Context of Errors*, *Urging Learners to Revise*, and/or *Identifying Learners' Knowledge Gaps*. Altogether, John's interactions with J1 and J2, like other participants in this study, mirror Initiate-Respond-Evaluate (IRE) but in reverse. Namely, students initiate with a question, GTAs respond with a thorough explanation, and students like J1 and J2 evaluate with either positive or negative responses (e.g., "Yeah," "What?" and "Oh okay").

The last observation for this theme, according to Table 5.7, is the shocking observation that no participants in any instance whatsoever encouraged *Preparing Learners for Transfer*. What this means is that GTAs do not direct their students' attention to key features that may be relevant for future experiments or contexts. At the same time, participants were not observed belittling the experiment. There were no instances where participants conveyed to students that features of the experiment had little relevance for later events. This trend of neither supporting nor preventing *Preparing Learners for Transfer* may be due to several reasons. For example, participants could be overburdened with focusing on the present experiment. With all contextual features considered, GTAs have numerous responsibilities that may prevent them from having additional objectives in mind. This may also allude to the notion that participants lack the resources and/or experience to engage in conversations that utilize future contexts to promote *Reflect*. Finally, perhaps identifying future salience is not explicitly assessed for students which may lower GTAs' priorities of foregrounding this practice. Exploring the absence of this pedagogical practice requires the latter part of the results and may prove to be one pragmatic avenue in which GTAs can enhance *Reflect* among chemistry learners in the laboratory.

Theme Three: GTAs enact actions related to learners' experiences and target concepts, but there is a potential issue in the manner of their implementation

Table 5.7 shows that participants enact actions that predominantly support *Experiences and Concepts*. There were more instances of participants' actions enabling *Leveraging Learners' Prior Experiences/Understanding*, *Directing Learners to Target Concepts*, and *Enabling Learners to be Collaborative*. Furthermore, there were relatively fewer instances in which GTAs' actions opposed these aforementioned pedagogical practices. In terms of *Enabling Learners to be Collaborative*, participants were observed to leverage this practice more frequently than they did prevent it. However, *Enabling Learners to be Collaborative* appeared to be the only practice within this construct that had a sizable uncoded number which may be due to a limitation inherent to the laboratory itself. Students may have more individual questions, responsibilities, and expectations in which the GTA cannot feasibly facilitate collaboration. Overall, the one noticeable discrepancy in *Experiences and Concepts* was *Avoiding Direct Instruction*, in which there were far greater instances where participants' actions were coded to counteract this practice. This means that participants would often provide students answers directly, relying on information dissemination as a foundational aspect throughout GTA-student interactions. Altogether, Table 5.7 shows that while participants enact actions that leverage learners' experiences and direct their attention to key concepts, participants do so in a teacher-centric fashion. This may be problematic because direct instruction, although useful for short-term success, may not be conducive for success in the long-term. At its worst, students within the laboratory could cultivate a dependency on the GTA for both the canonical answers and the associated sensemaking.

To highlight how participants can incorporate *Experiences and Concepts* while still relying on direct instruction, I present Helga who helps students understand a crystal violet (CV) and sodium hydroxide reaction with its corresponding rate law in Figure 5.7 below.

a b

Figure 5.7. Helga explains rate constants to students

H1: Helga *((Holds paper to cover mouth))*

Helga: What's up *((Moves closer to H1 and stands to the right))*

H1: So we answered the questions

Helga: Okay

H1: Possibly *((Looks down at paper and back up at Helga))*

Helga: Okay

H1: So *((Looks down at paper))*

H1: It was important for us to remove the invalid data point because we were trying to measure positive reaction? And when the line flattened *((Looks at Helga))*

H1: I use that word *((Holds hand emphatically out and extends fingers))*

Helga: Mmhmm *((Nods head))*

H1: It would measure the reverse reaction *((Points down))*

Helga: Correct yeah *((Nods head))*

H1: Okay

Helga: But instead if I'm being, it's not positive, it's forward reaction

H1: *((Looks at Helga and then back at paper))*

Helga: If I'm just being super nit-picky about *((Waves hand in air))*

H1: Okay I can fix that

Shown in Figure 5.7a, H1 (holding the paper indicated by the red circle) initiates the conversation by calling out Helga's name. The action of holding a paper to cover the face may be a contextualization cue that suggests feelings of diffidence. Establishing a students' hesitance in the beginning may be crucial because it hints at the challenging complexity of the larger concept H1 will later address. Furthermore, although there is another student to H1's right, this student does not participate in the conversation and appears to be preoccupied with writing the report. As H1 and Helga begin taking turns in the interactions, Helga sustains a space where H1 begins talking about the analysis. H1 describes key points in the sensemaking process (e.g., "remove the invalid data point" "measure positive reaction") and establishes a context to situate the emergent question. Throughout this process, H1 has a paper in front (indicated by the red circle) which may serve as an additional resource to help H1 articulate relevant sensemaking. From Helga's perspective, it appears likely that Helga's head nod affirms H1's decision to ignore the latter end of the graph (i.e., "When the line flattened") because it would no longer be related to the forward reaction (i.e., "it would measure the reverse reaction"). Afterwards, Helga then draws the H1's attention to a previously mentioned detail during this interaction. Helga corrects H1 by stating how "it's not positive, it's forward reaction" and adds the "super nit-picky" pretense.

This moment highlights that although *Avoiding Direct Instruction* is not incorporated, Helga's actions are still productive for student's sensemaking. First, what Helga corrects appears to be more related to semantics than the underlying chemistry. Perhaps Helga's later punctuation of "super nit-picky" alludes to the notion that the difference between forward and positive reaction is relatively insignificant to the other target concepts H1 had previous described. Thus, Helga may have felt more warranted to provide this direct instruction because H1 had already demonstrated understanding of the topic. Second, Helga still achieves *Leveraging Learners' Prior Experiences/Understanding*. Helga inherently sustains a space in which H1 feels comfortable sharing the experimental results ("invalid data points") and the corresponding conceptual features ("measure the reverse reaction"). By incorporating H1's previous statements about the reaction's direction, Helga then utilizes *Directing Learners to Target Concepts*. Helga guides H1's attention to the terminology that had been previously used and offers the correction so that H1 has a more comprehensive canonical understanding. Overall, this interaction largely consists of H1 having the most turns which situates Helga's direct instruction as more of a push towards the correct direction that H1 had already begun establishing.

Shown in Figure 5.7b, Helga's direct instruction grows to become more emphatic. Specifically, H3 (in the black shirt to the right) joins the discussion as Helga begins divulging more specific details about the rate constant equations.

Helga: Okay so we took

H1: *((Puts down paper and faces Helga))*

Helga: 1 drop of CV *((Waves hand in air))*

Helga: And how much OH-? *((Raises second hand in air))*

H1: Mmhmm

Helga: How much do you remember *((Moves extended arm))*

Helga: I don't remember

H1: Between 0., between 0.75 to 0.01

Helga: No, the volume, not the concentration

H1: Oh

Helga: Just the volume

H3: It said to fill the cuvette with 80 percent

Helga: Okay so basically *((Turns head to face H3, hands wave and go up and down as Helga talks))*

Helga: You have way more OH- than CV right? *((Turns to face H1))*

Helga: Because of that, you can assume that the concentration of OH-, because it's in excess, is not affecting the rate of the reaction. What's actually determining the rate is the amount of CV.

H1: Oh so the amount

H3: No the constant is still gonna be CV right?

Helga: *((Turns to face H3))* CV is constant yeah. But that's not what allowed you to determine the CV order *(Waves hands again))*

H1: No it was the

Helga: The constant CV allowed you to determine the order with respect to OH- *((Makes a small chopping gesture with hand))*

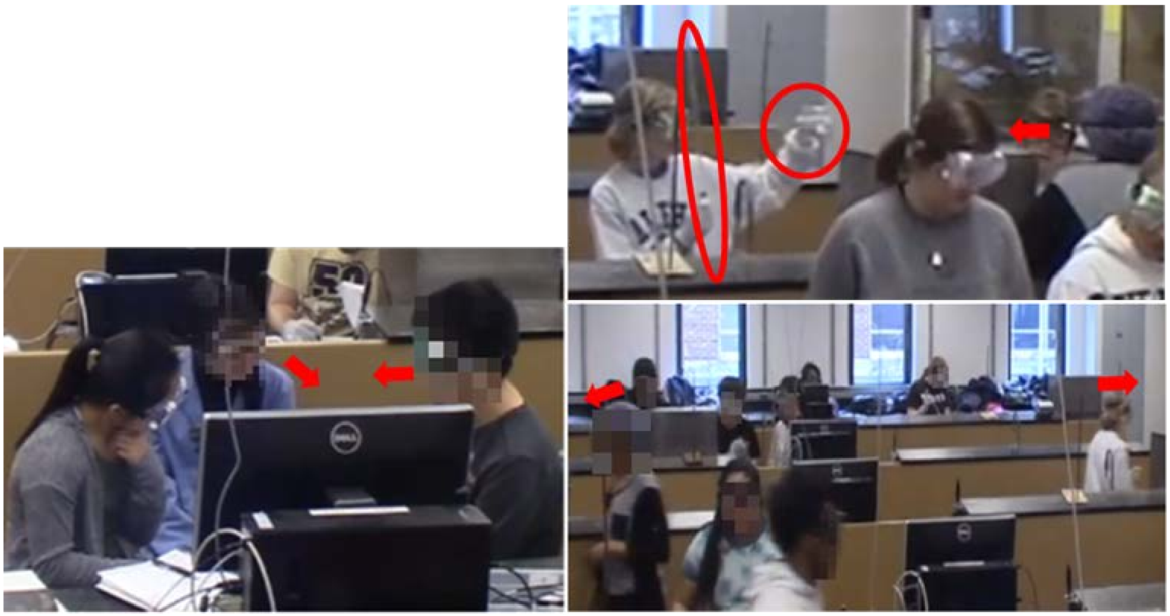
H1: Yeah so

Helga: We're not saying OH- is constant, we're saying it's in excess *((Waves hands more))*

Again, Helga opts for *Leveraging Learners' Prior Experiences/Understanding* by asking H1 how much sodium hydroxide was used during their kinetics experimentation. Even when H1 had provided Helga with an answer that seemed incorrect, Helga appears emphatic about the information pertaining to the volume to which H3 then responds. Once Helga hears "fill the cuvette with 80 percent," she then initiates a teacher-centric mode, similar to what John had done in a previous example, that incorporates *Directing Learners to Target Concepts*. Helga first introduces the concept of excess solvent being reduced to a constant (i.e., "because it's in excess, is not affecting the rate) and how finding the observed rate constant depends on the crystal-violet concentration (i.e., "What's actually determining the rate is the amount of CV"). H3 appears to not understand and offers a counterpoint by proposing the crystal violet concentration should still be constant. In response, Helga does incorporate what H3 says but provides the rationale instead of creating a space in which H3 can discover the rationale. The turn-taking within this interaction is dramatically different than the previous one. By neglecting *Avoiding Direct Instruction*, Helga provides explanations which somewhat prevent H1 and H3's participation and encourage a mode of listening instead. This is further reinforced by H1 attempting several times to enter the discussion but going unnoticed. This may likely be due to Helga's insistence on giving students the correct rationale so that they can understand the rate law.

The first potential issue with direct instruction shown in Figure 5.7b is that whether H1 and H3 actually understand the difference between finding the order of the reaction with respect to crystal violet and sodium hydroxide remains unclear. It is difficult to say whether students understand that finding the rate constant of the base actually requires a particular order: one needs to find the observed rate constant with respect to crystal violet first and then relate varying concentrations of sodium hydroxide to find the order with respect to the base. When Helga directly instructs, "we're not saying OH- is constant, we're saying it's in excess," this information is actually disjointed from the flow of the conversation. Saying sodium hydroxide is constant refers to the first half of the experimentation where one finds the order with respect to crystal violet. But what H3 was describing appears to be more related to the second half of the experimentation where one finds the order with respect to sodium hydroxide. This particular moment highlights the pitfalls of direct instruction within the chemistry setting: the rationale GTAs provide may be so comprehensive that students may struggle interconnecting related concepts into the broader picture. Secondly, Helga's direct instruction may not sustain a space for students to contribute to discussion. For instance, H1 attempted several times to re-enter the conversation despite initiating it in the beginning. Helga instead seemed to have adopted tunnel-vision in which she was so focused on explaining the content to H3 that H1 no longer had any stake in the conversation. Helga's actions have inherently positioned learners as listeners as opposed to contributors to the emergent discussion. From this interaction, Helga's direct instruction has both the potential and intention to help. But when executed too extremely, the fidelity of direct instruction may have the opposite effect, limiting students' sensemaking within-the-moment instead.

To highlight instances where GTAs could leverage *Avoiding Direct Instruction*, I present two excerpts in Figure 5.8. For Figure 5.8a, Beatrice is shown helping two students make sense of a particular dilution. For Figure 5.8b, Dani (in the purple hat) addresses a question a student has about the experimental protocol. In both cases, the participants exercise a degree of restraint that is unobserved in every other participant.



a b

Figure 5.8. Beatrice and Dani avoiding direct instruction in different ways

Beatrice: So what concentration did you measure here? *((Points to something in front of B4 and B5))*

B4 and B5: *((Both turn to face whatever Beatrice is pointing at))*

Beatrice: *((Facing B4))* The sample solution or the original solution?

B5: Um

Beatrice: *((Turns to face B5))*

B5: The diluted

Beatrice: The diluted one which is the?

B5: The diluted one *((Nods head))*

Beatrice: Which is the?

B4: *((Scans between the laboratory manual and B5))* The sample solutions

Beatrice: *((Turns to face B4))*

B4: Of the copper

Beatrice: Okay okay so *((Nods head))*

B4: So the penny one

Beatrice: Exactly. So you with that absorbance *((Points to something to the right))*

B4 and B5: *((Turns to face whatever Beatrice is pointing at and then back to her))*

Beatrice: You are determine this concentration right?

B5: Yes

B4: Yeah

Beatrice: And then you know what volume is? *((Turns to face B5))*

B5: 25

Beatrice: 25 *((Turns to face middle))*

Beatrice: And then how much you take from the *((Turns to face H2))*

B5: 100

Beatrice: *((Turns to face B5))* Did you take 100 to dilute it into 25? Does it make sense?

B5: Uh *((Looks up))*

B5: No *((Looks down and to the middle))* It doesn't make sense. It's 10

B4: *((Glances at Beatrice and then back down towards the middle))*

Beatrice: It's 10 right?

Throughout this interaction as shown in Figure 5.8a, the turns that Beatrice takes usually involve a question. For instance, in the beginning of the conversation, Beatrice repeats questions about identifying the diluted sample ("which is the?") and waits until B4 (sitting to the left) provides the answer before continuing. Once the penny solution has been established, Beatrice draws B4 and B5's attention to finding the absorbance and links it to finding concentration. Beatrice then transitions to volume in which she then prompts B5 (sitting to the right) to explain what had happened experimentally. In this instance, B5 (shown with the red arrow facing Beatrice) states that 100 mL was taken from the source reagent and diluted into a 25 mL volumetric flask which

Beatrice immediately recognizes is incorrect. However, instead of directly correcting B5's response, Beatrice facilitates an opportunity for B5 to confront the error. Beatrice explicitly asks B5 whether taking a large volume and diluting it into a smaller volume makes sense. This question inherently utilizes *Leveraging Learners' Experiences/Understanding* by prompting B5 to think what had been done experimentally and *Directing Learners to Target Concepts* by guiding B5 to think about dilution factors. B5 responds momentarily contemplating before correcting the answer. The way that Beatrice initiates these questions exercises a degree of patience in which she gives time for students to think about what they had done to situate their more abstract numbers. These moments accentuate how Avoiding Direct Instruction is feasible as long as the GTA withholds information at key interactive moments with students. Establishing the norm that students like B5 should realize the error, reflect, and then produce the answer on their own may be more effective than GTAs simply giving the answer.

In another case, Figure 5.8b showcases Dani who actively leverages Avoiding Direct Instruction and Enabling Learners to be Collaborative.

Dani: *((Turns around to face D1))* Yes ma'am

Dani: *((Approaches D1))*

D1: Um so this solution *((Holds up a buret))*

D1: That we rinsed it with, do we put it back into this? *((Holds up a beaker with the other hand))*

D1: Or do we just put it down the sink?

Dani: Did you ask somebody?

D1: Yeah

Dani: What did they say?

D1: They didn't know

Dani: One group didn't know? *((Shakes head))*

D1: Yeah

Dani: Did you ask another one?

D1: No

Dani: Let me know if three groups don't know

D1: *((Lowers glassware in both hands))*

Dani: I need to make an announcement *((Turns away and walks to the left))*

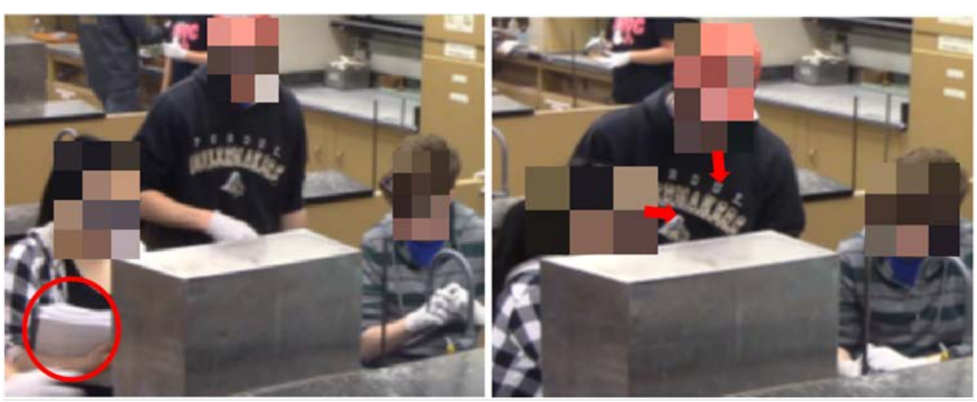
D1 directs Dani's attention by raising a buret in one hand and a beaker in another (indicated by red circles) to contextualize her question. Asking about the disposal of the rinse is a question that pertains both to safety and proper laboratory practice which may not be explicitly clear in the protocol. In this type of situation, Dani could have opted to give the answer similar to how Helga corrected the semantics between positive reaction and forward reaction. Instead, Dani transforms this interaction into an opportunity where D1 has to discover the answer. The rest of this conversation mirrors that of Beatrice's; the turns that Dani takes are strictly comprised of questions. When asking if D1 had asked someone else, D1 had affirmed and responded that other people did not know. At this stage, Dani again could have directly provided the answer but decides to persist by asking D1 to ask another group of students. The interaction concludes by Dani walking away from D1, which then prompts D1 to walk towards another group of students to initiate the same question.

