BECOMING A CHEMIST: GRADUATE STUDENTS' PERSPECTIVES ON CHEMISTS AND CHEMISTRY

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BECOMING A CHEMIST: GRADUATE STUDENTS' PERSPECTIVES ON
CHEMISTS AND CHEMISTRY

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Chemistry

by
Bethany M. Walls
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Accepted by:
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ABSTRACT

In order to better understand the development of chemistry graduate students throughout the research phase of their Ph.D. degrees, we conducted a study on graduate students' self-concept of being chemists. This research is motivated by our previous results that forming identities as chemists is a key step in the transformation of organic chemistry graduate students from laboratory technicians into practicing chemists. In this research study, analytical, inorganic, and physical chemistry graduate students participated in a single, semi-structured interview designed to probe how their beliefs on what it means to know and practice chemistry affect their graduate training. Results from these interviews will be presented along with previous results from our work with organic chemistry graduate students.

Although research has been conducted in other professional fields, such as medicine, nursing, law, and teaching, there has been little research done relating professional identity development to the chemical sciences. How and when professional identity is formed in chemistry graduate students is an essential component of becoming a practicing chemist. Our research investigates, from the perspectives of the students, the identity formation of chemistry graduate students at a large, publicly-funded, Southeastern university. This thesis will primarily focus on the professional identity development of chemists, through means of interviewing graduate students in the four traditional areas of chemistry.
DEDICATION

To my great uncle, Dr. George Wenzinger, who was an Associate Professor of Chemistry at the University of South Florida. Uncle George passed away in the fall of 2007 before I finished my M.S. degree, however always supported me in my chemistry endeavors. I enjoyed our chemistry-filled conversations at the holidays and his passion for organic chemistry, as well as his passion for my success in chemistry.
ACKNOWLEDGMENTS

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CHAPTER I
INTRODUCTION

Over the last several years there has been an emerging discourse in the chemistry community regarding the training of future practicing chemists (Breslow & Tirrell, 2003). This ongoing discussion has raised some concerns about adequately preparing future professional chemists capable of tackling the challenges of the 21st century. Despite these concerns, little is known about the evolution of students into professional chemists, and there is still a significant absence of research in this area. Ph.D. programs in chemistry, therefore, continue to operate on the presumption that students are ready to assume the roles of professional chemists upon graduation.

Previous research by Bhattacharyya showed that advanced organic chemistry graduate students had relatively naïve conceptualizations of Bronsted acidity of organic compounds, primarily referring to their sophomore-level organic chemistry course (Bhattacharyya, 2006). To take the first steps to better understand this apparent lack of conceptual development, I began to investigate what organic chemistry graduate students (for the purposes of this thesis, “graduate student” and “Ph.D. student” will be used synonymously) believe they learned during the research phase of the Ph.D. degree (Walls, Clark, & Bhattacharyya, manuscript in preparation).

The results of this study indicated a disconnect between the students’ and research advisors’ approaches to learning chemistry. Furthermore, the results suggested that these students’ decisions were based on their identities as
The focus of the research detailed in this thesis was to probe chemistry graduate students’ perspectives on chemistry and chemists. In addition to the organic chemistry graduate students in the previous study, this research included participants from the other traditional areas of chemistry: analytical, inorganic, and physical. Biochemistry was not included as an area in this investigation because the institution in which the data were collected did not have a significant number of research groups in that area within the Department of Chemistry.

When I began graduate school, I was primarily interested in organic chemistry, with intentions of working for a pharmaceutical company upon completion of my degree. I loved organic chemistry as an undergraduate and did synthetic organic chemistry research during my senior year at the University of New Hampshire. I thought that my undergraduate research experience would prepare me for my future in a graduate program. However, upon entering graduate school, my intentions and expectations changed.

My first semester was devoted to classes and choosing a research advisor. Instead of working exclusively on synthetic organic chemistry, I chose a research group that focused on nanomaterials, which included synthesis of nanomaterials as well as the application of these materials. During this time, I realized that my interest in chemistry did not extend to conducting research in a wet laboratory setting. I also realized that there were other important aspects in my life, which include my family, my friends, and interactions with others. I wanted to incorporate all of these aspects into my life, and by joining the
Chemical Education division of the Department of Chemistry, I was able to keep my interest in chemistry but extend it to learning about how others learn chemistry, while also becoming part of the Chemical Education family. Instead of wearing a lab coat and safety glasses everyday, I learned that there were other options that involve the use of my chemistry knowledge. Upon joining Dr. Gautam Bhattacharyya's group, I quickly found that I was able to interact in a variety of ways with others in the chemistry field. This allowed me to use my social skills that I felt were being left behind in a laboratory setting, as well as contribute research in the field of Chemical Education.