Towards the end, Dani makes the claim that if "three groups don't know" then she needs to "make an announcement," suggesting that this type of question does not necessarily warrant the GTA's attention. It appears that Dani will only provide an answer if the question is negatively affecting larger groups of students. This interaction between D2 suggests that Dani has established a norm within the laboratory that foregrounds *Enabling Learners to be Collaborative* and *Avoiding Direct Instruction*. Namely, Dani insists that students seek, not the GTA, but each other out for clarifying information. Such a norm reinforces student responsibility in which they should not always rely on the GTA. Dani inherently shifts the GTA role away from a convenience that students can rely on for instructions to a point of contact for more outstanding issues. Students thus become more collaborative as they become less reserved speaking to members not only within their bench but from other benches in the laboratory as well. Altogether, Dani's actions parallel what Beatrice had done with D4; both participants spark initiative for students to discover solutions on their own. Beatrice and Dani ask their students questions and retain information when appropriate, setting the expectation that students must be actively responding instead of passively listening and affirming.

Theme Four: GTAs enact actions that foster positive affects and lower the difficulty but potentially at the expense of learners' agency

The coding from Table 5.7 demonstrates that participants enact actions that incorporate more instances of encouraging as opposed to discouraging *Motivation*. For example, participants' actions leverage *Reducing Negative Affects* and *Adjusting the Difficulty* with zero instances of their doing the opposite. This finding in sensible considering the interactivity within the laboratory space and the appeal for positive rapport. Although there is still a sizable number of uncoded instances with regards to *Reducing Negative Affects* and *Adjusting the Difficulty*, this may be due to the social appropriateness of such practices. It is likely to be more of a social faux-paus if a GTA were to constantly endeavor to boost positive affects or engage with a learner as opposed to enacting such practices when the situation is befitting. However, although participants' actions were coded to primarily support *Promoting Learner Agency*, it is the only practice of this construct in which participants would enact counterproductive actions. Furthermore, *Promoting Learner Agency* is the only pedagogical practice for *Motivation* that either has actions that support or prevent it with zero uncoded instances. What this suggests is that in given moments, participants defer to two distinct routes: encouraging student-centric control of the experiment or establishing a teacher-centric control of the experiment. Thus participants may be enacting actions that support *Motivation* but potentially at the expense of their students' agency.

Below in Figure 5.9, I present Esther who leverages *Adjusting the Difficulty* and *Reducing Negative Affects* with her student.



a b

Figure 5.9. Esther helps with conceptualizing reducing agent strength

E1: So do I just like write down all the oxidizing agents here? *((Points at form and makes a small circle gesture with extended index finger))*

Esther: Not, you have to rank them in order of strength

E1: Okay

Esther: So if it's a really strong oxidizing agent *((Holds hand up and shakes head slowly))*

Esther: It's gonna go up here so like strong is at the top

E1: *((Nods head))*

Esther: And weak is at the bottom

E1: Ah that's strong, strong okay *((Points at laboratory report))*

Esther: Mmmhmm

Esther: How I personally rank this is I did this *((Sets held laboratory manual down on benchtop in front of E1 and begins pointing at it))*

Esther: So I made this extra column over here

E1: *((Moves closer to the benchtop and tilts head down to look at what Esther is pointing at))*

Esther: To make it easier to compare things so I ranked things in terms of reducing agent strength

Esther: *((Looks up at H1))* I thought about everything as a reducing agent to keep it cohesive

Esther: *((Looks back at her laboratory manual on benchtop))* For my brain

Esther: So what is three, these should be switched um so

Esther: *((Taps something in front of her))* These are switched

E1: Mkay

Esther: So you're oxidizing agent is what's being reduced. You correctly identified *((Looks at E1))*

Esther: Over here in your actual reaction in your equation *((Looks back down in front of her))*

Esther: But you're gonna have to switch there so whatever is reduced is your oxidizing agent and whatever's oxidized is your reducing agent

E1: Okay *((Nods head))*

Esther (who is holding a laboratory manual indicated by the red circle) is interacting with E1 (in the black sweatshirt) shown in Figure 5.9a. Although there is another student (in the gray-striped jacket) sitting to the right, this student does not engage with the conversation and appears to be more passively listening. When presented with a laboratory report question regarding oxidizing agents, Esther responds by first correcting ("you have to rank them in order of strength") and later elaborating ("like strong at the top" and "weak is at the bottom"). At this stage, Esther may be attending to several features related to E1's sensemaking within this interaction. Perhaps the concept of oxidizing agent strength is a difficult feature for E1 to grasp within-this-moment. In addition, Esther may have recognized that the instructions within the report form are somewhat unclear, serving as the impetus for E1 to initiate this type of question. There is also the possibility that Esther is worried that her later elaboration did not have the ameliorating effect that she had intended.

Based on whatever Esther may have noticed during this interaction, she opts to provide the student a solution that slightly deviates from what she was talking about in the previous turn. Shown in Figure 5.9b, Esther recommends incorporating an additional column to "make it easier to compare things." By foregrounding herself first ("How I personally rank this"), Esther signals to the student that her suggestion is worth noting. Her usage of the words, "I personally" perhaps has the intention of marketing herself as a more experienced chemist or a GTA who wants to help. Either role nevertheless contextualizes her subsequent advice as an approach that is potentially more accessible for E1 to conceptualize oxidizing agent strength. This type of follow-up highlights *Adjusting the Difficulty*. Esther's column suggestion becomes a solution for E1 which may reduce the challenges inherent within the laboratory report task. This is further reinforced when Esther says, "to keep it cohesive for my brain." Esther's message showcases her intent for this auxiliary column to minimize confusion for herself. At the same time, Esther's actions may be leveraging the assumption that if the content made more sense to her in this manner, then it should likely make more sense for E1 as well. Overall, Esther appears to be acknowledging the difficulty within the laboratory report and providing a more feasible approach for E1 to make sense of oxidation and reduction.

As Esther continues talking, she offers more directed advice by attending to E1's already written analysis. Esther tells E1 that some of the answers "need to be switched." Based on the context of the information, it is likely that E1 switched the definitions of oxidizing and reducing agent. Specifically, E1 had incorrectly written that the oxidizing agent was oxidized, and the reducing agent was reduced. Before concluding the interaction by reminding E1 to switch the labelling, it is important to note that Esther explicitly acknowledges that E1 had correctly written the oxidation-reduction equations. Such a remark to affirm E1's previous analysis could be an instance of *Reducing Negative Affects*. By explicitly acknowledging that E1 had the correct equations, Esther minimizes the gravity of E1's error. It is as if Esther is assuring E1 that the bulk of the concept (i.e., being able to correctly write oxidation-reduction equations) had been correctly understood. E1's error subsequently becomes more of a slight misstep, a labelling issue that can be immediately resolved. Given the context of the conversation, it is reasonable to interpret that Esther's action inherently safeguards E1 from potentially feeling upset over a mistake such that E1 can continue feeling capable of interpreting oxidation and reduction reactions.

In Figure 5.10 below, I highlight an interaction which entails the ebb and flow of control between the Isiah and the student. Although pedagogical practices of *Motivation* are incorporated, enacted actions can still limit the agency of students during experimentation.

Figure 5.10. Isiah helps a student with calibrating the LabQuest device

I2: It's still not working

Isiah: Kay let me take a look *((Walks over to bench and stands in front of LabQuest device))*

I2: There's nothing showing up still

Isiah: Kay *((Looks to the left at the experimental set-up))*

Isiah: So you've turned it on obviously and *((Turns to the right))*

Isiah: Okay *((Faces down at the bench in front))*

Isiah: Okay so what you're going to do is the first thing that you'll do is go here *((Manipulates LabQuest))*

I2: *((Turns to look at what Isiah is doing))*

Isiah: Then you'll go into calibrate you need to have a *((Turns to face I2))*

Isiah: Blank in there

I2: Yeah *((Reaches for cuvette))*

Isiah: Stick your blank in

I2: *((Puts cuvette with blank into the spectrophotometer))*

Isiah: *((Leans left to see what I2 is doing))*

Isiah: And did you put enough DI water in here?

H2: *((Turns to the left and then right to face Isiah))*

Isiah: I think you need to have a little bit more DI water in here cuz I can see the top of the light source

Shown in Figures 5.10a and 10b, Isiah troubleshoots a technical difficult I2 is experiencing. It appears that the LabQuest calibration is not working which is the first step of a much longer experiment regarding absorbance and concentration. Because I2's initiates with "still not working," this may act as a cue for Isiah to assume control ("let me take a look"). Isiah then stands in front of the experimental set-up and scans the area for emergent issues. By vocalizing his thought process, Isiah may be attempting to turn his troubleshooting into a teaching moment. Specifically, Isiah shows I2 specifically what he is doing which is characterized by his frequent usage of the word, "you." For instance, he states "the first thing that you'll do," "you'll go into calibrate," and "you need to have." Although he is describing his actions, Isiah is somewhat preventing *Promoting Learner Agency*. Figure 5.10a shows Isiah manipulating the LabQuest (indicated by the red circle) and directing the student's attention to the troubleshooting process. Isiah inherently creates the pretense that within this moment, he is in control of the experiment.

By standing in front and being the only person manipulating the LabQuest, Isiah displaces I1's role away from an experimenter and more towards an observer.

Transitioning into Figure 5.10b, Isiah instructs I2 to "stick your blank in" which causes I2 to reach for and place a cuvette into the spectrophotometer (indicated by the red circle). Here, Isiah relinquishes control over to I2. By creating an opportunity for I2 to join the troubleshooting process, Isiah enables more access for I2 to also manipulate the experiment. But, Isiah's actions nevertheless follow the teacher-centric discourse such that I2's actions appear to be predetermined by Isiah's instructions. This is evident from Isiah's follow-up question ("did you put enough DI water in here?"). During this interaction, Isiah does not particularly wait for I2 to respond nor does I2 recognize the initiative to respond. By providing the rationale ("a little bit more DI water in here cuz I can see the top of the light source"), Isiah is potentially limiting the agency of I2's sensemaking. Specifically, it is unclear whether I2 understands the issue of having too little solvent for an absorbance calibration. While I2 is physically interacting with the experiment at this moment, I2's actions may not be the result of I2's understanding why the calibration is not working. Instead of an observer, I2 becomes more of a listener who is just following instructions from Isiah.

After leaving to fill the cuvette with more DI water, I2 returns and places the cuvette on the bench. Isiah then reaches for the cuvette and wraps up the troubleshooting as shown in Figure 5.10c.

> Isiah: Kay cool so we should already be warmed up since this has been on for a while so we'll skip warm up, put blank in *((Places cuvette with blank into spectrophotometer))*
>
> Isiah: Then you're gonna hit I'll let you one of you guys do it but you can hit *((Moves to the right, out of the way))*
>
> I2: *((Moves to the right in front of LabQuest, where Isiah was previously standing))*
>
> Isiah: Finish calibration *((Looks at LabQuest))*
>
> I2: *((Manipulates LabQuest))*
>
> I2: And I hit okay?
>
> Isiah: Yep hit okay

Isiah resumes the conversation in a similar fashion as before. Isiah enunciates his thought process ("so we should already be warmed up") as he places the cuvette into the spectrophotometer. However, there is reason to believe that Isiah himself may have realized how much control he has assumed over the experiment throughout his interactions with I2. Thus, Isiah leverages *Promoting Learner Agency* as a response. Isiah explicitly states, "I'll let you one of you guys do it but you can hit finish calibration" and moves away from the experiment. Unlike the previous interaction, Isiah moves to the right and provides the space for I2 to be in front of the LabQuest just as he was moments earlier. Although it can be argued that Isiah's is still limiting the student agency by instructing I2 to finish the calibration, how Isiah negotiates his response is still different from the discourse in Figures 10a and b. Once I2 is manipulating the LabQuest, Isiah remains quiet and does not direct I2 in any way throughout the configuration. Isiah only affirms when I2 reinitiates the conversation ("And I hit okay?"). Overall, Isiah's actions in this moment speak more strongly towards positioning I2 as a fellow experimenter as opposed to an observer and listener on the periphery. Control over an experiment appears to be more dynamically negotiated in which context informs how a GTA may intervene or step back to affect students' agency within the laboratory.

The analysis of the participants' video recordings showcase that what GTAs do is nuanced in a variety of ways. Namely, there are instances where *PFRL* do and do not function in the chemistry laboratory. Participants had been observed enacting actions that both encouraged and discouraged *PFRL*-related pedagogical practices. Although some aspects of *Play* can be supported, participants' pedagogy is still somewhat limited due to the necessity of preventing experimental errors. Participants can leverage *Reflect* during interactions with their students, but the manner in which participants teach at times can resemble reverse IRE. Furthermore, participants can effectively incorporate *Experiences and Concepts*. There were instances in which participants productively direct their students to what was done previously in the experiment as well as key features of the target chemistry concept. However, participants may rely too heavily on direct instruction. At times, this direct instruction may be so overwhelming that it could negatively affect *Motivation*. Despite participants demonstrating actions that can help promote more positive attitudes in the laboratory, they may inadvertently do the experiment for their students which ultimately limits students' agency in the laboratory.

At this stage of the analysis, I have a better understanding of participants' teaching contextualized within the pedagogical framework of *PFRL*. Transitioning to the next stage of the findings, I utilize the VSR interviews to explore participants' rationale for enacting certain actions. By understanding why participants enacted their pedagogy from their perspective, I can begin more effectively conceptualizing the interface in which *PFRL* and the chemistry laboratories can overlap.

5.6.2 RQ2: Why do GTAs enact actions that support or fail to support *PFRL?*

Table 5.8 describes major themes that were inductively coded from the VSR interviews. Within this table are three columns. The leftmost column describes the major theme of the rationale (e.g., *Timely Completion*, *Laboratory Success*, and *Lack of Conceptual Understanding*). The column designated as "# of Participants" refers to the total number of participants whose interview data had been coded with an instance of the corresponding rationale, the total of which is equal to nine. Finally, the column designated as "# of References" refers to the total number of unique instances in which excerpts of participants' interview data was coded with the corresponding rationale. To organize the analysis, I selected and grouped certain rationales (each of which were mentioned by all nine of the participants) and aligned them the four themes of *PFRL* as showcased by RQ1's findings. Although the rationales were selected and grouped to be more narratively appropriate given the context of what participants had said during the interviews, it is important to recognize that these rationales nevertheless overlap across all theoretical constructs of *PFRL*. In other words, a rationale being associated with a particular *PFRL* theme does not mean that the former is restricted to the latter. GTAs' rationales are quite diverse such that the following grouping primarily functions to provide more contextual insight. Thus, to address RQ2, I present four major rationales that align with RQ1's four themes: 1. GTAs are motivated by *Timely Completion* and *Laboratory Success*. 2. GTAs are concerned with *Wanting Learners' to Understand* and *Transferability*. 3. GTAs assume learners *Lack Conceptual Understanding* and *Experimental Preparation*. 4. GTAs feel *Responsible*, especially in terms of *Positive Affects* and *Safety*.

Table 5.8. Themes inductively coded from the VSR interviews

GTA Rationales	# of Participants	# of References
Timely Completion	9	87
Laboratory Success	9	77
Lack of Conceptual Understanding	9	76
Lack of Experimental Preparation	9	74
Positive Affects	9	68
Wanting Learners to Understand	9	63
GTA Responsibility	9	56
Safety	9	54
Transferability	9	44
Collaboration and Participation	7	60
Reports, Points, and Grades	7	37
Student Accountability	6	15
Lack of Student Attention	5	11
The Experiment Itself Needs Improvement	4	24

Rationale One: GTAs are motivated by Timely Completion and Laboratory Success

Timely Completion (# or References = 87) and *Laboratory Success* (# of References = 77) are rationales that were mentioned by all nine participants. Timely Completion refers to participants describing their negotiations with the time constraints of the laboratory. For instance, Helga mentioned that she remembers her video-recorded experiment as a "lab that [coordinators] thought was going to take a long time" and that students would "take the lab report home if they didn't finish." On a similar note, Linda describes that as the experiment concludes, "the main goal is to wrap up" and to "clean up everything" on time. The limitation on time creates a context that informs participants' actions in several ways. For instance, Beatrice would need to constantly be "checking that [students] were on-time" because "[students] need someone to be behind them to push them." Some participants like Dani would negotiate pedagogical practices that enabled highest efficiency, such as recommending students to use "a beaker so that they don't have to go back and forth to the waste container." The concern with time becomes so significant that it becomes a metric to which GTAs use to gauge the overall progress of the laboratory. As Ashley mentions, “the previous [experiment] didn’t go well. [Students] waste a lot of time on that, and some of them didn’t finish the report.”

As a result, *Timely Completion* has become so ingrained in participants’ motivation that they associate it their definition of success. *Laboratory Success* becomes a theme of avoiding experimental errors. As Isiah notes, he envisions his role as a medical doctor such that students “are coming and saying, ‘What’s wrong with me?’” and he needs to “diagnose the issue” and provide a “prescription on what [students] could do to fix the issue.” This mode of interacting with students is further reiterated among other participants. In addition, Esther “wants [students] to ask [her] questions” because she has “some groups of students who just refuse to ask questions” and then “they did everything wrong.” This norm that foregrounds success so strongly in learners’ performance assessment then affects the entire process of experimentation. When students have an error that goes unnoticed, participants like Selina would resort to simply stating, “Hey you might have to redo this.” A laboratory that goes well becomes reduced to what John describes as a period of “no big sort of screw ups on the actual method” where students are able to get their data and complete their experimentation and report appropriately.

These two rationales *Timely Completion* and *Laboratory Success* complicate the purpose of *Play*. Given that students need to correctly obtain data and complete their laboratory reports, the context in which GTAs are obligated to teach creates a strong incentive to prevent students from committing errors. However, the issue with avoiding errors to this extent is that the laboratory becomes less about a space for sensemaking but a space for completion. What participants do in-practice involve reducing the impasses that students may encounter. Similar to Linda who positions the glassware for her students and describes the height to which students must pull the nylon thread, participants risk distorting the nature of learning from experimentation when errors are so extremely removed. Learners potentially no longer have to be concerned with the contextual features related to the experiment. Instead, learners only need to focus on the doing of the task instead of understanding why or how these chemistry practices interrelate. Furthermore, these two rationales in conjunction affect how participants themselves perceive the instructional laboratories. From participants’ perspective, the productiveness of the laboratory appears to hinge on learners’ avoiding mistakes. It is likely the merits of errors in participants’ evaluation of students’ performance are disincentivized given the social context of the laboratory. Participants are obligated to prioritize avoiding errors altogether such that the possibility of incorporating errors in learners' sensemaking is low.

Rationale Two: GTAs are concerned with Wanting Learners to Understand and Transferability

Although there is evidence to suggest that learning from failure within *Play* is not largely foregrounded in participants' laboratory pedagogy, what participants do for *Reflect* appears to take a difference stance. Namely, all nine participants are concerned with *Wanting Learners to Understand* (# of References = 63) and *Transferability* (# of References = 44). The former rationale refers to how participants enact actions that aim to facilitate their students' understanding of the experiment. For instance, Ashley describes how she would "rather just explain things in detail" so students "know what's the meaning behind those calculations." Linda states that she "will go like row by row and make sure everyone gets it" while Dani notes that the laboratory is "not just a four-hour torture session" and that "there's something [students] are supposed to get out of this before they leave." As summarized by Beatrice, it is clear that participants have the intention of making students "aware of what's going on" such that students can better "understand everything that they were doing" throughout the laboratory.

However, helping students understand the connections between the experiment and the chemistry content is not straightforward. Mentioned by Isiah, GTAs potentially need to wrestle with the notion that "in order to help a student" understand the context of the experiment, it is necessary to "take a lot of steps back" because "there's a lot that goes into helping someone." As a result, it becomes a lot more sensible for GTAs to enact the reverse-IRE discourse when interacting with students. From the pedagogical perspective, it appears somewhat imperative that GTAs deliver as thorough of an explanation as possible. Although GTAs and students alternate turns in which GTAs respond and students simply affirm, this mode of discourse may be the most appropriate means of enabling students to understand given the context of the laboratory. GTAs, obligated to ensure their students successfully perform their tasks, may resort to this style of instruction because it appears to be the most efficient form of assistance. What GTAs could do more of in terms of *PFRL* is leveraging the other pedagogical practices in Reflect and noticing opportune moments of encouraging learners' contribution instead of their listening.

Another emergent insight is that the pedagogical practice of encouraging transfer among students is underutilized, despite all nine participants describing its importance during their interviews. For example, Helga thinks "it's important to like, if [students] do care about something outside of the lab, to try and encourage that." On a similar note, Linda wants students to perceive the fun in chemistry "because we can apply to real life." Dani further reiterates this rationale by stating that she wants to give students something that "they can take with them when they move on, when they leave." Even though all participants described their concerns with transferability, their video observations demonstrate no instances where their actions reflected their intentions. What this may suggest are two potential scenarios. First, participants may be unaware of pedagogical practices that can directly capitalize on their motivation to encourage students to make these different connections. Second, this discrepancy between what participants say and do may also suggest that the context of the laboratory may not be pragmatic for encouraging students to perceive avenues of transfer. In other words, participants may be too overwhelmed with ensuring that their students correctly complete their experiments to focus on other pedagogical goals such as transfer. If GTAs continue this reverse-IRE style of encouraging *Reflect* strictly in terms of the concepts, then students will likely have fewer opportunities to create and make sense of conceptual connections for themselves.

Rationale Three: GTAs assume learners Lack Understanding and Experimental Preparation

Previously described in the findings for RQ1, participants appeared to rely on direct instruction throughout their interactions with their students despite incorporating pedagogical practices related to *Experiences and Concepts*. The reason for this may be due to all nine participants stating their students' *Lack of Conceptual Understanding* (# of References = 76) and *Lack of Experimental Preparation* (# of References = 74). These two reasons may also explain why participants utilize the reverse-IRE discourse as a means to guarantee that students understand the chemistry concepts. When it comes to *Lack of Conceptual Understanding*, participants would describe a variety of unique details. For example, Helga's sentiments underscore how students have "a harder time connecting what they did in class to what they were expected to do in the lab." The chemistry in the laboratory, according to Linda, may "be a little bit high level for [students] to understand." On the more extreme end, some participants like Esther feels that her students "don't have the background knowledge in order for this lab to make any sort of sense for them." Overall, participants like Selina are concerned that students "don't see the big picture."

Participants express similar sentiments with regards to students' *Lack of Experimental Preparation*. Beatrice in particular mentions how it bothers her that students "don't read the manual and they don't see the set-up they have in the manual." Furthermore, Esther adds that students "don't really listen to the announcements in the beginning" and that students "just show up thinking everything will be fine." Students' lack of experimental preparation could also be due to the noticeable gap between their recitations and their laboratory times. Linda notes that her "recitation is on Friday and this lab happens on Monday morning" so students most likely "didn't come fresh to the lab." Because GTAs perceive this degree of unpreparedness, participants like John respond by emphasizing the need to "hold [students] hands a lot" throughout the laboratory. To some extent, even the participants themselves are unaware of what is happening experimentally. Selina contributes that at times, she and her students would need to "sit down together and be like, 'Okay this is what's happening, this is what's going on.'" These perspectives highlight that participants collectively assume a certain degree of preparedness to navigate the complexity of the laboratory.

These rationales offer different interpretations of how *PFRL* and chemistry can integrate. For instance, the design of the experiment itself could currently be unsuitable for participants to enact *PFRL* pedagogy. With so many experimental requirements at the front end that necessitate a deluge of information with which students must engage prior to the laboratory, students may feel more uncomfortable offering their own solutions as opposed to relying on their GTAs'. Student-GTA discourse consequently becomes more akin to troubleshooting and less about exploration and investigation. There may not even be enough flexibility within the experiment itself where participants can promote student engagement with learning activities that incorporate uncertainty and curiosity. As a result, students may not understand the process of chemistry experimentation if they simply follow the trajectory their GTAs establish. Overall, these rationales culminate into a likely issue of participants assuming their learners are underprepared. Participants may feel that the most effective way of helping their students is providing direct answers. This may not be as beneficial because participants' explanations may be so comprehensive that it is outside of their students' current scope of contextual understanding. At the same time, participants may feel more reluctant to encourage students' hypotheses if they are unrelated to the overall success of the experiment. While this method may be more conducive for completing short-term goals such as the laboratory report, the long-term benefits for students' sensemaking are more dubious. If only correct ideas were legitimized in the sensemaking process, then students would lose opportunities to understand the other dimensions of their experiment and their underlying chemistry concepts.

Rationale Four: GTAs feel Responsible, especially in terms of Positive Affects and Safety

The last theme resonates with the nature of the laboratory: it is an interactive space in which participants need to interact with their students. Because of the rapport that will naturally develop between GTA and student, it becomes sensible that all nine participants described *GTA Responsibility* (# of References = 56), *Positive Affects* (# of References = 68), and *Safety* (# of References = 54). In terms of responsibility, all participants described how their students' understanding and performance were dependent on their respective performances as GTAs. For example, Ashley talked about how she feels students are "going to blame [her]" if she "can't answer their questions in time." And yet, Ashley does not make any excuses on her behalf, stating that she simply does not "want [students] to feel bad about themselves" if they struggle during the laboratory. Reflecting upon their pedagogy during their interview, participants often blamed themselves if they noticed instances of student confusion. Linda states how "maybe [she] talked too fast or something." John expresses how he would feel frustrated when he "couldn't answer [student questions] exactly as quickly as [he] wanted to." As summarized by Dani with which all participants would most likely agree, GTAs have a "responsibility to at least check and make sure that [students] get the right answer."

Positive Affects and *Safety* are also unique characteristics of the laboratory setting. For the former, GTAs have to keep in mind that productivity in the laboratory necessitates a positive demeanor. Participants clearly recognize that laboratory activities can be difficult for students. As Esther describes, students are "in a lab setting, they're stressed, they can't comprehend what's going on." Beatrice also adds that students have a "fear to start the experiment" such that she is careful her actions do not "make them feel dumb or anything." Participants also wrestle with the notion that some students simply do not want to be in the laboratory. John notes that "no one really enjoys being forced to do stuff and being forced to get into lab." Dealing with these emergent negative affects, Dani opts for a particular goal that participants again would likely also pursue: establish solidarity with students so "we can have fun, we can learn, and we can get out of here." For the latter, participants also have to be concerned with the potential dangers unique to a chemistry laboratory. Most participants often described the mandatory duties they must fulfill.

Helga describes how she needs to check that "[students] aren't doing anything unsafe" especially if students "don't know if [chemicals are] hazardous or not." Linda states that one of her "responsibilities is to maintain the safety of the lab" so she has to "keep an eye on the class." Participants recognize that there can always be potential danger related to the experiment. Summarized by Beatrice, "everybody around you is going to be at risk."

What participants describe in their interview reflects a tone of safekeeping. Participants understand that the laboratory is a challenging environment which can demotivate students who struggle navigating the finer details of chemistry practices. As individuals who are more experienced, participants may understand their GTA role as more of a babysitter. This term by no means intends to disparage students, but rather to evoke the image of GTAs' obligation to take care of their students, keep them motivated, and prevent them from undertaking unnecessary risks. It is also appropriate that along these lines, participants attempt to establish positive rapport among their students. There needs to be a sense of trust between students and GTAs such that the former can comply with the latter in case of sensitive situations. The issue when all of these themes interconnect is that participants may assume that displacing the student away from the role of an experimenter and towards the role of a listener or observer is beneficial for students' learning. In other words, if a participant observes students experiencing difficulties, then it would be easier to simply do the mechanical and cognitive tasks in their place. Inadvertently, participants may have normalized "helping" as "replacing the student." Because of the advantages of keeping students safe, preventing feelings of discouragement, and ensuring experimental and laboratory report success, it may not be obvious to participants why compromising students' agency could be detrimental to long-term benefits. Participants may not even ascertain the impact that they are having on their students' agency, focusing more on the ends (i.e., results) as opposed to the means (i.e., methods) of experimentation. While students may have the answers, it is unclear whether they understand how or why such answers had emerged which would be problematic for the future.

5.7 Discussion

Responding to Loibl, Roll, and Rummel's (2017) call for new explorations of productive failure in different disciplinary contexts, this study explores how *PFRL* can be better theorized within the chemistry laboratory context. Addressing RQ1, the findings from the video analysis conveyed that aspects of *PFRL* (e.g., utilizing learners' prior experiences and drawing learners' attention to features of target concepts) are being productively leveraged by participants. However, other *PFRL* aspects also appear to be disincentivized (e.g., permitting errors and refraining from direct instruction), underutilized (e.g., facilitating learners' transfer), or even compromised (sustaining learner agency) for the laboratory. Addressing RQ2, the VSR interviews showcased four rationales that allude to accepted social norms of learning and teaching within the laboratory. Reasons associated with successful and efficient laboratory completion, underprepared learners, and personal responsibility suggest an overarching narrative of participants' fervent obligation to support their learners. Combining the pedagogical themes and rationales together, it is likely that participants have appropriated their laboratory teaching to predominantly favor learners' short-term success and have not yet considered the value of learners' failures for long-term learning.

There exists a complex entanglement of factors that affect the integration of learning from failure and the chemistry laboratory. While some factors are attributed to the social context of the laboratory, others can be due to inherent theoretical limitations as well. The purpose of this discussion is to unpack the findings, zooming in on smaller pieces of the puzzle before assembling them into the broader reconceptualization. Specifically, I forward three compromises to realign *PFRL* and the chemistry laboratory: 1. Errors and direct instruction need to be theoretically reconsidered. 2. GTAs should enact actions that prepare learners for long-term learning. 3. GTAs must not enact actions at the expense of learner agency. My implications will later synthesize these discussion points, recommending suggestions for re-envisioning the role of the GTA and features of the laboratory context such as the design of both the experiment and assessment.

5.7.1 Errors and direct instruction need to be theoretically reconsidered

GTAs confront the challenge of facilitating their learners' experimentation and development of chemistry knowledge and practices (Carmel, Wood, & Cooper, 2017; Elliot, Stewart, & Lagowski, 2008). As evidenced by the video analysis, participants enact actions that effectively minimize the difficulties within the laboratory. The findings show that that participants' pedagogies leverage *Play* and *Reflect*, incorporate learners' *Experiences and Concepts*, and boost learners' *Motivation*. This may be due to participants' feeling that their role is to ensure their learners complete the experiment efficiently and correctly. Such actions are unsurprising considering how other chemistry laboratory frameworks have recommended that instruction is paired with heavy guidance to prevent the learner from feeling overwhelmed (Seery, Agustian, &

Zhang, 2019). Experimental and/or laboratory report mistakes may compromise short-term performance, so participants rely on direct instruction to prevent their learners from veering into failure (Kirschner, Sweller, & Clark, 2006). In conjunction with how participants assume their learners may lack experimental and chemistry understanding, the former may appropriate the practice of direct instruction to minimize learners' errors as a necessary component of laboratory pedagogy.

Unlike a mathematics context, the chemistry laboratory has features pertaining to safety, glassware manipulation, and experimental planning. In addition, the design of the experiments and assessments themselves may be too restricted to permit learners' deviations from the prescribed instructions. These features make the problem-solving activity within the laboratory more complicated and inflexible than what Kapur (2016) had initially considered. Furthermore, if one assumes that learners were unaccustomed with the laboratory and the given experiment, it is less reasonable to expect GTAs to completely withhold information. Similar to what Ashman, Kalyuga, and Sweller (2020) describe, instruction first may be more superior if the problem is overly complex. *PFRL* and other theories that inform learning from failure may need to theoretically redefine what an error specifically is within the chemistry context. Because committing errors may be more detrimental than beneficial for learners' motivation and grades, hypothetical errors could be a potential compromise (Chowira, Smith, Dubois, & Roll, 2019). In other words, instead of immediately correcting, GTAs could ask learners to play out the scenario hypothetically and address potential errors, creating opportunities for sensemaking that would have otherwise been missed. In addition, aspects of the chemistry laboratory may be so distant from learners' prior experiences that learners may not be able to effectively make sense of problem's context and its corresponding solutions (Kapur, 2016). Thus, the onus falls on the GTA to notice when providing explicit guidance to prevent errors is appropriate. Enabling some direct instruction, enough for learners to develop a better conceptual and mechanical grasp on the situation, could be more propitious for learning from failure. GTAs concurrently must be wary to not overly simplify the context of the problem itself.

5.7.2 GTAs should enact actions that prepare learners for long-term learning

Building off the first discussion point, participants' tendency to provide explicit guidance could be limiting learners' attention to the procedures of problem-solving and hindering long-term learning (Schwartz, Lindgren, & Lewis, 2009). On one hand, participants actively use their learners' experiences and foreground target concepts to support their learners' consolidation of the canonical answer for that laboratory period. Findings from the VSR interview also coincide with these enacted actions, showcasing participants' concern for their learners' development of chemistry understanding. On the other, the ways in which participants engage with their learners also implies that the former's pedagogy center around facilitating the latter's short-term successes (Kapur, 2016). Participants during the laboratory focused on the present task at hand, showing zero instances in which they enacted pedagogies related to facilitating transfer. This is alarming considering how all participants during the VSR interviews described valuing learners' connection of chemistry to different contexts. Based on this incongruity, participants may assume that facilitating short-term successes is synonymous with enabling long-term learning (Sweller, Ayres, & Kalyuga, 2011). If GTAs were to continue underutilizing the pedagogical practice of priming learners for transfer, they may risk sustaining a context of unproductive success. Learners may as a result be unprepared to adapt to unexpected and novel problems emergent in the laboratories (Mylopoulos, Brydges, Woods, Manzone, & Schwartz., 2016).

The absence of pedagogies that support transfer is expected considering the underlying social context. As previously described, teaching and learning within the laboratory currently favors successes, not failures, as part of the sensemaking process. By minimizing learners' errors through explicit guidance, participants lack the resource (i.e., mistakes) that would traditionally be used to promote transfer (Kapur, 2016). While many have advocated for pushing learners to understand the whys and hows of their experiment (e.g., Galloway & Bretz, 2016), the social norm of undergoing this type of reflection via previous mistakes has not yet been established. And yet at the same time, the lack of pedagogies that support transfer is unexpected considering the various ways chemistry concepts can be interrelated (Cooper & Klymkowsky, 2013). For example, the discipline of chemistry can situate a variety of salient topics such as history, culture, and global issues (e.g., climate change and HIV/AIDS) (Avargil, Herscovitz, & Dori, 2013; Pinto & Garrido-Escudero, 2016). Learners also typically reencounter similar chemistry techniques in later experiments, providing another layer of relevance within the laboratory (Cascella & Jez, 2018). Consequently, PFRL and other theories of learning from failure may need to loosen their definition of preparing learners for transfer. Assuming the traditional notion of errors is incompatible with the chemistry laboratory, encouraging learners to apply ideas in different contexts such as everyday phenomena or past/future experiments could be another solution to promote long-term learning. Nevertheless, GTAs should more prominently incorporate pedagogies of transfer regardless of a success-driven or failure-driven perspective. Participants already exhibit the corresponding motivation, thus nudging GTAs towards enacting this practice may broaden learners' perspectives to ascertain the bigger picture of chemistry. Recognizing the relevance of chemistry in the laboratory may benefit learners' participation, their longstanding identities-as-chemists, and the depth of their understanding (Ryu, Nardo, & Wu, 2018).