By interacting with graduate students during the interviews I conducted for this research, I was able to find out more about myself and my passions, as well as learning about the professional identity development of graduate students in the Department of Chemistry.
CHAPTER II
LITERATURE REVIEW

This chapter will describe the literature base that helped inform the current study. The two areas reviewed are social cognitive theory and professional identity. Since the literature base on professional identity is broad, this review will focus on the following areas: law, teaching, and the health sciences – i.e., medicine and nursing.

Social Cognitive Theory

Social cognitive theory evolved over time from Bandura’s (1977) social learning theory (Schunk, 1989; Schunk, 2001; Schunk & Zimmerman, 2008). Bandura developed social learning theory to explain how people learn in social environments. Since science research groups are one form of social learning environment, this theory is a particularly appropriate one for describing that environment. With the advent of cognitive theories of learning in the 1970s and 1980s, Bandura expanded his theory to include a cognitive component, thus developing social cognitive theory (Schunk & Zimmerman, 2008).

According to Bandura’s theory, the “reciprocal relationship” between three factors – behavior, environmental variables, and personal variables, including cognition – governs human actions (Bandura, 2006). Chief among these constructs is perceived self-efficacy, which Schunk (2001) defines as, “beliefs about one’s capabilities to learn or perform behaviors at designated levels” (Schunk, 2001). Thus, each of the three factors mentioned above, has a direct
effect on an individual’s perceived self-efficacy, which, in turn, determines how people think, are motivated, feel, and behave (Bandura, 2002).

Perceived self-efficacy is a key component of professional identity development. For example, Luehmann discusses how teachers need to develop their own confidence as being efficient instructors. Referencing Bandura (1993), Luehmann notes that “. . . a person with the same knowledge and skills may perform poorly, adequately, or extraordinarily depending on fluctuations in self-efficacy thinking” (Luehmann, 2007). Thus, it is important to attain a certain level of confidence needed for one’s profession.

A second important outcome of Bandura’s theory is the notion of observational, or vicarious, learning. The idea that an individual can learn without doing was a significant departure from previous learning theories of the time, especially Skinnerian behaviorism (Schunk, 2001). According to social cognitive theory, observing models, whether real or symbolic, contributes significantly to an individual’s learning. Thus, one can learn things without direct experience.

A third outcome of social cognitive theory is self-regulated learning, which defines the way in which people reach their own goals through the manner in which they orient their cognitions, affects and behaviors (Schunk & Zimmerman, 2008). Self-regulated learning is defined by Pintrich (p. 453) as “an active, constructive process whereby learners set goals for their learning and attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment”
Schunk proposes that self-regulation is indexed, or situational, according to social cognitive theory (Schunk, 2001). This implies that an individual’s self-regulation is unlikely to be the same across all domains. Rather, it is highly contextual. Thus, students who are in an open environment must take it upon themselves to have a high level of self-regulation, such as the graduate students in this research study.

One of the controlling factors of achieving this self-regulation is motivation. Research shows that people can not only control their behavior, but they can also control their cognitive processes (Schunk, 2001). Further, those individuals who are relatively better self-regulators are more likely to set attainable learning goals, use more efficient manners to achieve those goals, and also are able to monitor and evaluate their progress with those goals than their less-effective counterparts. In addition, the better self-regulated learners are more likely to seek assistance and modify their goals as needed (Schunk & Zimmerman, 2008).

Professional Identity

There are several definitions in the scholarly literature of “professional identity.” This is primarily because professional identity has been studied in a variety of disciplines.

Cohen-Scali cites a definition from the French researcher Blin (Cohen-Scali, 2003). Blin’s definition (translated from French) is that “basic professional identity not only constitutes an identity at work, but also and more importantly a
projection of oneself in the future, the anticipation of a career path and the implementation of a work-based logic or even better a training oriented logic” (Cohen-Scali, 2003). Ibarra defines professional identity as the “attributes, beliefs, values, motives, and experiences in terms of which people define themselves in a professional role” (Ibarra, 1999). Lastly, Tracy and Naughton define professional identity as “self in situation, and central to this concept is the notion that self is constructed, maintained, and challenged by self’s and interlocutor’s communicative practices” (Tracy & Naughton, 1994). Common themes in these and other definitions are the interactions of the self and the community of practice (CoP). The variation in the definitions is primarily a function of the extents to which each contributes to the formation of an individual’s professional identity.

*Medicine and Nursing:*

In the medical education literature, there are many studies that relate to the professional identity development of medical students. For example, Pratt et al., describe how medical students in residency develop professionally (Pratt, Rockmann, & Kaufmann, 2002). They did a qualitative study over a period of six years and learned that the students did in fact develop professional identities as physicians. These developments, however, were defined as “slight”, meaning that the students created a more developed idea of what professional identity actually is. Other responses were defined as more “dramatic”, whereas the students provided responses that actually portrayed a change in his/her own professional identity. However, it was first discovered, based on their responses,
that what the students did for work actually varied from who they were as individuals. This points out that they were not sure how their personal beliefs aligned with their professional beliefs. These were called “work-identity violations”. The way in which the students handled the work-identity violations was by using methods of “enriching”, “patching”, and “splinting”. Identity enriching experiences were those that expand the students’ understanding of their own professional identities. Identity patching considers the idea that medical students use their general knowledge to “patch” holes in their professional identities. Lastly, identity splinting is defined as when students resorted back to a former identity because of their situation at hand. For example, the radiation medical students spent the first year of their clinical experience in a classroom setting rather than reading x-rays and conversing with patients. Because of this, it was easy for them to revert back to their previous identity as students (Pratt et al., 2002). Acknowledging that there was a disconnect allowed the researchers to realize there was a connection between identity and learning cycles as related to their occupation, and that programs must be consistent to allow for professional identity development to occur, and not be restrained as it did in some cases.

Goldie, et al. (2007), conducted a qualitative study of undergraduate medical students and their tutors to further understand how professionalism can increase through teaching. The tutors served as role models to their student counterparts. It was reported that both students and tutors became more aware of their professionalism through these teaching experiences. Further, it was
discussed that in addition to the teaching, clinical experiences were an essential component to identity development. The link between teaching and clinical experiences to professional identity development then lies in reflection; that both of these experiences encourage reflection of one’s experiences. By reflecting upon one’s actions and experiences, they have the potential to see their professional development. Further, completing clinical experiences such as those required by medical students, they are being exposed to the CoP to which they will belong. If this happens earlier than medical school (i.e., during an undergraduate experience such as in Goldie, et al., students may enter medical school more prepared and more able to develop professional identity. In addition, their experiences with role models will help them evaluate themselves based on their interactions with their tutors (Goldie, Dowie, Cotton, & Morrison, 2007).

Niemi (1997) completed a six-year study that followed medical students through their entire medical school experience to observe professional identity development. As with all professional degree programs, it is assumed that students possess the critical thinking and problem solving skills required. However, Niemi wanted to find out how students actually acquired these skills during their pre-clinical years in medical school and how these related to their ability to develop professionally as doctors. The students who participated were involved in a “strand” in which they had regular visits to observe the interactions between doctors and patients. He then asked students to complete learning logs, which were descriptions of the observations that they had made. Niemi
suggests that by encouraging the students to actually think about their observations through a means of writing, they can combine that experience with the theoretical knowledge that they already have. He proposes that this is a way to help medical students in the pre-clinical stage of medical school learn how to reflect on their experiences, which is an essential part of professional identity development. It is important to note that despite this suggestion, Niemi acknowledges that professional identity development is not linear and that no long-term conjectures can be made based off of this single way to get medical students to reflect on their experiences in professional environment earlier (Niemi, 1997). However, this is consistent with the idea of Communities of Practice and also with the ideas of self-efficacy and motivation, as the students are more likely to be motivated to create their own identities based on being aware of the interactions that they observe prior to their own clinical experiences.

In a study reported by Bleakley and Bligh (2008), the authors investigated the implicit learning that occurs in new doctors during their residency experiences. Initially, these physicians identify more with the patients, and less with their mentoring doctors. However, through the process of engaging in active experiences with senior doctors and handling patients in “real-life” situations, the students begin to take ownership of their experiences. This evolution results in a gradual distancing of the residents from their patients. The authors suggest that this distancing demonstrates greater professionalism by the residents as they become more comfortable with their surroundings and responsibilities (Bleakley & Bligh, 2008). Thus, there seems to be a gradual period of identity development.
of medical students, as they are increasingly exposed to a “real-life” setting, *i.e.*, a hospital.

Edmond (2001) in the nursing education literature, suggests that a combination of experience and “practical education” play essential roles in identity development. Edmond also discusses “clinical credibility” and how there has been discussion about how practical clinical experiences are lacking in terms of clinical mentors being overloaded with the number of clinical students, as well as the lack of resources. She proposes that a combination of both lectures and clinical experiences, with appropriate funding, will accommodate the “nursing crisis” that currently exists and will develop credible nurses who can be considered professional (Edmond, 2001).

*Law:*

In a comparative study between medical and law school students, Cavenagh (2000) gave surveys to first year students in both fields. He asked questions relating to professional identity, such as how long they have been interested in their chosen career path, their commitment to their career, and other potential career options. According to the surveys, medical students were more likely to choose their career earlier and also stick with their choice to pursue medical school, despite not being accepted upon their first application. It was suggested that this was due to the required coursework for pre-medical students being much greater than that of the pre-law students (Cavenagh, Dewberry, & Jones, 2000). Thus, the professional identity development of medical students typically begins at an earlier age than that of lawyers, as they have a conscious
thought of the pre-requisites to medical school sooner. This could play a potential serious role in the future professional identity development of future doctors and lawyers.