5.7.3 GTAs must not enact actions at the expense of learner agency

Promoting learner agency within the laboratory, similar to enabling learners to make mistakes as well as avoiding explicit guidance, is a *PFRL* pedagogical practice that participants were observed to be contrary against. Again, agency is operationalized as the freedom of effort and of interpretation, a contextual feature one would expect a good video game to sustain for players (Klopfer, Osterweil, & Salen, 2009). Situated in the laboratory context, agency refers to the cognitive and mechanical sensemaking with which learners can engage. These processes, however, may at times be commandeered by the GTA instead. Such scenarios would involve participants doing the experiment for the learners or explaining and giving the answers without productively incorporating learners' inputs. Building off of previous rationales, participants may feel more personally responsible for ensuring their learners' success due to inherent doubts that learners are conceptually and experimentally prepared for the laboratory. The VSR interviews also show that this responsibility further encompasses safeguarding learners from dangers in the laboratory as well as boosting their positive affects. Participants may be negotiating the idea that if they themselves were to provide the sensemaking and do the experiment or the laboratory report writing in place of their learners, this substitution would become the most beneficial form of assistance.

This finding demonstrates how it is crucial to investigate learning within-the-moment. Assuming a more macro-perspective, how GTAs help their learners may still resume the guise of pedagogy that maintains student-centric sensemaking. In other words, throughout most of the laboratory, GTAs are orchestrating learners' doing and sensemaking of the experiment. However, taking a more micro-perspective reveals brief but crucial moments of teacher-centric pedagogy and discourse akin to reverse-IRE. Such moments would involve participants themselves doing the sensemaking and creating the canonical pathway for learners to later follow. This evolution of explicit guidance to the extent that participants do the reasoning and learners are repositioned as observers or listeners instead of active participants is problematic. The reason is that it fundamentally conflicts with the original intent of the laboratory. All laboratory reform efforts share the commonality of being grounded in active learning where at the very least, learning must be student-centered (e.g., Atkin & Karplus, 2002; Varma-Nelson, 2006; Veale, Krause, & Sewry, 2018). Compromising learners' agency in key moments risks creating a norm in which learners can depend on their GTAs for the correct answers. Learners would consequently no longer recognize the initiative to plan, execute, and reason with their experimentation which would negatively impact their long-term learning. At worst case scenario, the laboratory becomes reappropriated as a space for learners to listen, watch, and emulate what the GTA says. For learning from failure and chemistry to productively co-exist, GTAs must be wary of overstepping their boundaries and compromising the space in which learners can independently make sense of the contextual problem. GTAs need to simultaneously negotiate when to exercise this degree of restraint, identifying crucial moments in which it may be more appropriate to step-in. GTAs may accordingly benefit from practices of noticing in which they attend to learners' ideas first, interpret the meaning, and then decide how to respond in the next discursive move (Jacobs, Lamb, & Philipp, 2010). Just as how learners must actively learn within the laboratory, there is the implicit impetus that GTAs must actively teach as well, responding to situations in which both successes and failures can potentially be utilized.

CHAPTER 6. CONCLUSION

In this chapter, I summarize the findings for both phases of the GTA project. In addition, I discuss corresponding limitations for both phases and how that limits the extent of the analysis. I conclude by recommending future lines of research to more effectively address the inherent limitations within these studies.

6.1 Phase One of the GTA Project

Phase One of the GTA project situated participant experiences within the theoretical perspective of Communities of Practice. Here, the findings show that GTAs' experiences as CoP-TC newcomers were more uniform and limited compared to their memberships as old-timers in CoP-LC. While the former conveyed themes of primarily following the rules and facilitating learners' experiment, the latter was more nuanced in which participants self-recognized their idiosyncratic ways of laboratory teaching. This study recognizes that participants, as nexuses of multimembership, are active sensemakers of their pedagogy in which they must negotiate their obligations as both CoP-TC newcomers and CoP-LC old-timers. Findings from the interview allude to the underlying norm that participants perceive their GTA training to be better chemists as opposed to better teachers. In other words, the communal features of spaces in which GTAs learn to teach encourage GTAs to more effectively conduct and troubleshoot learners' experiments instead of using these experiments to facilitate learners' sensemaking. Practices involving supporting good laboratory report grades, timely experimental completion, and positive affects may paradoxically hinder the learning experience. We as a chemistry education community need to address the within-the-moment contexts in which GTAs inhabit throughout their teaching appointment if we aim to improve their enacted pedagogy and learners' sensemaking within the laboratory. Sustaining a space in which GTAs can actively learn about their pedagogy can potentially be instigated by first reexamining the community's mutual engagement, joint enterprise, and shared repertoire.

There are two primary limitations, theoretical and methodologically respectively, that constrain the findings for this phase of the GTA project. First, the theory of CoP lacks key constructs that other social learning theories incorporate. CoP overly conflates the notion of a community in which aspects such as race, culture, ethnicity, power, and other important factors of identity become somewhat effaced. In contrast, Holland and colleagues' (1998) introduce the concept of figured worlds as a socially organized and reproduced historical phenomena. Their equivalent of a community of practice is a conceptualization of subjectivities, consciousness, and agency (defined as the realized capacity of people to act purposively and reflectively in their world) (p. 43-44). Because CoP lacks the theoretical scope to explore these facets of identity, one emergent finding from the data that could not further explored was international participants' experiences as GTAs. While these participants discussed themes of struggling with English proficiency, being anxious in the ways they were perceived by their students, and rehearsing their pedagogy beforehand, these experiences could not be adequately addressed by CoP. These factors reasonably affected their identities-in-practice but were not anticipated by the theory itself.

Second, this study's methodological limitation is that analysis was centered on data obtained from an interview setting. Briggs (1986, p. 3) argues that "since the context-sensitive features of such discourse are more clearly tied to the context of the interview than to that of the situation it describes," researchers always risk "misinterpreting the meaning of the response." This researcher states that methodological conservativism is somewhat required in the sense that one cannot simply rid themselves of bias but instead practice reflexivity throughout this ongoing tension. In the context of this study, while participants' perspectives of their CoPs may not be generalizable, I contend that emergent analysis may nevertheless be beneficial for GTAs' learning of their pedagogy. I also incorporate my own perspectives as a GTA and a former supervisor to help inform my interpretation of what participants say throughout the interview. This type of interview setting also foregrounds self-recognition as opposed to the enacted practice itself. What this means is that what participants say may not necessarily align with what they do. Observing what GTAs actually do in naturalistic settings would be the most effective way of addressing the aforementioned limitation. Consequently, the limitation of self-recognition became the motivation for designing Phase Two of the GTA project. The research team had designed it so that the first phase would initiate the call (i.e., concluding that analysis that foregrounds how GTAs teach within-the-moment is underexplored) to which the second phase would respond with its incorporation of video analysis and VSR interviews.

6.2 Phase Two of the GTA Project

Phase Two of the GTA project foregrounds pedagogical considerations to facilitate learning from failure in a chemistry laboratory context. With regards to participants' currently enacted teaching, there are aspects that can be leveraged to sustain a failure-driven learning context. However, there are also incongruities that must be addressed for more seamless integration. Explicit guidance and the nature of errors must first be theoretically reconsidered. Due to how current social norms and curricula design appropriate errors as being unproductive throughout the laboratory, committing errors may be too detrimental for learners. Redefining an error as something hypothetically explored may be a more sensible approach. At the same time, GTAs should also incorporate more opportunities to connect the chemistry to different contexts. Despite mentioning the importance of transfer in their VSR interviews, there were no instances in which GTAs' pedagogy explicitly orchestrated long-term learning. The principal finding of this study is that for a failure-driven learning context to function as intended, GTAs must enact student-centric pedagogy without compromising learners' agencies. Although relying on the reverse-IRE discourse or doing the cognitive and mechanical tasks for the students may help with short-term performance, these enacted actions may be detrimental for long-term learning. GTAs' acting as a substitute for their learners in key sensemaking moments may enforce a norm in which learners see less initiative to work independently and more initiative to passively listen and observe.

Beyond the limitations that this phase of the project shares with the previous phase, this study's most prominent limitation is that the video analysis was done by myself, contrary to what the literature recommends as norms for conducting video analysis. Again, the purpose of watching a video clip in a collaborative space is to generate a variety of interpretations to reveal and challenge the unique biases of individual researchers (Jordan & Henderson, 1995). Because the coding was not done in a group of people, I as a current GTA, former course instructor, and former supervisor, and supporter of failure-driven learning, am predisposed to view the data corpus in a particular manner. The ways in which I had selected events, the types of questions that were emergent during the VSR interviews, and the subsequent coding and analysis are all derivative from my own researcher perspective. If I had additional research members who participated in the video analysis process, I hypothesize that different ideas of verbal and non-verbal communication, contrary coding schemes, and debate about the underlying chemistry reasoning may have manifested. As a result, this study is primarily exploratory and interpretive. In spite of the limitations, I argue that that the conducted research process was nevertheless rigorous and aligned with what the literature recommends. Thus, the insight derived from these findings are worthwhile to consider for both researchers and laboratory instructors.

6.3 Implications

Combining the findings from both phases of the study points to specific recommendations for future research in chemistry education. First, on the topic of GTAs, I agree that their training should span beyond orientation, be led by committed and enthusiastic facilitators, and incorporate collaborative spaces as other studies have shown (e.g., Zotos et al., 2020). However, I also argue that there exist larger communal features that may otherwise disincentive what GTAs learn about pedagogy. For Phase One of the study, participants expressed actions that may deter their students' learning despite participating in a semester-long pedagogical training program that all first-year graduate students at the research site must complete. I fear that obligations in spaces such as staff meeting may minimize the sustainability of GTAs' learning and implementation of research-based instructional strategies. As Luft and colleagues (2004) have noted, expecting GTAs to achieve their potential without proper instructional support is like growing a garden without water. Extending this analogy, I assert that the soil itself also needs to be properly addressed. It is insufficient to expect GTA training to bear fruit if the contexts in which GTAs reside are unconducive for their growth.

I recommend that individuals spearheading GTA staff meeting should reconceptualize GTAs' situated roles and incorporate their input more actively. Such practitioners should leverage and direct GTAs' negotiations by providing additional opportunities during staff meeting where GTAs can discuss, reflect, and customize their pedagogy based on contextual affordances and restrictions. Specifically, I suggest implementing aspects of video club: a training model in which GTAs investigate teaching and learning from video recording excerpts of their own classrooms (Sherin & Han, 2004). Establishing parts of video club as communal norms would change CoP-TC mutual engagement such that participants would be more invited to use their resources and sensemaking to catalyze their growth as researchers of their own pedagogy (Karsenty & Sherin, 2016). Using video club can also adjust CoP-TC and CoP-LC joint enterprise such that GTAs are pushed to reflect on their pedagogy to conceptualize teaching as ongoing inquiry (Ball, 1993).

GTAs would have more opportunities to discover applied solutions in which they can better attend and respond to their learners' sensemaking in future interactions (González & Skultety, 2018).

Aspects of video club can also facilitate GTAs' learning of enacting pedagogy that promotes learning from failure. The main goal of video club is prime participants to "attend to and interpret" learners' sensemaking emergent within grounded contexts (van Es, 2012, p. 184). Known as the practice of noticing, this mode of viewing video data can help foreground potential moments in which learners' errors can be productively leveraged. By specifically highlighting these types of interactions, GTAs can begin building a pedagogical toolkit to inform later teaching practice (Mason, 2002, p. 29). In other words, by introducing moments in which GTAs can capitalize on learners' failures, GTAs may be better prepared to notice such moments for the future as well. Noticing is crucial for promoting change; if one does not notice, one cannot intentionally decide to act differently (Rosaen, Lundeberg, Cooper, Fritzen, & Terpstra, 2008).

Another benefit to GTAs' understanding of pedagogy that facilitates learning from failure is the collaborative nature of video club. Within this space, it is expected that participants exercise critical colleagueship which is a "professional discourse that includes and does not avoid critique" (Lord, 1994, p. 195). GTAs who watch these video clips of their pedagogy would discuss and offer competing views (e.g., probing each other's thinking, posing questions, and using evidence-based claims) to understand the effects of their teaching on learners (van Es, Tunnney, Goldsmith, & Seago, 2014). Similar to that of researchers' conducting video analysis, the reconciliation of different ideologies and assumptions would further refine GTAs' toolkit of failure-driven pedagogy. Promoting norms of questioning, commenting, and elaboration (Wineburg & Grossman, 1998) helps transform a community into one that is continually reflective of and transformative in its teaching practices (Achinstein, 2002; Charalambous, Philippou, & Olympiou, 2018). This type of community is imperative if learning from failure is to be seriously pursued in the chemistry context.

I recommend that those in charge of staff meeting to reconsider the design of CoP-TC and CoP-LC resources to better support GTAs' enacting and learning of pedagogy. This is especially true in the case of failure-driven pedagogy as well. For instance, CoP-LC materials (e.g., laboratory reports and assessments) designed to reward learners' in-moment sensemaking can shift GTAs' attention away from solely the accuracy and precision of experimental outcomes. Introducing more instances in the experimental protocol and the assessments that not only permit experimental failures but also explicitly encourage learners to make sense of their failures may obligate GTAs to facilitate these processes accordingly. Learners may consequently have a more cohesive understanding of the process of experimentation. In addition, there can be more instances that meaningfully reinforce long-term learning. If the protocol and assessments encouraged learners to connect to past/future experiments and everyday phenomena, GTAs may feel more incentivized to enact pedagogies of transfer. Overall, these redesigned resources may help sustain a pedagogy that encourages learners to hypothesize observations and appropriate chemistry models as tools for learning instead of information to be memorized (Gouvea & Passmore, 2017).

For researchers who are interested in what transpires within the laboratory, I recommend conducting more naturalistic observations of GTA-student interactions. As previous studies have shown, what GTAs do in their teaching spaces and their corresponding rationales is still underexplored in terms of its depth and breadth (e.g., Velasco et al., 2016). Incorporating a more fine-grained perspective for future video analysis may be beneficial. Attending to multiple modalities that explore specifically what learners write, the spatial positioning of the experiment, and the finer linguistic features of spoken discourse may generate new insight on the context from which learning emerges. Implementing ethnographic or autoethnographic methods may also help unpack these inherent complexities. Ethnography is one of the major foundations of cultural anthropology in which the researcher aims to understand human society and culture (Bernard, 2011). As mentioned previously in Phase One, every laboratory was unique in the ways participants would enact their pedagogies. These idiosyncrasies could warrant further exploration to understand how learning and teaching could unfold within-the-moment. By utilizing ethnographic methods, the researcher may be able to generate more nuanced insight that can pinpoint practical recommendations for participants' benefit. I myself have been attempting to incorporate more failure-driven pedagogy in my own teaching. The reflections of my experiences will be discussed in the final chapter of this dissertation.

Finally, I hope that future researcher re-engage with the theoretical considerations of their study. First, studies that utilize CoP should realize this framework's theoretical robustness. I bring to attention that CoP provides a means to conceptualize the individual as a nexus of multimembership, a perspective that few studies that utilize CoP acknowledge. Even though Phase One explicitly focused on two CoPs, there are other CoPs that may be significant for GTAs' experiences. With regards to other constructs that involve research, gender, race, culture, and others intrinsic to identify formation, CoP may not be theoretically sufficient. Accordingly, I encourage future researchers of GTAs' identities to create conceptual frameworks appropriate for their study so that they can better determine how GTAs' learning to teach is socially influenced. This rationale is how I came to formulate *PFRL*. Because chemistry learning in the laboratory and productive failure as an ensemble is largely undertheorized, I had to incorporate a several bodies of literature to better reconceptualize failure-driven pedagogy. The current conception of *PFRL* is by no means complete, but should ideally act as a baseline for further theoretical refinement. I recommend that future researchers begin implementing *PFRL* slowly, observing the effects of certain teaching moves before implementing more macro-level changes. Similar to redefining errors and direct instruction, I anticipate further revisions to *PFRL*-related pedagogical practices for more fitting application in the laboratory context.

CHAPTER 7. REFLECTION

In this chapter I document my personal experiences attempting to incorporating *PFRL* in my teaching laboratories. I reflect upon the feasibility, factors to consider for *PFRL* and the laboratory to co-exist, and my impressions of my own students' response.

7.1 My history of teaching general chemistry laboratories

My history of being a graduate teaching assistant spans across six years. During my master's program, I was a GTA for a general chemistry course that was a prerequisite for any science-related majors. I was also the head supervisor throughout this period in which I had the opportunity to observe other GTAs' interactions with their students. Transitioning into my doctoral program, I had the opportunities to teach a variety of different general chemistry courses unlike my master's program. Specifically, I had taught general chemistry to students of various majors: chemistry, engineering, nursing, and education. For a semester I was even a course instructor for a general chemistry laboratory course. Because of these experiences, I consider myself to be fairly comfortable being a general chemistry GTA. I am thoroughly familiar with the experiments learners need to do, the corresponding learning objectives, and the type of sensemaking for which the experiment is designed. However, in my recent attempts to implement *PFRL,* I have noticed a very broad range of pedagogical practices that are both feasible and unfeasible. Below, I present my reflections on my own teaching experiences with *PFRL*.

7.2 Trying out *PFRL* in my own laboratories

From the beginning, I recognized the importance of viewing and presenting the laboratory not as something isolated but rather a vignette of a more connected experience. This meant that I had to actively teach in a way that encouraged my students to understand the relevance of past and future experiments as well as everyday connections. Because of this, I had to negotiate more explicit guidance in the beginning to create a space in which my learners can develop a stronger foundation of chemistry knowledge and practices. One example that comes to mind is the proper usage of glassware: pipets, beakers, Erlenmeyer flasks, and graduated cylinders. The goal of this experiment is to demonstrate to learners that pipets are more accurate and precise while the beaker is not. This is further reinforced with the laboratory report prompting students to report the mass of waters they measure with each glassware, the densities at the given temperature, and the corresponding volumes (all of which presume correct significant figures for full points). Given this context of students who may be unfamiliar with the laboratory and chemistry in general, I had to negotiate explicit guidance in several ways.