A study by Floyd (2002) at the Texas Tech University Law School examined the professional identity development of law students. He wanted to learn how law students develop into lawyers, similar to our research study on how chemistry graduate students evolve into chemists. The key here was asking the law students about their experiences in law school and how those experiences (both positive and negative) played a role in professional lawyers’ lives. Floyd’s goal was to examine how the law school experience was affecting the preparation and future sense of professional selves of the students he had. His population included students in several of his classes. In addition, Floyd brought in professionals and held seminars on Legal Education, in hopes of providing a connection for the law students to relate to the professionals in their field (Floyd, 2002).

This is similar to the idea of establishing supportive CoP’s and the interactions that chemistry graduate students have with their research advisors. However, most chemistry graduate students only get the opportunity to view their advisors (and other professors) as “professional chemists” and rarely get the chance to have interactions with professionals outside of academia.

Teaching:

In addition to professions that require many years of training after a traditional undergraduate program, it is important to also include teachers in this
literature review, as they are also deemed professionals, most commonly by their students. Although teaching usually requires a Masters degree and/or certification, a one-year student teaching position is also common. Thus, it is also important for teachers to establish their professional identities so that they have the high-level of self-efficacy to be positive and knowledgeable role models to their students in their classrooms. Luehmann’s (2007) study describes the necessity to establish professional identity of science teachers. Further, she proposes strategies to incorporate her findings, which include creating environments for new science teachers to “try on” identities as teachers in environments that are not necessarily school settings. The second strategy she proposes is that there is a need to provide experiences for the teachers to be recognized by both themselves and by other professionals in their field. This would allow them to receive feedback from professionals in order to monitor their progress through “ongoing, structured, and supported reflection” (Luehmann, 2007).

In addition, Smith (2006) examined the professional identity development of math teachers. Using Wenger’s Social Theory of Learning (1998), Smith acknowledges that the ideas that encompass Communities of Practice are essential. Smith states that “the construct of identity creates a partnership between the social and the individual that highlights the person within the practice of teaching and emphasizes the importance of knowing who we are and what we believe as teachers” (Smith, 2006). As with the other accounts of professional identity, there must be a balance between the individual’s beliefs as
well as how those relate to their professional goals. Smith continues that “learning in teacher education is evidenced when there is increased participation in: mutual and meaningful activities; negotiating and making meaning; and developing a sense of becoming and belonging within multiple communities of practice” (Smith, 2006). This again aligns with studies in the medical education literature where one who engages in activities related to their future profession (i.e., clinicals), they are likely to increase their professional identity.

This literature review provided a general view of professional identity development in other professional fields. These studies provided the framework for my study on professional identity development of chemistry graduate students, and specifically the Ph.D. students who will assume “professional” roles upon the completion of their degrees.
CHAPTER III
METHODOLOGY

The primary objective of my research was to characterize professional identity across all domains of chemistry. However, my initial goal was to investigate the conceptual development of organic chemistry graduate students. In describing the methods I used to conduct the study on professional identity of chemists, I will also, briefly, demonstrate the evolution of this research.

Pilot Study

Becoming a practicing chemist requires the individual to develop two fundamental components. One is the experimental manipulations required to create new substances or make measurements of existing substances. The second is conceptual understanding of the theoretical constructs or models that help the scientist to rationalize experimental results or to develop novel scientific ideas. The vast majority of “instructional time” for chemistry graduate students occurs while they participate in a research group. It is assumed that graduate students develop the previously described faculties in that context.

Previous research, however, showed that organic chemistry graduate students’ conceptualizations of Bronsted Acids lacked the sophistication that one may have expected after years of advanced training (Bhattacharyya, 2006). Furthermore, the participants’ conceptions in that study stemmed primarily from their sophomore-level courses in organic chemistry, rather than their graduate courses or research experiences. Given this apparent lack of deep conceptual
development, we decided to take a holistic approach and investigate what organic chemistry graduate students believe they learn during their Ph.D. training.

Due to the difficulty of addressing the issue of what students learn, or believe they learn, during membership in research groups, few studies have been conducted in this area. For example, Hunter et al., (2007) showed that undergraduates who participated in undergraduate research had both personal and intellectual gains in their research experiences. (Hunter, Laursen, & Seymour, 2007). The landmark studies on research laboratories that have been conducted, however, focused on the construction of scientific knowledge in the context of a community of practice (CoP), not in the mind of learners (Knorr-Cetina, 1999; Knorr-Cetina, 1983; Latour & Woolgar, 1986). Thus, little research has been done in the area of the conceptual development of chemistry graduate students and how this relates to their transition of becoming practicing chemists based on their graduate school experiences.

The goal of the present research was to take the first steps to understand how graduate students conceptualize their experiences of the research phase of their Ph.D. degrees. The focus of this study, therefore, was graduate students and not their faculty mentors. Although the faculty’s views regarding what their students learn or should learn are important, that aspect is left for another study. Accordingly, we developed the following guiding research questions:

- What types of knowledge do organic chemistry graduate students believe they learn during their membership in a research group?
• What factors affect how and what the students learn?

Since, these research questions represent one of the first attempts at studying this phenomenon, we did not believe that insightful hypotheses could have been generated \textit{a priori}. Therefore, we adopted a qualitative approach to address our guiding questions. Using qualitative methodology would help us to uncover the students’ conceptualizations, thereby giving a voice to the research participants (Patton, 2002).

Phenomenography and grounded theory served as the theoretical frameworks for this study. Marton describes phenomenography as “… the empirical study of the limited number of qualitatively different ways in which various phenomena in, and aspects of, the world around us are experienced, conceptualized, understood, perceived, and apprehended” (Marton, 1994). It is important to note, however, that phenomenography’s aim is not to investigate the phenomenon or the research participants’ experiences of the phenomenon. Rather, phenomenography is used to probe the participants’ conceptualizations of their experiences with the phenomenon. This distinction acknowledges that there may be – and probably are – differences between the participants’ experiences and their conceptualizations of said experiences. Phenomenography was appropriate for this study because we are interested in the students’ beliefs of what they learned, not their actual learning. Researching the latter would not be feasible at this point.

Grounded theory allows the researchers to generate a theory based on the collected data; thus, the theory is grounded in the data and emerges from the
data (Glaser & Strauss, 1967). Grounded theory is a powerful framework in situations, such as the present research, for which no a priori hypotheses can be formulated, nor when the researchers have not decided on a particular lens through which the data can be analyzed. Thus, phenomenography was used for data collection and analysis, while grounded theory was applied only to the analysis.

Twelve graduate students from the organic division of the Department of Chemistry at a large, research-oriented state-supported university participated in this study. These volunteers were not compensated in any manner. Their experience in the program ranged from the end of the 2nd-year through the end of the 5th-year. This requirement was placed so that we would have students who had enough time to be immersed in the research group environment. Furthermore, we only recruited participants who were members of research groups whose primary focus is organic chemistry. This stipulation was placed because there are students who identify themselves with one area, but join research groups that are focused in other areas. At this stage, we wanted to concentrate on graduate students' experiences in a single sub-discipline of chemistry, since there may be significant cultural differences between the different sub-disciplines (Bhattacharyya & Bodner, 2005). All of the participants had finished their required course work at the time of data collection. In addition, the students were all taking (or had completed) cumulative examinations, which are one of the requirements for candidacy to the Ph.D. degree. There were eight
male participants and four female participants, which was similar to the gender distribution of the entire organic division of the department.

The students participated in a single semi-structured, audiotaped interview lasting between 30 and 45 minutes. The interview topics included the students’ expectations and intentions of learning from the research group environment, the students’ beliefs of what they learned during the research phase of their degrees, the students’ descriptions of their laboratory work, as well as the students’ beliefs of the chemical concepts they use in the course of their research.

The students were explained the difference between “expectations” and “intentions”, to ensure that the participants understood the researchers’ definitions of these terms. “Expectations” were described as “what the environment would teach you”, while “intentions” were described as “what you hoped to take from the environment” upon entering the graduate research program. The students were asked to describe their laboratory work to get a preliminary comparison between beliefs and practices. Thus, students were asked how they set up an experiment they have not previously performed and how they troubleshoot experiments when undesired results are obtained. Further, they were questioned about what chemical concepts they use in their research. This was asked at the end of the interview so that the question would not affect the responses to the questions about daily laboratory experiences. The interviewer wrote observations during the interviews as field notes and recorded post-interview notes, as necessary.
All of the interviews were transcribed verbatim. In concert with grounded theory, all of the data – interview transcripts and field notes – were repeatedly examined to find trends in the data. Since the other framework was phenomenography, the unit of analysis was the entire group of participants. The initial set of trends was further grouped to create categories of description, which are typical of phenomenographic studies (Marton & Wing Yan Pong, 2005). In creating these categories, it also became clear that the participants could be divided in a way that a developmental model could be created. The details of this are discussed in the following sections. The final results, including our model, were discussed with members of the organic faculty to ensure that the researchers’ interpretations were consistent with their experiences of training graduate students.

When analyzing the data, it was clear that students’ views changed significantly as a function of time in the program and that this change, roughly, occurred during similar periods for all the students – during the third year of study. In the present context, the “early years” are defined as those students who have up to three years doctoral research experience and the “later years” are defined as those students who possess four years or more of doctoral research experience. The data suggest that the transition from the “early years” to the “later years” occurs, primarily, in three areas: group interactions, personal goals, and in the use of resources.

The data suggest that evolution into self-regulated learners is the overall outcome of the doctoral experience. As defined by Pintrich (p.453), self-regulated
learning is “an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment” (Pintrich, 2000). The participants in the study described a cycle through which this occurred.