First, I had resolved that if students had questions about the protocol, it would be inappropriate if I completely withheld information. My compromise involved pointing to the laboratory manual in which the information can be obtained or encouraging the student to ask her or his partner. However, for questions that could neither be addressed in such fashion and required a more thorough explanation, I found myself asking students for their hypotheses first. I would create a space where students felt invited to participate through asking them directly, staying quiet so they would feel compelled to speak, and turning my body to make sure the proxemics indicated that this was a collaborative space. Prompting students to give their hypotheses works well and can enable learners to explore different avenues of the experiment that they may not have considered. However, because I knew that errors would negatively impact students' grades via their assessments later on, I could not withhold information as envisioned by *PFRL*. If students come not come to the correct solution on their own, I found myself leveraging explicit guidance more so in this experiment compared to later experiments in the semester. Actions such as directing students where glassware can be found, troubleshooting old pipet bulbs, and showing students how to use an analytical balance was definitely more teacher-centric than I had initially hoped.

Even with an experiment as introductory as measuring water with glassware, I still identified other learning objectives that I found personally relevant for transfer. For instance, one underlying chemistry practice that this experiment facilitates well is knowing what glassware to use in certain contexts. Specifically, one needs to use a pipet for exact volume determination. One could use a graduated cylinder for volumes that have more leeway. And finally, beakers are better for holding waste and transferring liquids while Erlenmeyer flasks are better for mixing reactions. Throughout the experiment, I would engage in discussion with my students and draw their attention to the shape of the glassware in conjunction with their numbers. I would prompt them to think about what these shapes reminded them of in terms of everyday objects. I would then conclude by asking them when it would be appropriate to use these glassware items in a more grounded example. The question I typically relied on was asking students which glassware is appropriate when getting reagents from a stock bottle. This helped me later establish the norm of students bringing a beaker, as opposed to a graduated cylinder, to the reagent bench where it is a lot safer to pour into a glassware that has a wider mouth. To further advance long-term learning, I instilled a norm in my class that necessitated students to check in with me before they leave the laboratory. During this moment, I would ask a more unrelated question that still pertained to that experiment's topic so that learners can apply their reasoning. For example, I sometimes would ask students what would happen if they skipped an experimental step and how it would affect their data and their conclusions. I would also prompt students with everyday examples or connections to different disciplines to broaden their perspectives of certain chemistry phenomena. Most recently during an experiment about conductivity, I remember talking about the differences between voltage and current among my students who were electrical engineering majors. On the topic of solubility, I also had a discussion with another student of mine, who would always bring his longboard to the laboratory, about why skaters use ethanol to remove rust in their wheel bearings and why it had to be ethanol instead of water or oil.

My student's reactions to my *PFRL*-inspired pedagogy has been somewhat mixed. On one hand, I detect some levels of frustration when I answer a question with another question. I distinctly remember the soured faces when students inquire about the correctness of their experimental set-up and I respond by asking them what they think. Perhaps my students do not recognize the same degree of value I recognize when I create moments for independent sensemaking. To address this, I had to rely on being transparent with my teaching practices, explicitly telling my students what my goals are and my expectations of them as well. On the other hand, I have seen students respond positively. Some become genuinely interested in how some laboratory techniques will be reincorporated later on, how chemistry concepts can be integrated in other topics, and the connections they themselves make with their previous experiences as well. From my observations, it does appear that incentivizing long-term learning results in my students' demonstrating a more comprehensive sensemaking across different experiments. I would see students short-cutting or revising the protocol steps in light of what they had done previously to make things more efficient. I would also see students rationalize certain calculations or phenomena based on what they would expect in real-life or from a previous experiment. As I enter my tenth week of teaching, I perceive my students to be a lot more independent than they were in the beginning. My students more readily enact authentic chemistry practices and undergoing sensemaking with their peers before relying on me as a model or purveyor of information.

Overall, I think it is feasible to enact *PFRL*-related pedagogical practices in the chemistry laboratory setting given certain factors. If the assessments and the design of the experiment had more instances in which students' failures are foregrounded as part of the sensemaking activity, it would definitely be more straightforward to sustain a failure-driven learning context. At the same time, I can also relate to what participants have described as a general lack of experimental preparation or chemistry understanding among their students. Learning from failure would be more ineffective if learners were more hesitant or uncomfortable with uncertainty. To mitigate this for my own teaching laboratory, I at the very least try not to be a source of information but rather a map to find the information. I have consistently tried to position my students as chemists who must rationalize and then propose a solution to the problems they face. Trying out *PFRL* for myself has made me realize the importance of attending to my students' sensemaking within-the-moment in which I need to constantly adapt my teaching to given circumstances. Moments in which I feel more pressured to enact explicit guidance and even consider assuming control of the experiment or the sensemaking only emerge when time is an issue. To avoid scenarios like this, I need to adequately prepare for the laboratory to gauge how much time is available for me to fulfill both my own and students' learning agendas. This preparation for the laboratory is perhaps the most intrinsic feature to negotiate a failure-driven pedagogy. Before one can catalyze learning opportunities from students' failures, one must first be comfortable with as many aspects of the experiment as possible. This awareness is not just limited to the experiment itself but also as a broad continuum, representative of the entire course or even something bigger.

For *PFRL* to pragmatically work, my experiences suggest that small steps need to be taken first to establish norms of failure-driven learning. Students may initially be taken aback to the notion of making mistakes in the laboratory. Time is required for students to gradually warm up to the sensemaking expectations and be receptive to pursuing their curiosity as they tinker more with their experiments. At the same time, inexperienced GTAs may also be very unused to *PFRL*. I admit that my familiarity with the laboratory teaching provides more flexibility when it comes to adapting failure-driven pedagogy in a largely success-driven learning environment. I recommend distilling *PFRL* into a few pedagogical moves for inexperienced GTAs to try out first as a gentler induction to this style of teaching. Finally, I conclude this reflection by asserting that instructors need to be patient when it comes to enacting *PFRL*. First, instructors need to be patient with their learners. Personally, I think is more important to create opportunities for students to at least try and make sense of the phenomena, regardless of how correct it may be. As an instructor, its crucial to be patient and work with your learners' ideas, albeit incorrect, to legitimize their sensemaking. This patience also incorporates the anticipation of *PFRL*'s benefits to learner. On the short-term, GTAs like myself may encounter student frustration or unwillingness to engage with their failures. It is tempting to revert back to success-driven pedagogy especially when the context appears appropriate. However, seeing the growth of my students has made me more resolved that sustaining these failure-driven norms in the beginning may be more beneficial in the end. As the weeks progress, I can slowly see my students' growth beyond the prescribed learning objectives. Learning with failure also becomes easier as topics become more interconnected and there are more chances in which I can introduce past or hypothetical errors. I have realized that the success of teaching should not be determined at the end of each laboratory period. Instead, it is something that is constantly ongoing, perhaps observed in fleeting moments. From an instructor perspective, the strongest asset of *PFRL* is perhaps the continual need to improve teaching by responding to new emergent failures. In these laboratories, there is typically only one canonical answer for a given general chemistry experiment. But with the countless ways in which learners can make mistakes around that single answer comes a wealth of opportunities to foster sensemaking for a more comprehensive understanding of chemistry.

REFERENCES

Abrahamson, H. B. (2011). Review of Foundations of Chemistry – Applying POGIL Principles, 4th edition. *Journal of Chemical Education*, *88*, 1213-1214.

Achinstein, B. (2002). *Community, Diversity, and Conflict among Schoolteachers: The Ties that Blind*. New York, NY: Teachers College Press.

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

Akerson, V. L., Cullen, T. A., & Hanson, D. L. (2009). Fostering a Community of Practice through Professional Development Program to Improve Elementary Teachers' Views of Nature of Science and Teaching Practice. *Journal of Research in Science Teaching*, *46*(10), 1090-1113.

Alibali, M. W., & Nathan, M. J. (2007). Teachers' gestures as a means of scaffolding students' understanding: Evidence from an early algebra lesson. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video research in the learning sciences* (pp. 349-365). Mahwah, NJ: Lawrence Erlbaum Associates.

Anderson, C. G., Dalsen, J., Kumar, V., Berland, M., & Steinkuehler, C. (2018). Failing up: How failure in a game environment promotes learning through discourse. *Thinking Skills and Creativity*, *30*, 135-144.

Atkin, J. M., & Karplus, R. (2002). Discovery or Invention? In R. G. Fuller (Ed.), *A Love of Discovery: Science Education – The Second Career of Robert Karplus* (pp. 83). New York, NY: Kluwer Academic/Plenum Publishers.

Ashman, G., Kalyuga, S., & Sweller, J. (2020). Problem-solving or Explicit Instruction: Which Should Go First When Element Interactivity Is High? *Educational Psychology Review*, *32*, 229-247.

Austin, A. (2002). Preparing the Next Generation of Faculty: Graduate School as Socialization to the Academic Career. *Journal of Higher Education*, *73*(1), 94-122.

Avargil, S., Herscovitz, O., & Dori, Y. J. (2012). Teaching Thinking Skills in Context-Based Learning: Teachers' Challenges and Assessment Knowledge. *Journal of Science Education and Technology*, *21*, 207-225.

Bamber, J. & Schön, D. A. (1991). Learning as reflective conversation with materials. In F. Steirer (Ed.), *Research and Reflexivity* (pp. 186-209). London: Sage Publications.

Balicer, R. (2007). Modeling infectious diseases Dissemination through Online Role-Playing Games. *Epidemiology, 18*(2), 260-261.

Ball, D. L. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. *Elementary School Journal*, *93*, 373-397.

Belenky, D. M., & Nokes-Malach, T. J. (2012). Motivation and Transfer: The Role of Mastery-Approach Goals in Preparation for Future Learning. *Journal of the Learning Sciences, 21*(3), 399-432.

Belenky, D. M., & Schalk, L. (2014). The Effects of Idealized and Grounded Materials on Learning, Transfer, and Interest: An Organizing Framework for Categorizing External Knowledge Representations. *Educational Psychology Review*, *26*, 27-50.

Bernard, H. R. (2011). *Research Methods in Anthropology: Qualitative and Quantitative Approaches* (4th ed.). New York, NY: Alta Mira Press.

Bidjerano, T. (2010). Self-conscious emotions in response to perceived failure: a structural equation model. *Journal of Experiential Education*, *78*(3), 318-342.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., & Runmble, M. (2014, December 8). *Partnership for 21st century skills*. Retrieved from http://www.p21.org/.

Bloome, D., Carter, S. P., Christian, B. M., Otto, S., & Shuart-Faris, N. (2005). *Discourse Analysis & The Study of Classroom Language & Literacy Events—A Microethnographic Perspective*. Mahwah, NJ: Lawrence Erlbaum Associates.

Bolinger, A. R., & Brown, K. D. (2015). Entrepreneurial Failure as a Threshold Concept: The Effects of Student Experiences. *Journal of Management Education, 39*(4), 452-475.

Bond-Robinson, J., Bernard Rodriques, R. A. (2006). Catalyzing Graduate Teaching Assistants' Laboratory Teaching through Design Research. *Journal of Chemical Education*, *83*(2), 313-323.

Brand, C., Massey-Allard, J., Perez, S., Rummel, N., & Roll, I. (2019). What Inquiry with Virtual Labs can Learn from Productive Failure: A Theory-Driven Study of Students' Reflections. In Isotani S., Millán E., Ogan A., Hastings P., McLaren B., & Luckin R. (Eds.), *Artificial Intelligence in Education* (pp. 30-35). Springer, Cham.

Brophy, J. (2004). *Motivating students to learn*. New York, NY: Lawrence Erlbaum Associates, Inc.

Brown, T. (2009). *Change by design: How design thinking transforms organizations and inspires innovation*. New York, NY: Harper Business.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32-42.

Briggs, C. L. (1986). *Learning to ask*. New York, NY: Cambridge University Press.

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the Level of Inquiry in the Undergraduate Laboratory. *Journal of College Science Teaching, 38*(1), 52-58.

Budner, D., & Simpson, B. (2018). Project-Based Integrated Lecture and Laboratory Quantitative Analysis Courses. *Journal of Chemical Education, 95*, 1533-1540.

Bulpin, K., & Molyneux-Hodgson, S. (2013). The disciplining of scientific communities. *Interdisciplinary Science Reviews*, *38*(2), 91-105.

Busse, A., & Ferri, R. B. (2003). Methodological reflections on a three-step design combining observation, stimulated recall, and interview. *Zentralblatt für Didatik der Mathematik, 35*(6), 257-264.

Buxton, C. A. (2006). Creating Contextually Authentic Science in a "Low-Performing" Urban Elementary School. *Journal of Research in Science Teaching, 43*(7), 695-721.

Carlone, H. B., & Johnson, A. (2007). Understanding the Science Experiences of Successful Women of Color: Science Identity as an Analytic Lens. *Journal of Research in Science Teaching*, *44*(8), 1187-1218.

Carlsen, W. S. (2007). Language and science learning: In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 57-74). Mahwah, NJ: Lawrence Erlbaum Associates.

Carmel, J. H., Ward, J. S., & Cooper, M. M. (2017). A Glowing Recommendation: A Project-Based Cooperative Laboratory Activity to Promote Use of the Scientific and Engineering Practices. *Journal of Chemical Education, 94*, 626-631.

Carter, M. (2015). Emitexts and Paratexts: Propaganda in *EVE Online*. *Games and Culture, 10*(4), 311-342.

Cascella, B., & Jez, J. M. (2018). Beyond the Teaching Assistantship: CURE Leadership as a Training Platform for Future Faculty. *Journal of Chemical Education*, *95*, 3-6.

Cetin, B., Ilhan, M., & Yilmaz, F. (2014). An investigation of the relationship between the fear of receiving negative criticism and of taking academic risk through canonical correlational analysis. *Educational Sciences: Theory and Practice*, *14*(1), 146-158.

Chadha, D. (2013). Reconceptualising and reframing graduate teaching assistant (GTA) provision for a research-intensive institution. *Teaching in Higher Education*, *18*(2), 205=217.

Chan, C. K. K., & Yang, Y. (2018). Developing scientific inquiry in technology-enhanced learning environments. In J. Voogt, G. Knezek, R. Christensen, & K. W. Lai (Eds.), *Second handbook of information technology in primary and secondary education* (pp. 161-180). Switzerland: Springer

Charalambous, C. Y., Philippou, S., & Olympiou, G. (2018). Reconsidering the use of video clubs for student-teachers' learning during field placement: Lessons drawn from a longitudinal multiple case study. *Teaching and Teacher Education*, *74*, 49-61.

Charmaz, K. (2014). *Constructing grounded theory* (2nd ed.). London: Sage Publications.

Chase, A., Pakhira, D., & Stains, M. (2013). Implementing Process-Oriented, Guided-Inquiry Learning for the First Time: Adaptations and Short-Term Impacts on Students' Attitude and Performance. *Journal of Chemical Education*, *90*, 409-416.

Chen, M. G. (2009). Communication, Coordination, and Camaraderie in World of Warcraft. *Games and Culture*, *4*(1), 47-73.

Chi, M. T. H. (2000). Self-explaining expository texts: the dual process of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in instructional psychology* (pp. 161-238). Hillsdale, NJ: Lawrence Erlbaum Associates.

Chin, D. B., Chi, M., & Schwartz, D. L. (2016). A comparison of two methods of active learning in physics: inventing a general solution versus compare and contrast. *Instructional Science*, *44*(2), 177-195.

Chowira, S. G., Smith, K. M., Dubois, P. J., & Roll, I. (2019). DIY productive failure: boosting performance in a large undergraduate biology course. *npj Science of Learning*, *4*(1), 1-8.

Clarke, J. (2011). Revitalizing entrepreneurship: how visual symbols are used in entrepreneurial performances. *Journal of Management Studies*, *48*(6), 1365-1391.

Clifford, M. M. (1984). Thoughts on a theory of constructive failure. *Educational Psychologist*, *19*(2), 108-120.

Cobb, P. (2002). Reasoning with tools and inscriptions. *The Journal of the Learning Sciences*, *11*, 187-216.

Cooper, M., & Klymkowsky, M. (2013). Chemistry, Life, the Universe, and Everything: A New Approach to General Chemistry, and a Model for Curriculum Reform. *Journal of Chemical Education*, *90*, 1116-1122.

Current, K. & Grunert Kowalske, M. (2016). The effects of instructional method on teaching assistants' classroom discourse. *Chemistry Education Research and Practice*, *17*(3), 590-603.

Criswell, B. A. (2011). Reducing the degrees of freedom in chemistry classroom conversations. *Chemistry Education Research and Powers*, *13*, 17-29.

Davidson, S. G., & Hughes, R. (2018). Communities of practice as a framework to explain teachers' experiences with the community of science. *Journal of Research in Science Teaching*, *55*(9), 1287-1312.

DeKorver, B. K., & Towns, M. H. (2015). General Chemistry Students' Goals for Chemistry Laboratory Coursework. *Journal of Chemical Education*, *92*(12), 2031-2037.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Hall, Koschmann, T., Lemke, J. L., Sherin, M. G., & Sherin, B. L. (2010). Conducting Video Research in the Learning Sciences: Guidance on Selection, Analysis, Technology, and Ethics. *Journal of the Learning Sciences*, *19*(1), 3-53.

diSessa, A. A., Hammer, D., Sherin, B., & Kolpakowski, T. (1991). Inventing Graphing: Meta-Representational Expertise in Children. *Journal of Mathematical Behavior*, *10*, 117-160.

diSessa, A. A., & Sherin, B. L. (2000). Meta-representation: an introduction. *Journal of Mathematical Behavior*, *19*, 385-398.

Dohrn, S. W., & Dohn, N., B. (2018). The role of teacher questions in the chemistry classroom. *Chemistry Education Research and Practice*, *19*, 352-363.

Donaldson, S. (2017). Mechanics and Metagame: Exploring Binary Expertise in *League of Legends*. *Games and Culture*, *12*(5), 426-444.

Dood, A. J., Johnson, L. M., & Shorb, J. M. (2018). Electronic Laboratory Notebooks Allow for Modifications in a General, Organic, and Biochemistry Chemistry Laboratory to Increase Authenticity of the Student Experience. *Journal of Chemical Education*, *95*(11), 1922-1928.

Dourish, P. (2001). *Where the action is: The foundations of embodied interaction*. Cambridge, MA: The MIT Press.