When students obtained their desired results in an experiment, they simply moved on to the next step. However, unexpected or undesired results forced the students to stop and reflect on their work. In situations where students were allowed to work through these problems by themselves with guidance and support from their advisors, students gained a sense of accomplishment and enhanced self-esteem. These feelings encouraged students to try things by themselves, without first consulting senior peers or research advisors. Trying new things, in turn, periodically led to successes which spurred students along in this positive cycle of events, thus promoting their development as self-regulated learners.

It is important to note that faculty mentors have a critical role in this process. It was important for the faculty mentors to give students guidance without “giving them answers.” Furthermore, while it was important for research advisors to expect their students to produce results, it was equally vital that, in the face of difficulties, the mentors were patient and restrained in their demands.

Perhaps the most surprising outcome of this research was that students did not appear to demonstrate significant conceptual development during their graduate study. When the interviewer asked the participants about which
concepts they believed they relied upon the most for their research, all of the participants’ initial response was to the effect of, “What do you mean by ‘concepts’?” Upon being prompted with examples of chemical concepts, the participants either responded with constructs that are considered skills – such as, electron-pushing or spectral interpretation – or said that they were not aware of any concepts that they used. All the participants were resolute in their beliefs even after the interviewer asked them leading questions about specific concepts. Upon further analysis of the data, the participants’ lack of conceptual development was consistent with their descriptions of their experimental practices.

Given these results, further investigation of the students’ conceptual development seemed unnecessary at this point. However, the students’ development as self-regulated learners suggested that their choices of what to learn and what not to learn would be dictated by their perceptions of what it means to be a chemist or to know chemistry. This was the inspiration of the current study on the professional identity development of chemistry graduate students.

**Guiding Questions**

Educational research studies are most effective when they are based on well-developed guiding questions (Bunce & Cole, 2008). Guiding questions provide a structure to the overall goal of the study, by focusing on several main
questions of interest (Bodner & Orgill, 2007). The study was based on the following guiding questions:

1. What do chemistry graduate students believe is chemistry?
2. What do chemistry graduate students believe practicing chemists do?
3. How do chemistry graduate students believe one becomes a professional chemist?
4. How do chemistry graduate students believe that one learns chemistry?

It was my goal to research what perceptions the graduate students possess about what it means to know and practice chemistry and what experiences they have had that have led them to their understanding of these phenomena and learn how their experiences promote identity development.

As in the case of the pilot study, I did not have existing hypotheses regarding the students’ beliefs when I began this study. Thus, I chose to use qualitative methodology again.

**Theoretical Frameworks**

Phenomenenography was the lens through which I conducted this research. Based on its Greek etymology, Hasselgren and Beach define phenomenenography as a “description of appearances.” As I described previously, phenomenenography is a third-order perspective, which seeks to uncover individuals’ different conceptualizations of their experiences with a particular phenomenon.
In this case, the use of phenomenography is important because accessing the abstract constructs that are the objects of this research would be very difficult, if not impossible. However, with phenomenography, I only needed the participants’ conceptualizations of those abstract constructs, such as the meaning of chemistry. Again, the current study was focused on the students’ perspectives and not on what their faculty mentors believed they learned or should have learned and how they should become a professional chemist throughout the research phases of their Ph.D. degrees. This portion of advisors’ perspectives will be left for a future study.

Participants and Setting

Due to the time-consuming nature of the data collection process in qualitative studies, participants are purposefully sampled, *i.e.*, individuals who are most likely able to provide information regarding the goals of the study are recruited. We used criterion purposeful sampling, a technique in which participants are chosen based on a set of specific characteristics (Patton, 2002).

Thirty-one graduate students enrolled in a Ph.D. program in the Department of Chemistry at a large, publicly funded Southeastern university participated in this research study. Eight students were from the organic division, eight were from the inorganic division, ten were from the analytical division, and five were from the physical division. There were nine female participants and twenty-two male participants. All of the participants ranged from their first year in graduate school through their fifth year at the time of the interview. The
participants were volunteers who were recruited from group meetings where the students were given information about the study. To protect the identities of the participants, each was given a pseudonym prior to data analysis, such that only the interviewer knew their identities.

**Data Collection**

Since the focus of phenomenography is the participants’ conceptualizations, observing them during their participation in the various activities as members of a research group would have limited utility. The primary source of data, therefore, had to be interviews. Each volunteer participated in single, semi-structured, and individual interviews lasting approximately 30 minutes. The interview guide is shown below in Figure 3.1.

Before I started collecting data, I spent some time explaining: (a) my goal for the research as wanting to understand their beliefs regarding what it means to be a chemist and know chemistry; (b) that their participation was completely voluntary and that they reserved the right to cease participation at any time; (c) that anything they told me during the study was confidential; and (d) the procedures that would be used to guarantee their confidentiality. At the end of this explanation, I asked if they had any questions for me. Once any questions were answered, each participant was asked to sign two copies of an IRB “Informed Consent Form.” A copy of this form is shown in Appendix A (organic students) and Appendix B (inorganic, physical, analytical students). I kept one copy and gave them the other.
**Background**
In what year of graduate school are you currently?  
Prior to coming here, what types of experiences did you have with scientific research? How long did those last?  
Before coming to Clemson, did you work in a scientific field? If so, can you please explain what you did and for how long?  
Without revealing any proprietary information, can you please explain your research?  
How did your interest in your discipline develop?  

**Lab Learning**
There is a saying among chemists, “You learn it in the lab.” For you, what are the “its”? What promotes your learning, *i.e.*, in what situations do you think most of your learning takes place? What inhibits your learning?  
Could you explain what you do on a daily basis in your research lab?  
When you have to perform a new experiment, how do you go about setting it up? What resources do you use and why do you use them?  
When this new experiment doesn’t give you the expected results, how do you try to overcome that obstacle? Why?  
How do your interactions with other group members (peers, post-docs, mentor) or members of the Department (committee members, fellow students, other professors) affect your research? How have these interactions changed over time?  
What chemical concepts do you think you use the most in your research? In what contexts do you think you use them? How do they aid you in your research efforts?  
What do these concepts mean to you?  
What experiences do you believe have contributed to your current understanding of these concepts?  
What characteristics do you possess that facilitate learning in your discipline?  
How do these qualities or characteristics affect your research?  

**Identity as Chemists**
In your opinion, what does it mean to be a chemist, *i.e.*, what does a professional chemist do? What does it mean to be a successful chemist? What experiences have promoted your understanding of this phenomenon?  
In your opinion, what does it mean to understand, or know, chemistry? How do you learn chemistry?  
What does it mean to be a successful graduate student? How have you come to this conclusion?

FIGURE 3.1: Interview protocol for inorganic, physical and analytical students
Because the primary goal of the interviews was to uncover the participants’ conceptualizations, the questions in the interview protocol were designed with the idea to promote responses with descriptive answers. For example, I asked participants the question “What chemical concepts do you use in your research?” instead of “Do you use any chemical concepts in your research?” The latter question induces a “yes”, “no”, or “sometimes” response, whereas the former is more likely to elicit detailed and meaningful responses. It also permits the researcher to adapt the interview protocol as the interview progresses and probe the participants’ responses to obtain deeper understanding of the participants’ conceptualizations of their experiences.

The organic chemistry participants were interviewed in a second interview relating to the pilot study, but were asked similar questions to those of the other participants in the study. This was to ensure we could compare the responses from students in all disciplines. The interview protocol is shown here in Figure 3.2.
Role of Researcher and Researcher Bias

My role as the researcher was that of participant observer (Patton, 2002). My primary function was observing the students during the interviews for affective responses and gestures. However, I was also a participant by engaging the interviewees in a process of meaning making during the data collection.
The major potential source of bias is my own training as a chemistry education graduate student. Based on anecdotal data, it appears that the chemical education research groups function in significantly different ways than the other research groups in this Department. Therefore, I had to ensure that I minimally superimposed my experiences into the data. Using multiple participants’ utterances as evidence for any conclusions was one way of minimizing this effect.

A potential drawback of my role is that my participants and I were a part of the same department. Therefore, I had to establish a trust with them that I would indeed not reveal any of my collected raw data. Furthermore, there was a possibility that the participants may have not revealed their “true” thoughts due to fear of social embarrassment. There were several steps taken to minimize this possibility. I looked over the entire interview to make sure that each participant’s responses were consistent throughout the interview. Also, I did not interview students with whom I have personal friendships and/or frequent social interactions.

**Data Analysis**

All of the interviews were transcribed verbatim. The data were sorted using a two-tiered system. First, the data were sorted by question, *i.e.*, all of the responses for each question were compiled. These answers were further organized by division. As the data were analyzed, it became clear that there were minimal differences in the students’ responses as a function of division.
Therefore, the data were analyzed by question to find themes. Due to the existence of this framework, grounded theory was not required as a lens for this study, unlike the case of the pilot study.

The data were analyzed by myself and another member of Dr. Bhattacharyya’s research group. I worked with another rater so that I could use inter-rater reliability as one measure of validity (Patton, 2002). Each rater individually coded the participants’ responses to one question. Once the researchers finished their individual coding, they discussed their codes. In cases that the two researchers made the same, or similar, observations, the codes were accepted without further alteration. In cases where there was a disagreement, codes were discussed until a consensus was reached. There were no instances where a code was discarded due to inability to reach consensus.

In further analysis, it became clear that the codes could be separated into three groups. Furthermore, we found that the groups were related in a developmental sense. We, therefore, combined the aggregate data into a model of professional identity development that is discussed in the next chapter.