Dragisich, V., Keller, V., & Zhao, M. (2016). An Intensive Training Program for Effective Teaching Assistants in Chemistry. *Journal of Chemical Education*, *93*, 1204-1210.

Duffy, T. M., & Raymer, P. L. (2010). A practical guide and a constructivist rationale for inquiry based learning. *Educational Technology*, *50*(4), 3-15.

Elliot, M. J., Stewart, K. K., Lagowski, J. J. (2008). The Role of Laboratory in Chemistry Instruction. *Journal of Chemical Education*, *85*(1), 145-149.

Enyedy, N., & Stevens, R. (2014). Analyzing Collaboration. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 191-212). New York, NY: Cambridge University Press.

Eren-Sisman, E. N., Cigdemoglu, C., & Geban, O. (2018). The effect of peer-led team learning on undergraduate engineering students' conceptual understanding, state anxiety, and social anxiety. *Chemistry Education Research and Practice*, *19*, 694-710.

Erickson, F. (1982). Classroom discourse as improvisation: Relationships between academic task structure and social participation structure in lessons. In L. C. Wilkinson (Ed.), *Communicating in the classroom* (pp. 153-182). New York, NY: Academic.

Erickson, F. (1992). The interface between ethnography and microanalysis. In M. D. LeCompte, W. L. Millroy, & J. Preissle (Eds.), *The Handbook of Qualitative Research in Education* (pp. 201-205). San Diego, CA: Academic Press.

Erickson, F. (2006). Definition and analysis of data from videotape: Some research procedures and their rationales. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), *Handbook of complementary methods in education research* (pp. 177-205). Mahwah, NJ: Lawrence Erlbaum Associates.

Fairbrother, H. (2012). Creating space: maximizing the potential of the Graduate Teaching Assistant role. *Teaching in Higher Education*, *17*(3), 353-358.

Farré, A. S., & Lorenzo, M. G. (2009). Another piece of the puzzle: the relationship between beliefs and practice in higher education organic chemistry. *Chemistry Education Research and Practice*, *10*, 176-184.

Feder, E., Khan, L., Mazur, G., Vernon, T., Janke, T., Newbrough, J., … & Varma-Nelson, P. (2016, April 4). *Accessing collaborative online learning with mobile technology in Cyber Peer-Led Team Learning*. EDUCAUSE Review Online. https://er.educause.edu/articles/2016/4/accessing-collaborative-online-learning-with-mobile-technology-in-cyber-peer-led-team-learning.

Fischer, C., Fishman, B., Dede, C., Eisenkraft, A., Frumin, K., Foster, B., Lawrenz, F., Levy, A. J., & McCoy, A. (2018). Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science reform. *Teaching and Teacher Education*, *72*, 107-121.

Fitzgerald, A., Hackling, M., & Dawson, V. (2013). Through the Viewfinder: Reflecting on the Collection and Analysis of Classroom Video Data. *International Journal of Qualitative Methods*, *12*, 52-64.

Flaherty, A., O'Dwyer, A., Mannix-McNamara, P., & Leahy, J. J. (2017). Evaluating the Impact of the "Teaching as a Chemistry Laboratory Graduate Teaching Assistant" Program on Cognitive and Psychomotor Verbal Interactions in the Laboratory. *Journal of Chemical Education*, *94,* 1831-1843.

Flynn, A. B., & Biggs, R. (2012). The Development and Implementation of a Problem-Based Learning Format in a Fourth-Year Undergraduate Synthetic Organic and Medicinal Chemistry Laboratory Course. *Journal of Chemical Education*, *89*, 52-57.

Foroudastan, S. (2009). Enhancing undergraduate performance through peer-led team learning (PLTL). *American Society for Engineering Education*, 1-12.

Frey, R. F., Fink, A., Cahill, M. J., McDaniel, M. A., Solomon, E. D. (2018). Peer-Led Team Learning in General Chemistry I: Interactions with Identity, Academic Preparation, and a Course-Based Intervention. *Journal of Chemical Education*, *95*, 2103-2113.

Gafney, L., & Varma-Nelson, P. (2008). *Peer-Led Team Learning: Evaluation, dissemination and institutionalization of a college level initiative*. Springer: Dordrecht, Netherlands.

Gardner, G. E., & Jones, M. G. (2011). Pedagogical preparation of the science graduate teaching assistant: Challenges and implications. *Science Educator*, *20*(2), 31-41.

Garfinkel, H. (1996). Ethnomethodology's program. *Social Psychology Quarterly*, *59*(1), 5-21.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: a research and practice model. *Simulation & Gaming*, *33*(4), 441-467.

Gee, J. P. (1999). *An Introduction to Discourse Analysis: Theory and method*. New York, NY: Routledge.

Gee, J. P. (2007). *What video games have to teach us about learning and literacy* (rev. ed.). New York, NY: Palgrave Macmillan.

Gee, J. P. (2008). *Social Linguistics and Literacies: Ideology in Discourses* (3rd ed.). New York, NY: Routledge.

Gee, J. P., & Hayes, E. R. (2010). *Women and Gaming: The Sims and 21st Century Learning*. New York, NY: Palgrave Macmillan.

Geertz, C. (1973). *The interpretation of cultures*. New York, NY: Basic Books.

Gibbs, J. (2011). *Player agency, critical states, and games as formal systems*. Retrieved from Gamasutra website: http://gamasutra.com/blogs/JoeyGibbs/20110713/89809/Player_Agency_Critical_States_and_Games_as_Formal_Systems.php

Gillon, G., and Hoad, J. (2001). *Postgraduate students as teachers*. Lancaster, UK: NPC.

Glaser, B. G. (1965). The constant comparative method of qualitative analysis. *Social Problems*, *12*(4), 436-445.

Glogger-Frey, I., Fleischer, C., Grüny, L., Kappich, J., & Renkl, A. (2015). Inventing a solution and studying a worked solution prepare differently for learning from direct instruction. *Learning and Instruction*, *39*, 72-87.

Goldman-Segall, R. (1998). *Points of viewing children's thinking: A digital ethnographer's journey*. Mahwah, NJ: Lawrence Erlbaum Associates.

González, G., Deal, J. T., & Skultety, S. (2016). Facilitating Teacher Learning when Using Different Representations of Practice. *Journal of Teacher Education*, *67*(5), 447-466.

González-Howard, M., & McNeill, K. L. (2016). Learning in a Community of Practice: Factors Impacting English-Learning Students' Engagement in Scientific Argumentation. *Journal of Research in Science Teaching*, *53*(4), 527-553.

Gouvea, J., & Passmore, C. (2017). ‘Models of’ versus ‘Models For:’ Toward an Agent-Based Conception of Modeling in the Science Classroom. *Science & Education*, *26*, 49-63.

Granberg, C. (2016). Discovering and addressing errors during mathematics problem-solving—A Productive struggle? *The Journal of Mathematical Behavior*, *42*, 33-48.

Grossnickle, E. M. (2016). Disentangling Curiosity: Dimensionality, Definitions, and Distinctions from Interest in Educational Contexts. *Educational Psychology Review*, *28*, 23-60.

Hadfield, M., & Haw, K. (2012). Video: modalities and methodologies. *International Journal of Research & Method in Education*, *35*(3), 311-324.

Halliday, M. A. K., & Hasan, R. (1985). *Language, context, and text: Aspects of language in social-semiotic perspective*. Waurn Ponds, Australia: Deakin University.

Hammer, D., Elby, A., Scherr, R., & Redish, E. F. (2005). Resources, framing, and transfer. In J. P. Mestre (Ed.), *Transfer of Learning from a Modern Multidisciplinary Perspective* (pp. 89-119). Greenwich, CT: IAP.

Hammond, K. J., Converse, T. M., & Grass, J. W. (1995). The stabilization of environments. *Artificial Intelligence*, *72*, 305-327.

Harland, T., & Plangger, G. (2004). The Postgraduate Chameleon: Changing Roles in Doctoral Education. *Active Learning in Higher Education*, *5*(1), 73-86.

Harré, R., & Moghaddam, F. (2003). Introduction: The Self and Others in Traditional Psychology and in Positioning Theory. In R. Harré & F. Moghaddam (Eds.), *The self and others: Positioning individuals and groups in personal, political, and cultural contexts* (pp. 1-11). Westport, CT: Praeger Publishers.

Hayes, E. R., & King, E. M. (2009). Not Just A Dollhouse: What *The Sims 2* Can Teach Us About Women’s IT Learning. *On The Horizon*, *17*(1), 60-69.

Hein, S. M. (2012). Positive Impacts Using POGIL in Organic Chemistry. *Journal of Chemical Education*, *89*, 860-864.

Hickey, D. T., & Zuiker, S. J. (2012). Multilevel Assessment for Discourse, Understanding, and Achievement. *Journal of the Learning Sciences*, *21*(4), 522-582.

Hiwiller, Z. (2015). *Players Making Decisions: Game Design Essentials and the Art of Understanding Your Players*. Berkeley, CA: New Riders.

Holland, D., Lachicotte Jr, W., Skinner, D., & Cain, C. (1998). *Identity and Agency in Cultural Worlds*. Cambridge, MA: Harvard University Press.

Hopper, M. J., & Quiñones, S. (2012). A Hunch Without a Sound: Co-Constructing Meanings of Nonverbal and Verbal Interactions in Video Data. *International Journal of Qualitative Methods*, *11*(5), 547-572.

Huang, R., Shimizu, Y. (2016). Improving teaching, developing teachers and teacher educators, and linking theory and practice through lesson study in mathematics: an international perspective. *ZDM Mathematics Education*, *48*, 393-409.

Hung, A. C. Y. (2011). *The Work of Play: Meaning-Making in Video Games*. New York, NY: Peter Lang Publishing.

Hunicke, R. (2005). The case for dynamic difficulty adjustment in games. *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology*, 429-433.

Hunnicutt, S. S., Grushow, A., & Whitnell, R. (2015). Guided-Inquiry Experiments for Physical Chemistry: The POGIL-PCL Model. *Journal of Chemical Education*, *92*, 262-268.

Irwn, S. V., & Naweed, A. (2018). BM'ing, Throwing, Bug Exploiting, and Other Forms of (Un)Sportsmanlike Behavior in CS:GO Esports. *Games and Culture*, 1-23.

Jacobs, W. R. (2002). Using Lower-Division Developmental Education Students as Teaching Assistants. *Research and Teaching in Developmental Education*, *19*(1), 41-48.

Jacobs, V. R., Lamb, L. L. C., & Philipp, R. A. (2010). Professional Noticing of Children's Mathematical Thinking. *Journal for Research in Mathematics Education*, *41*(2), 169-202.

Jonassen, D. H. (2000). Towards a design theory of problem solving. *Educational Technology, Research and Development*, *48*(4), 63-85.

Jordan, B., & Henderson, A. (1995). Interaction Analysis: Foundations and Practice. *The Journal of the Learning Sciences*, *4*(1), 39-103.

Jordan, K., & Howe, C. (2018). The perceived benefits and problems associated with teaching activities undertaken by doctoral students. *Teaching in Higher Education*, *23*(4), 504-521.

Juul, J. (2013). *The Art of Failure: An Essay on the Pain of Playing Video Games*. Cambridge, MA: The MIT Press.

Kahn, J. (2020). Learning at the Intersection of Self and Society: The Family Geobiography as a Context for Data Science Education. *Journal of the Learning Sciences*, *29*(1), 57-80.

Kalmpourtzis, G. (2019). *Educational Game Design: A Journey to Creating Intrinsically Motivating Learning Experiences*. Boca Raton, FL: CRC Press.

Kampmeier, J. A., & Varma-Nelson, P. (2009). Peer-led team learning: organic chemistry. In N. J. Pienta, M. M. Cooper, & T. J. Greenbowe (Eds.), *Chemists' guide to effective teaching* (Vol. 2). Upper Saddle River, NJ: Pearson Prentice Hall.

Kapanadze, D. Ü. (2018). The effect of using discourse analysis method on improving cognitive and affective skills in language and literature teaching. *European Journal of Education Studies*, *4*(5), 92-107.

Kapur, M. (2008). Productive failure. *Cognition and Instruction*, *26,* 379-424.

Kapur, M. (2010). Productive failure in mathematical problem solving. *Instructional Science*, *38*, 523-550.

Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science*, *40*, 651-672.

Kapur, M. (2013). Learning from productive failure. *Learning: Research and Practice*, *1*(1), 51-65.

Kapur, M. (2014). Productive failure in learning math. *Cognitive Science*, *38*(5), 1008-1022.

Kapur, M. (2016). Examining Productive Failure, Productive Success, Unproductive Failure, and Unproductive Success in Learning. *Educational Psychologist*, *51*(2), 289-299.

Kapur, M., & Bielaczyc, K. (2012). Designing for Productive Failure. *Journal of the Learning Sciences*, *21*(1), 45-83.

Kapur, M., & Rummel, N. (2012). Productive failure in learning from generation and invention activities. *Instructional Science*, *40*, 645-650.

Karsenty, R., & Sherin, M. G. (2017). Video acts as a catalyst for mathematics' teachers' professional growth. *Journal of Mathematics Teacher Education*, *20*(5), 409-413.

Ke, F., Lee, S., & Zu, X. (2016). Teaching training in a mixed-reality integrated learning environment. *Computers in Human Behavior*, *62*, 212-220.

Ke, F., Xie, K., & Xie, Y. (2016). Game-based learning engagement: A theory- and data-driven exploration. *British Journal of Educational Technology*, *47*(6), 1183-1201.

Kelly, P. (2006). What is teacher learning? A socio-cultural perspective. *Oxford Review of Education*, *32*(4), 505-519.

Kendon, A. (1985). Behavioral foundations for the process of frame attunement in face-to-face interactions. In G. P. Ginsburg, M. Brenner, & M. von Cranach (Eds.), *Discovery strategies in the psychology of action* (pp. 229-253). London: Academic.

Khan, Y. A., Ahamad, Z., & Kousar, S. (2013). Factors influencing academic failure of university students. *International Journal of Educational Administration and Policy Studies*, *5*(5), 79-84.

Kiili, K. (2007). Foundation for problem-based gaming. *British Journal of Educational Technology*, *38*(3), 394-404.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work. *Educational Psychologist*, *41*(2), 75-86.

Kisiel, J. F., (2010). Exploring a School–Aquarium Collaboration: An Intersection of Communities of Practice. *Science Education*, *94*(1), 95-121.

Klopfer, E., Osterweil, S., & Salen, K. (2009). *Moving learning games forward*. Cambridge, MA: The Education Arcade.

Kulatunga, U., & Lewis, J. E. (2013). Exploration of peer leader verbal behaviors as they intervene with small groups in college general chemistry. *Chemistry Education Research and Practice*, *14*, 576.

Lamnina, M., & Chase, C. (2019). Developing a thirst for knowledge: How uncertainty in the classroom influences curiosity, affect, learning, and transfer. *Contemporary Educational Psychology*, *59*, 101785.

Lane, A. K., Hardison, C., Simon, A., & Andrews, T. C. (2018). A model of the factors influencing teaching identity among life sciences doctoral students. *Journal of Research in Science Teaching*, *56*(2), 141-162.

Latimer, D. R., Ata, A., Forfar, C. P., Kadhim, M., McElrea, A., & Sales, R. (2018). Overcoming the Hurdle from Undergraduate Lab to Research Lab: A Guided-Inquiry Structural Organization of a Complex Mixture in the Upper-Division Undergraduate Organic Lab. *Journal of Chemical Education*, *95*(11), 2046-2049.

Lastowka, G. (2009). Rules of Play. *Games and Culture*, *4*(4), 379-395

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. New York, NY: Cambridge University Press.

LeBaron, C. (2005). Considering the social and material surround: toward microethnographic understandings of nonverbal behavior. In V. Manusov (Ed.), *The Sourcebook of Nonverbal Measures* (pp. 493-506). Mahwah, NJ: Lawrence Erlbaum Associates.

Lemke, J. (1990). *Talking science: language, learning, and values*. Westport, CT: Ablex.

Lester, J. N., Lochmiller, C. R., & Gabriel, R. (2016). Locating and applying critical discourse analysis within education policy: An introduction. *Education Policy Analysis Archives*, *24*(102). 1-15.

Lester, J. N., Lochmiller, C. R., & Gabriel, R. (2017). Exploring the Intersection of Education Policy and Discourse Analysis: An Introduction. *Education Policy Analysis Archives*, *25*(25), 1-13.

Lewis, S. E. (2014). Investigating the Longitudinal Impact of a Successful Reform in General Chemistry on Student Enrollment and Academic Performance. *Journal of Chemical Education*, *91*, 2037-2044.

Litts, B. & Ramirez, D. (2014). Making people fail: Failing to learn through games and making. *Proceedings GLS*, *10*, 160-166.

Loibl, K., Roll, I., & Rummel, N. (2017). Towards a theory of when and how problem solving followed by instruction supports learning. *Educational Psychology Review, 29*(4), 693-715.

Lord, B. (1994). Teachers' professional development: critical colleagueship and the role of professional communities. In N. Cobb (Ed.), *The future of education: Perspectives on national standards in America*. New York: College Board.

Lottero-Perdue, P. S., & Parry, E. A. (2017). Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering. *Journal of Pre-College Engineering Education Research, 7*(1), 47-67.

Luft, J. A., Kurdziel, J. P., Roehrig, G. H., & Turner, J. (2004). Growing a Garden without Water: Graduate Teaching Assistants in Introductory Science Laboratories at a Doctoral/Research University. *Journal of Research in Science Teaching*, *41*(3), 211-233.

Mackay, T. (2003). *Gee's theory of D/discourse and research in teaching English as a second language: Implications for the mainstream*. University of Manitoba. Retrieved from https://umanitoba.ca/faculties/education/media/MacKay-2003.pdf

Marbach-Ad, G., Schaefer, K. L., Kumi, B. C., Friedman, L. A., Thompson, K. V., & Doyle, M. P. (2012). Development and Evaluation of a Prep Course for Chemistry Graduate Teaching Assistants at a Research University. *Journal of Chemical Education, 89*, 865-872.

Mauser, K., Sours, J., Banks, J., Newbrough, J. R., Janke, T., Shuck, L., Zhu, L. (2011). Cyber Peer-Led Team Learning (cPLTL): Development and implementation. *EDUCAUSE Review Online*, *34*(4), 1-17.

Mason, J. (2002). *Researching your own practice: The discipline of noticing*. London: Routledge-Falmer.

Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist*, *59*, 14-19.

McCreary, C. L., Golde, M. F., Koeske, R. (2006). Peer instruction in the general chemistry laboratory: Assessment of student learning. *Journal of Chemical Education*, *83*(5), 804-810.

McDonald, J. T. (2002). Using problem-based learning in a science methods course. *Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science*, ERIC ED 465 621, Charlotte, NC.

McGill, T. L., Williams, L. C., Mulford, D. R., Blakey, S. B., Harris, R. J., Kindt, J. T., … Powell, N. L. (2019). Chemistry Unbound: Designing a New Four-Year Undergraduate Curriculum. *Journal of Chemical Education, 96*, 35-46.

McNaughton, M. J. (2009). Closing in on the Picture: Analyzing Interactions in Video Recordings. *International Journal of Qualitative Methods*, *8*(4), 27-48.

Mehan, H. (1979). *Learning lessons*. Cambridge, MA: Harvard University Press.

Miller, K., & Zhou, X. (2007). Learning from a classroom video: What makes it compelling and what makes it hard. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video research in the learning science* (pp. 321-334). Mahwah, NJ: Lawrence Erlbaum Associates.

Mitchell, Y. D., Ippolito, J., Lewis, S. E. (2012). Evaluating Peer-Led Team Learning across the two semester General Chemistry sequence. *Chemistry Education Research and Practice*, *13*, 378-383.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory Into Practice, 31*(2), 132-141.

Moog, R. S., & Spencer, J. N. (2008). POGIL: An Overview. In R. S. Moog & J. N. Spencer (Eds.), *Process Oriented Guided Inquiry Learning* (pp. 1-13). American Chemical Society.

Morse, W., Nielsen-Pincus, M., Force, J., & Wulfhorst, J. D. (2007). Bridges and barriers to developing and conducting Interdisciplinary graduate-student team research. *Ecology & Society*, *12*(2), 1-14.

Muir, T. (2010). Using Video-Stimulated Recall as a Tool for Reflecting on the Teaching of Mathematics. In L. Sparrow, B. Kissane, & C. Hurst (Eds.), *Shaping the future of mathematics education: Proceedings of the 33rd annual conference of the Mathematics Education Research Group of Australiasia* (pp. 438-445). Fremantle: MERGA.

Mutambuki, J. M., & Schwartz, R. (2018). We don't get any training: the impact of a professional development model on teaching practices of chemistry and biology graduate teaching assistants. *Chemistry Education Research and Practice*, *19*, 106-121.

Muzuka, V. (2009). The niche of Graduate Teaching Assistants (GTAs): perceptions and reflections. *Teacher in Higher Education*, *14*(1), 1-12.

Mylopoulos, M., Brydges, R., Woods, N. N., Manzone, J., & Schwartz, D. L. (2016). Preparation for future learning: a missing competency in health professions education? *Medical Education*, *50*(1), 115-123.

Nicholson, S. (2014). A RECIPE for Meaningful Gamification. In T. Reiners & L. C. Wood (Eds.), *Gamification in education and business* (pp. 1-20). Cham, Switzerland: Springer.

Nguyen, N. T., & Tangen, D. (2017). Video-stimulated recall in cross-cultural research in education: a case study in Vietnam. *International Journal of Research & Method in Education*, *40*(5), 445-455.

Olitsky, S. (2006). Structure, agency, and the development of students' identities as learners. *Cultural Studies of Science Education*, *1*, 745-766.

Olitsky, S. (2007). Promoting Student Engagement in Science: Interaction Rituals and the Pursuit of a Community of Practice. *Journal of Research in Science Teaching*, 44(1), 33-56.

Pagano, J. K., Jaworski, L., Lopatto, D., & Waterman, R. (2018). An Inorganic Chemistry Laboratory Course as Research. *Journal of Chemical Education*, *95*, 1520-1525.

Park, C. C. (2002). Neither fish nor fowl? The perceived benefits and problems of using graduate teaching assistants (GTAs) to teach undergraduate students. *Higher Education Review*, *35*(1), 30-42.

Park, C., & Ramos, M. (2002). The Donkey in the Department? Insights into the Graduate Teaching Assistant (GTA) experience in the UK. *Journal of Graduate Education*, *3*, 47-53.

Parker, I. (2013, March 26). Improv, robots, parkour and more: Boss level at Quest to Learn. Retrieved January 5, 2019, from Institute of Play website: http://www.instituteofplay.org/2013/03/improv-robots-parkour-and-more-boss-level-at-quest-to-learn/

Paul, C. A. (2011). Optimizing play: How theorycraft changes gameplay and design. *Game Studies*, *11*(2), 1-16.

Peterson, E. (1990). Helping TAs teach holistically. *Anthropology and Education Quarterly, 21*, 179-185.

Piaget, J. (1952). *The origins of intelligence in children*. Madison, CT: International Universities Press.

Pink, S. (2007). Walking with video. *Visual Studies*, *22*(3), 240-252.

Pinto, G., & Garrido-Escudero, A. (2016). Chemistry and Explosives: An Approach to the Topic through an Artistic and Historical Contribution Made by a Spanish Global Explosives Supplier. *Journal of Chemical Education*, *93*(1), 103-110.

Pirie, S. E. B. (1996, October 14). Classroom Video-Recording: When, Why and How Does It Offer a Valuable Data Source for Qualitative Research? *Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, 1-18.

Plucker, J. A., & Makel, M. C. (2010). Assessment of Creativity. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 48-73). New York, NY: Cambridge University Press.

Potter, J. (2004). Discourse analysis as a way of analysing naturally occurring talks. In D. Silverman (Ed.), *Qualitative Research: Theory, method and practice* (2nd ed., pp. 200-221). London: Sage Publications.

Powell, E. (2005). Conceptualising and facilitating active learning: teachers' video-stimulated reflective dialogues. *Reflective Practice*, *6*(3), 407-418.

Przybylski, A. K., Rigby, C. S., & Ryan, R. M. (2010). A Motivational Mode of Video Game Engagement. *Review of General Psychology*, *14*(2), 154-166.

Puntambekar, S., & Hübscher, R. (2005). Tools for Scaffolding Students in a Complex Learning Environment: What Have We Gained and What Have We Missed. *Educational Psychologist*, *40*(1), 1-12.

Puntambekar, S., & Kolodner, J. L. (2005). Toward Implementing Distributed Scaffolding: Helping Students Learn Science from Design. *Journal of Research in Science Teaching*, *42*(2), 185-217.

Ramirez, D., Seyler, S., Squire, K., & Berland, M. (2014). I'm a Loser, Baby: Gamer Identity & Failure. *Proceedings of DiGRA*. Retrieved from http://www.digra.org/digital-library/forums/8-digra2014/

Ratcliff, D. (2003). Video methods in qualitative research. In P. M. Carmic, J. E. Rhodes, & L. Yardley (Eds.), *Qualitative research in psychology: Expanding perspectives in methodology and design* (pp. 113-129). Washington, DC: American Psychological Association.

Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General*, *118*(3), 219-235.

Richards, L. (2015). *Handling qualitative data* (3rd ed.). London: Sage Publications.

Roehrig, G. H., Luft, J. A., Kurdziel, J. P., & Turner, J. A. (2003). Graduate Teaching Assistants and Inquiry-Based Instruction: Implications for Graduate Teaching Assistant Training. *Journal of Chemical Education*, *80*(10), 1207-1210.

Roelle, J., & Berthold, K. (2016). Effects of comparing contrasting cases and inventing on learning from subsequent instructional explanations. *Instructional Science*, *44*, 147-176.

Roll, I., Aleven, V., & Koedinger, K. (2011). Outcomes and mechanisms of transfer in invention activities. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *33*(33), 2824-2829.

Roll, I., Holmes, N. G., Day, J., & Bonn, D. (2012). Evaluating metacognitive scaffolding in Guided Invention Activities. *Instructional Science*, *40*, 691-710.

Rosaen, C. L., Lundeberg, M., Cooper, M., Fritzen, A., & Terpstra, M. (2008). Noticing Noticing: How Does Investigation of Video Records Change How Teachers Reflect on Their Experiences? *Journal of Teacher Education*, *59*(4), 347-360.

Rostvall, A. (2005). Theoretical and Methodological Perspecitves on Designing Video Studies of Interaction. *International Journal of Qualitative Methods*, *4*(4), 87-108.

Rowe, V. C. (2009). Using video-stimulated recall as a basis for interviews: some experiences from the field. *Music Education Research*, *11*(4), 425-437.

Rowe, J. P., Shores, L. R., Mott, B. W., & Lester, J. C. (2011). Integrating learning, problem solving, and engagement in narrative-centered learning environments. *International Journal of Artificial Intelligence in Education*, *21*(1), 115-133.

Ryan, B. J. (2014). Graduate teaching assistants; critical colleagues or casual components in the undergraduate laboratory learning? An exploration of the role of the postgraduate teacher in the sciences. *European Journal of Science and Mathematics Education*, *2*(2), 98-105.

Ryu, M., Nardo, J. E., & Wu, M. Y. M. (2018). An examination of preservice elementary teachers' representations about chemistry in an intertextuality- and modeling-based course. *Chemistry Education Research and Practice*, *19*, 681-693.

Salen, K., & Zimmerman, E. (2004). *Rules of Play – Game Design Fundamentals*. Cambridge, MA: The MIT Press.

Sandage, S. A. (2005). *Born Losers: A History of Failure in America*. Cambridge, MA: Harvard University Press.

Saposnik, G., Teasell, R., Mamdani, M., Hall, J., McIlroy, W., Cheung, D., … & Bayley, M. (2010). Effectiveness of Virtual Reality Using Wii Gaming technology in Strokme Rehabilitation: A Pilot Randomized Clinical Trial and Proof of Principle. *Stroke*, *41*, 1477-1484.

Sawyer, R. K. (2019). The role of failure in learning how to create in art and design. *Thinking Skills and Creativity*, *33*, 100527.

Seery, M. K., Agustian, H. Y., & Zhang, X. (2019). A Framework for Learning in the Chemistry Laboratory. *Israel Journal of Chemistry*, *59*, 546-553.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building environments: Extending the limits of the possible in education and knowledge work. In A. DiStefano, K. E. Rudestam, & R. Silverman (Eds.), *Encyclopedia of distributed learning*. Thousand Oaks, CA: Sage Publications.

Schegloff, E. A. (2006). Interaction: The infrastructure for social institutions, the natural ecological niche for language, and the arena in which culture is enacted. In N. J. Enfield and S. C. Levinson (Eds.), *Roots of human sociality: Culture, cognition and interaction* (pp. 70-96). New York, NY: Berg.

Schell, J. (2008). *The art of game design: A book of lenses*. Amsterdam: Elsevier/Morgan Kaufmann.

Scherr, R. E., & Hammer, D. (2009). Student Behavior and Epistemological Framing: Examples from Collaborative Active-Learning Activities in Physics. *Cognition and Instruction*, *27*(2), 147-174.

Schwarz, C. (2009). Developing Preservice Elementary Teachers' Knowledge and Practices through Modeling-Centered Scientific Inquiry. *Science Education*, 720-744.

Schwartz, D. L., Chase, C. C., Oppezzo, M. A., & Chin, D. B. (2011). Practice versus inventing with contrasting cases: The effects of telling first on learning and transfer. *Journal of Educational Psychology*, *103*(4), 759-775.

Schwartz, D. L., Lindgren, R., & Lewis, S. (2009). Constructivism in an age of non-constructivist assessments. In S. Tobias & T. M. Duffy (Eds.), *Constructivist Instruction* (pp. 46-73). New York, NY: Routledge.

Schwartz, D. L., & Martin, T. (2004). Inventing to prepare for future learning: The hidden efficiency of encouraging original student production in statistics instruction. *Cognition and Instruction*, *22*(2), 129-184.

Schwonke, R., Renkl, A., Krieg, C., Wittwer, J., Aleven, V., & Salden, R. (2009). The worked-example effect: Not an artefact of lousy control conditions. *Computers in Human Behavior*, *25*(2), 258-266.

Sears, D. A. (2006). Effects of innovation versus efficiency tasks on recall and transfer in individual and collaborative learning contexts. In Barab, S. A., Hay, K. E., & Hickey, D. T. (Eds.), *Proceedings of ICLS 2006* (pp. 681-687). Bloomington, IN: International Society of the Learning Sciences.

Shaffer, D. W. (2006). *How computer games help children learn*. London: Palgrave Macmillan.

Sherin, M. G., & Han, S. Y. (2004). Teacher learning in the context of a video club. *Teacher and Teacher Education*, *20*, 163-183.

Shrum, W., Duque, R., & Brown, T. (2005). Digital Video as Research Practice: Methodology for the Millennium. *Journal of Research Practice*, *1*(1), 1-19.

Sinha, T., Kapur, M., West, R., Catasta, M., Hauswirth, M., & Trninic, D. (2019). Impact of Explicit Failure and Success-driven Preparatory Activities on Learning. In *Proceedings of the annual meeting of the cognitive science society*.

Skolnik, M. R., & Conway, S. (2017). Tusslers, Beatdowns, and Brothers: A sociohistorical Overview of Video Game Arcades and the *Street Fighter* Community. *Games and Culture*, *14*(7-8), 742-762.

Smets, M., Burke, G., Jarzabkowski, P., & Spee, P. (2014). Charting new territory for organizational ethnography: Insights from a team-based video ethnography. *Journal of Organizational Ethnography*, *3*(1), 10-26.

Song, Y., & Kapur, M. (2017). How to Flip the Classroom – "Productive Failure or Traditional Flipped Classroom" Pedagogical Design? *Journal of Educational Technology and Society*, *20*(1), 292-305.

Spires, H. A. (2015). Digital Game-Based Learning: What's literacy got to do with it? *Journal of Adolescent & Adult Literacy, 59*(2), 125-130.

Squire, K. (2011). *Video games and learning: Teaching and participatory culture in the digital age. Technology, education-connections (the TEC Series)*. New York, NY: Teachers College Press.

Squire, K. (2012). Designed Cultures. In C. Steinkuehler, K. Squire, & S. Barab (Eds.), *Games, Learning, and Society: Learning and Meaning in the Digital Age* (pp. 10-31). New York, NY: Cambridge University Press.

Stains, M. (2019). Trajectories of Reform Implementation in Chemistry and Biochemistry Undergraduate Instruction. In S. Laursen & D. Smith (Eds.), *Levers for Change: An Assessment of Progress on Changing STEM Instruction* (pp. 40-63). Washington, DC: American Association for the Advancement of Science.

Steenhof, N., Woods, N. N., Van Gerven, P. W. M., & Mylopoulos, M. (2019). *Advances in Health Sciences Education*, *24,* 739-749.

Stegall, S. L., Grushow, A., Whitnell, R., & Hunnicutt, S. S. (2016). Evaluating the effectiveness of POGIL-PCL workshops. *Chemistry Education Research and Practice*, *17*, 407-416.

Stein, M., & Muzzin, M. (2018). Learning from failure. *Science and Children*, *55*(8), 62-65.

Strieker, T., Adams, M., Lim, W., & Wright, M. (2017). Using Discourse Analysis to Understand the Relationships and Practices of Pre-service Co-teachers. *Georgia Educational Researcher*, *14*(1), 40-68.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Measuring cognitive load. In *Cognitive load theory* (pp. 71-85). New York, NY: Springer.

Tang, K. (2017). Analyzing Teachers' Use of Metadiscourse: The Missing Element in Classroom Discourse Analysis. *Science Education*, *101*(4), 548-583.

Thomas, D., & Brown, J. S. (2007). The play of imagination: Extending the literary mind. *Games and Culture*, *2*(2), 149-172.

Tobias, S., & Duffy, T. M. (2010). *Constructive instruction: Success or failure*. New York, NY: Routledge.

Tosun, C., & Taskesenligil, Y. (2013). The effect of problem-based learning on undergraduate students' learning about solutions and their physical properties and scientific processing skills. *Chemistry Education Research and Practice*, *14*, 36-50.

Towns, M., Harwood, C. J., Robertshaw, M. B., Fish, J., & O'Shea, K. (2015). The digital pipetting badge: A method to improve student hands-on laboratory skills. *Journal of Chemical Education*, *92*(12), 2038-2044.

Upadhyay, B. R. (2006). Using Students' Lived Experiences in an Urban Science Classroom: An Elementary School Teachers' Thinking. *Science Education*, *90*, 94-110.

VanLehn, K. (1988). Toward a theory of impasse-driven learning. In H. Mandl & A. Lesgold (Eds.) *Learning issues for intelligent tutoring systems* (pp. 19-41). New York, NY: Springer.

VanLehn, K., Siler, S., Murray, C., Yamauchi, T., & Baggett, W. B. (2003). Why do only some events cause learning during human tutoring? *Cognition and Instruction*, *21*, 209-249.

van Es, E. A. (2012). Examining the development of a teacher learning community: The case of a video club. *Teaching and Teacher Education*, *28*, 182-192.

van Es., E. A., Tunney, J., Goldsmith, L. T., & Seago, N. (2014). A Framework for the Facilitation of Teachers' Analysis of Video. *Journal of Teacher Education*, *65*(4), 340-356.

van Manen, M. (1990). *Researching lived experience: Human science for an action sensitive pedagogy*. Albany: State University of New York Press.

Varma-Nelson, P., (2006). Peer-led team learning: the model, its dissemination and its future. *Metropolitan Universities Journal*, *14*(4), 19-29.

Veale, C. G. L., Krause, R. W. M., & Sewry, J. D. (2018). Blending problem-based learning and peer-led team learning, in an open ended 'home-grown' pharmaceutical chemistry case study. *Chemistry Education Research and Practice*, *19*, 68-79.

Velasco, J. B., Knedeisen, A., Xue, D. Vickrey, T. L., Abebe, M., & Stains, M. (2016). Characterizing Instructional Practices in the Laboratory: The Laboratory Observation Protocol for Undergraduate STEM. *Journal of Chemical Education*, *93*(7), 1191-1203.

Vygotsky, L. S. (1978). *Minds in Society: The Development of Higher Psychological Process*. Cambridge, MA: Harvard University Press.

Wagner, D. A. (2012). What should be learned from learning assessments? *COMPARE: A Journal of Comparative and International Education*, *42*(3), 510-512.

Warfa, A. M., Roehrig, G. H., Schneider, J. L., & Nyachwaya, J. (2014). Collaborative discourse and the modeling of solution chemistry with magnetic 3D physical models – impact and characterization. *Chemistry Education Research and Practice*, *15*, 835-848.

Wark, M. (2015). Losing is fun. In S. P. Walz & S. Deterding (Eds.), *The gameful world: Approaches, issues, and applications* (pp. 163). Cambridge, MA: MIT Press.

Weaver, G. C., Wink, D., Varma-Nelson, P., Lytle, F., Morris, R., Fornes, W., … Boone, W. J. (2006). Developing a new model to provide first and second-year undergraduates with chemistry research experience: Early findings of the center for authentic science practice (CASPiE). *Chemical Educator*, *11*, 125-129.

Wenger, E. (1998). *Communities of Practice: learning, meaning, and identity*. New York: Cambridge University Press.

Wheeler, L. B., Maeng, J. L., & Whitworth, B. A. (2015). Teaching assistants' perceptions of a training to support an inquiry-based general chemistry laboratory course. *Chemistry Education Research and Practice*, 16(4), 824-842.

Williams, D. P. (2017). Learn on the Move: A Problem-Based Induction Activity for New University Chemistry Students. *Journal of Chemical Education*, *94*, 1925-1928.

Williams, L. C., & Reddish, M. J. (2018). Integrating Primary Research into the Teaching Lab: Benefits and Impacts of a One-Semester CURE for Physical Chemistry. *Journal of Chemical Education*, *95*, 928-938.

Williams, D. P., Woodward, J. R., Symons, S. L., & Davies, D. L. (2010). A Tiny Adventure: the introduction of problem based learning in an undergraduate chemistry course. *Chemistry Education Research and Practice*, *11*, 33-42.

Wilson, S. B., & Varma-Nelson, P. (2016). Small Groups, Significant Impact: A Review of Peer-Led Team Learning Research with Implications for STEM Education Researchers and Faculty. *Journal of Chemical Education*, *93*, 1686-1702.

Wineburg, S., & Grossman, P. (1998). Creating a Community of Learners among High School Teachers. *Phi Delta Kappan*, *79*(5), 350-353.

Winter, J., Wentzel, M., & Ahluwalia, S. (2016). Chairs!: A Mobile Game for Organic Chemistry Students to Learn the Ring Flip of Cyclohexane. *Journal of Chemical Education*, *93*(9), 1657-1659.

Wodak, R., & Meyer, M. (2009). *Methods of critical discourse analysis* (2^{nd} ed.). London, England: Sage Publications.

Wood, D., Bruner, J. S., & Ross, G. (1976). The Role of Tutoring in Problem Solving. *Journal of Child Psychology and Psychiatry*, *17*(2), 89-100.

Woods, D. R. (1994). *Problem-Based Learning: Helping Your Students Gain the Most from PBL*, London: W. L. Griffen Printing.

Woods, M. B. (2013). Mathematical Micro-Identities: Moment-to-Moment Positioning and Learning in a Fourth-Grade Classroom. *Journal for Research in Mathematics Education*, *44*(5), 775-808.

Wortham, S. (2006). *Learning Identity: The Joint Emergence of Social Identification and Academic Learning*. New York, NY: Cambridge University Press.

Yoon, H., Woo, A. J., Treagust, D., & Chandrasegaran, A. L. (2014). The efficacy of problem-based learning in an analytical laboratory course for pre-service chemistry teachers. *International Journal of Science Education*, *36*, 79-102.

Zimmerman, E. (2007). Gaming Literacy: Game Design as a Model for Literacy in the 21st Century. *Harvard Interactive Media Review*, *1*(1), 30-35.

Zotos, E. K., Moon, A. C., & Shultz, G. V. (2020). Investigation of chemistry graduate teaching assistants' teacher knowledge and teacher identity. *Journal of Research in Science Teaching*, 1-25.

APPENDIX A. INTERVIEW PROTOCOLS

[Phase One]

I have three themes to discuss with you. I will ask you questions about what you do within the lab setting, outside of the lab, and how you learn to teach as a GTA. Although I have an interview guide, if there were things that I would like to know more about as we talk, I will ask you some follow-up questions as well (e.g., “Why is that,” “Could you elaborate more,” and “Could you give me some specifics”). But that does not mean your prior response was inadequate. I Just want to explore more of your response.

1. I would like to ask you about what you do during the laboratory for CHM ____
    a. Imagine a typical day. Can you briefly walk me through what you do from the beginning until the end of the laboratory? (Touch upon walking around, showing demos, enforcing safety, talking with students, and lecturing when appropriate)?
    b. Let’s talk more specifically about how you facilitate student learning. What do you think are key components that students must do well in the laboratory? (Target aspects such as laboratory technique, chemistry concepts, data analysis, group work, and observations)?
    c. Given how you describe your interactions with students, what are the roles you think you play as a GTA in the laboratory (can also be rephrased as particular goals and make sure you address challenges participants face and how they resoled those challenges)?
2. Now I would like to ask about what you do outside of laboratory for CHM ____
    a. What do you typically do to prepare for laboratory during your own time (pay attention to resources available such as the laboratory manual, talking to other GTAs or the laboratory supervisors, or other resources such as a chemistry textbook)?
    b. What do you typically do during recitation (attend to format, types of questions, the extent of consistency, nature of interactions, and the degree the recitation is connected to the laboratory)
    c. How do you prepare for recitation?

d. What do you think is your role in recitation?
e. Can you describe what typically happens during your staff meetings?
    i. What do you do typically during staff meeting (pay specific attention to whether the participant asks questions, takes notes, and the way the participant pays attention during staff meeting)?
    ii. What features presented during staff meeting do you find to be most helpful? Lease helpful?
    iii. Who do you interact with and how (address staff meeting coordinators, course supervisors, other GTAs, or the lecturers)?
f. What do you typically do during office hours (pay attention to the roles participants recognize themselves as)
g. What do you usually do during lecture (pay attention to who the GTA interacts before, during, and after lecture as well as the manner of interaction)?
h. How else might your students communicate with you (e.g., email, discussion boards, PSOs, review sessions, etc.)?
i. How do you typically grade your students' work (follow up with purpose and goals of grading)?
    i. How do you use your grading rubric (attend to how consistently they follow the rubric and whether they modify the rubric and the corresponding rationale)?

3. Now I would like to ask you about how you learn to teach as a GTA for CHM ____
    a. What are some currently available resources provided to you that support your learning how to teach (encourage elaboration on what is most and least useful)?
    b. What are some other resources that have helped you learn to teach (e.g., past undergraduate experiences with other GTAs)?
    c. If you were the head of the chemistry department or in a position of high enough power, what would you change about GTA preparation

[Phase Two]

During this interview, I will show you approximately 4-6 brief excerpts from the footage that was previously recorded from your laboratory section. After viewing these clips, I will ask you questions about what you did throughout the laboratory. If there are any instances that you do not want to answer, you can skip them at any point.

1. Can you briefly describe this laboratory period (e.g., how did it go, what were some things that you remember the most, the least)?
2. I would like to ask you about what you did at the beginning of the experiment
    a. [Show excerpt] In your announcement, you had mentioned ____ to students. What were key parts in your announcement that you think was most helpful for students? What was the reason that you included this in your announcement? Looking back, was there anything else that you would have included or done differently based on what had transpired during that laboratory period?
    b. [Show excerpt] In your demo, you had shown ____ to students. Why was this important for your students to observe? What were key aspects of your demo that you think was most helpful for students? What was the rationale for the way you conducted your demo? Was there anything in this demo you had presented that was not explicitly described in the protocol? Looking back, was there anything else that you would've included or done differently based on what had transpired during that laboratory period?
3. Now I would like to ask you about what your actions during students' experimentation and report writing (what were your goals for yourself and your students during this laboratory, was this lab representative of how you usually conduct your classroom, what was similar and different, etc.)?
    a. [Show excerpt] When you had approached this student, you had done ____. Can you describe your interactions?
        i. How well do you think you answered the student's question?
        ii. How well do you feel like you facilitated ____?
        iii. How well do you think the student understood the chemistry concept?
        iv. How appropriate of a solution do you think you provided?
        v. How well did you promote group work?
        vi. Do you feel like your student understands the bigger picture of this concept?
        vii. To what extent do you feel this was a positive interaction?

viii. To what extent do you feel you enforced safety in this interaction?

b. What were the reasons you had interacted with the student in the aforementioned fashion?

c. How closely did you follow GTA policies when doing this?

d. What were some challenges that your students experienced throughout the experiment? Challenges you experienced? How did you resolve these challenges? Is there anything you would have done differently in light of these challenges you had experienced?

4. Now I would like to ask you about what you did once the laboratory reached its final stages (Can you describe what you were thinking about at this point, was there anything you had begun to do differently, was there anything that you would have wished gone differently)?

   a. How successful was this lab in terms of the goals you had mentioned earlier? How do you define success?

   b. What are some resources that you felt supported your goals during this lab (Inquire about how beneficial were staff meeting, speaking with peers/faculty, recitation slides, and personal preparation)?

   c. What else would you have wanted to support your goals for the laboratory?

   d. Based off of everything that had occurred, how would you describe your role in this particular laboratory?

APPENDIX B. FIGURES AND TABLES

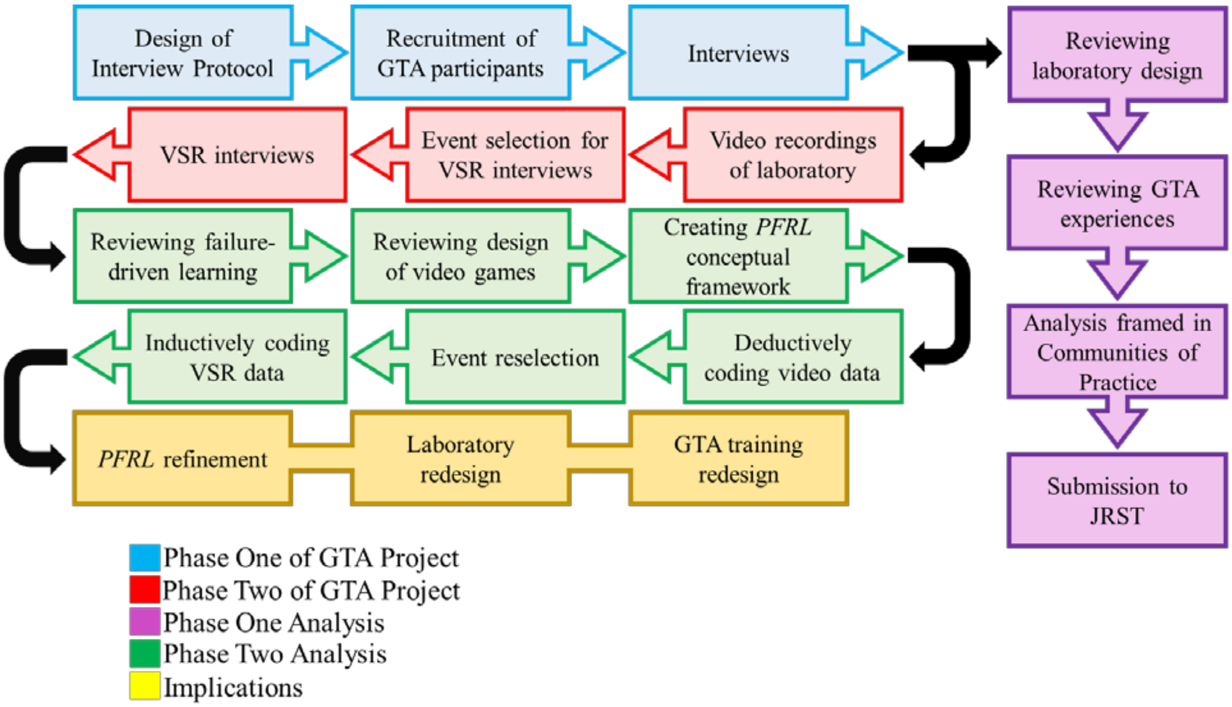


Figure B.1. Flow Chart of Conducted Studies

Table B.2 Phase Two Codebook

	Play		
	Encouraging Exploration of Different Options	**Fostering Various Sensemaking of Observations**	**Allowing for Errors**
Definition	Getting students to recognize and implement a variety of approaches and/or solutions regarding their experimentation	Getting learners to explicitly observe their experimental data and connect to their understanding of the experiment and/or broader chemistry concepts via hypotheses, suggestions, etc.	Incorporating an error from the problem-solving activity (experimentation) into the learner's sensemaking process instead of immediately rectifiying, preventing, or avoiding said error.
Example of O	Beatrice recommends a student to use another student's experiment (adjacent within the same fumehood) to gauge the student's own progress of nitric gas removal (Figure X)	Beatrice directs the student's attention to the solution, which causes the student to bend down and make some claims. Beatrice also bends down to look, and collaborates on the claim	N/A
Example of X	Linda's explicitly gives instructions for students to adhere to during the nylon-pulling step, creating a single pathway for the experiment with little flexibility on changing the approach	Student makes an observation about the appearance of nylon but Linda appears to ignore the comment and resumes the task at hand	Linda moves glassware closer to the student, points to where the scissors are, and gestures the height at which students must pull the nylon thread, all of which aim to ensure that students can perform the experiment without any mishaps

Table B.2 continued

	Reflect		
	Getting Learners to Understand the Context of Errors	**Urging Learners to Revise**	**Identifying Learners' Knowledge Gaps**
Definition	Foregrounding the whys and hows of an error (emergent from the experimentation and/or related to the laboratory report) and explaining the advantages and/or disadvantages of the learner's initial solution	Suggesting different solutions to resolve the error, typically in troubleshooting fashion in which the GTA helps the learner realign with the canonical approach	Getting learners to explicitly vocalize the differences between their understanding and the canonical understanding. Leraners should recognize the initial incongruity with their initial solution
Example of O	Ashley gives more context with regards to a calculation error by reminding the student what had been done experimentally with regards to the dilution	Ashley recommends a different number representing volume for a calculation to find the moles	Beatrice creates a space for the student to verbally identify a current incongruity, in this case the volume that was used for diluting a sample (100 mL vs. 10 mL)
Example of X	Esther provides a holistic answer for the student, namely to switch the aqueous ions and the solid ions during a precipitation reaction but does not give the corresponding rationale or context as to why	N/A	N/A
	Providing Feedback to Consolidate Canonical Answers	**Preparing Learners for Transfer**	
Definition	Giving feedback based on what learners themselves say. Unlike a full-blown explanation, this would involve GTAs explaining things by building off of what was mentioned previously by the learner	Promoting long-term learning by actively preparing learners to connect to future problem-solving contexts	
Example of O	Ashley and the student take alternating turns in which they almost build-off of each other's sentences throughout a process in which Ashley is double checking the student's calculations	N/A	
Example of X	N/A	N/A	

Table B.2 continued

	Experiences and Concepts			
	Leveraging Learners' Prior Experiences/Understanding	Directing Learners to Target Concepts	Enabling Learners to be Collaborative	Avoiding Direct Instruction
Definition	Incorporating previous experiences such as what learners had done experimentally, what was done in a previous laboratory section, what was introduced in recitation/lecture, etc.	Foregrounding the chemistry concepts and/or key features of the experiment/experimental practices that learners must know for a comprehensive understanding of said topic	Creating and/or sustaining spaces in which learners feel like they can contribute to the sensemaking process either among their peers and/or with their GTA	Not revealing key information related to the canonical solution and its corresponding approach
Example of O	Helga asks the student specifically how much volume the cuvette was filled to explain a kinetics phenomena and its corresponding calculation	When introducing the penny solution, John draws attention to other concepts like absorbances of diluted samples experimentally, the purpose of the trendline, and then doing a dilution calculation to find the concentration of the stock sample	Dani, withholding information, prompts a student to find out information about rinse disposal from another group of students	Beatrice asks questions to her students but refrains from stating the answer. Instead, she a sustains a moment of inquiry in which she gazes at the student, expecting them to provide an answer
Example of X	N/A	N/A	Helga resumes a discussion solely with one student, and does not appear to acknolwedge another student trying to participate	John provides a step-by-step explanation of what students need to do with their experimental data. The turns are mostly dominated by John in which students are simply listening. At the end, John also states the answer aloud as well

Table B.2 continued

	Motivation		
	Reducing Negative Affects	**Adjusting the Difficulty**	**Promoting Learner Agency**
Definition	Keeping the mood lively and respectful, avoiding scenarios where learners feel disgruntled or disparaged	After giving one approach of feedback and realizing that it is not working in terms of promoting learner understanding, and then trying a different approach so that the information is better conveyed	Creating and/or sustaining spaces in which learners do the mechanicall tasks (experimentation) and cognitive tasks (sensemaking) independently
Example of O	Esther assures her student that the latter's solution was entirely incorrect. Instead, there were aspects that were correctly done and that the student just needs to adjust a few other things.	Esther recommends to a student another way of organizing the chemicals to more directly display the order of reducing agent strength	Isiah moves out of the way so that the student can be in front of the LabQuest, prompting the student to resume control and finish the calibration of the LabQuest
Example of X	N/A	N/A	Isiah calibrates the LabQuest device, in silence, while the student watches

PUBLICATIONS

Ryu, M. Nardo, J. E., & **Wu, M. Y. M.** (2018). An examination of preservice elementary teachers' representations about chemistry in an intertextuality- and modeling-based course. *Chemistry Education Research and Practice*, *19*, 681-693.

Wu, M. Y. M., Nardo, J. E., & Ryu, M. (2020). Exploration of General Chemistry Graduate Teaching Assistants' Identities-in-Practice. *Journal of Research in Science Teaching*, Submitted.

Wu, M. Y. M., Roth, E., & Lang, F. (2020). Understanding First Year Graduate Teaching Assistants' Experiences in a Teaching Seminar. Manuscript in preparation.