Validity

I took several steps to ensure the validity of this study. First, all of the conclusions were grounded in the data. Second, all of the conclusions are based on the beliefs of the group, not on the perceptions of an individual. Third, I used a second rater for the analysis of the interview transcripts. Furthermore, only
codes that were common to both raters were used in the second stage of the data analysis, thus establishing a high inter-rater reliability (Patton, 2002). Finally, to ensure that this conceptualization of a chemist’s professional identity is comprehensive and includes characteristics of professional identity as determined in other disciplines, I reviewed the relevant literature in the medical/health sciences education (Apker & Eggly, 2004; Bleakley & Bligh, 2008; Cavenagh et al., 2000; Cowin, 2001; Cross, Hicks, Parle, & Field, 2006; Davis, 2006; Edmond, 2001; Fagermoen, 1997; Goldie et al., 2007; Grealish & Trevitt, 2005; Lingard, Garwood, Schryer, & Spafford, 2003; Macintosh, 2003; Madill & Latchford, 2005; Molnár, Nyári & Molnár, 2006; Niemi, 1997; Ohlen & Segesten, 1998; Pratt et al., 2002; Roberts, 2000; Stone et al., 2002; Swanwick, 2005) and teacher education (Beijaard, Verloop, & Vermunt, 2000; Beijaard, 2004; Burn, 2007; Luehmann, 2007; Melville & Wallace, 2007; Tsui, 2008; Volkmann & Anderson, 1998; Watson, 2006). Since self-efficacy is an important aspect of this construct, special attention was paid to that area. As a result, I also used Bandura’s social cognitive theory and self-efficacy theory (Bandura, 1986; Bandura, 1993; Bandura, 2002; Bandura, 2003).
As described in the previous chapter, analysis of the categories that emerged from the interviews led to the developmental model shown in Figure 4.1. This model is based on three primary components, foundation, experience, and outcomes, which function in an iterative cycle. Each of these components is explained in this chapter, using the categories that emerged from the data. Examples of each of the behaviors in the dimensions and subdimensions are shown in Table 4.1. Direct quotes from the interview transcripts are offered to support my findings. These quotes are not modified with regards to grammar and/or syntax. Comments in square brackets are added when supplying a context to a comment is necessary or any word or phrase that could be used to identify the participant has been removed. When an exchange is shown, the interviewer's words are indicated with an “I”.
FIGURE 4.1: Model of sense of professional self.

FOUNDATION
1.) Basic Knowledge Acquisition
2.) Develop Interest/Choose Domain
3.) Form Future Self Image

OUTCOMES
1.) Identity Learning
2.) Problem-Solving
3.) High Level of Self-efficacy

EXPERIENCE
1.) Engagement in Activity with Personal Relevance
2.) Incorporation into Community of Practice and Socialization
3.) Conquering Personal Challenges
4.) Reflection/Reconstruction of Knowledge
**TABLE 4.1: Examples of behavioral attributes in the sub-dimensions.**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Sub-dimension</th>
<th>Example of Behavioral Attribute</th>
</tr>
</thead>
</table>
| Foundation      | Basic Knowledge Acquisition            | • Awareness of terms and/or concepts  
• Ability to utilize basic problem solving skills                                                |
|                 | Develop Interest                       | • Seeing usefulness of field  
• Choosing a domain  
• Determining if field fits personal traits                                                    |
|                 | Formation of Future Self-Image         | • Generation of career path  
• Sense of future happiness, satisfaction, and fulfillment comply with perception of profession |
| Experience      | Incorporation into Community of Practice | • Being sought out for knowledge  
• Belief that professionals see you as peer  
• Being willing to seek knowledge  
• Knowing where to seek knowledge  
• Collaboration with members of community  
• Being mentored by senior members  
• Participation in social activities                                                              |
|                 | Conquering Personal Challenges         | • Overcoming experimental obstacles  
• Motivation and perseverance during times of few results                                             |
|                 | Reflection                             | • Observing role models to identify potential identities  
• Experimenting with provisional selves  
• Evaluating experience against internal standards and external feedback                           |
| Outcomes        | Problem-Solving                        | • Ability to solve any problem                                                                |
|                 | Self-Efficacy                          | • Belief in ability to solve problems  
• Belief in ability to fulfill expectations of self and others  
• Confidence to accept new challenges                                                              |
Foundation

The foundation dimension of this model illustrates basic information and skill acquisition that begins the cycle of professional identity development. Foundation includes subcategories of basic knowledge acquisition, development of an interest and choosing a domain within chemistry, and formation of future self-image.

Basic knowledge acquisition is the idea that one will gain rudimentary knowledge on certain subjects with the possibility of expanding that knowledge in the future. Although this learning can occur during any stage of the cycle, at this point some connection is made with previously-existing knowledge that motivates the individual to delve deeper into the field. This phenomenon is alluded to in the following comment from Maggie, a second-year physical chemistry student:

I think I learn the best whenever there’s like something I already know a little bit about it… I have to know a little bit about it and then the next time I get myself to do that is the next time I learn more.

Examples of attributes that demonstrate basic knowledge acquisition include having the awareness of some of the domain-specific terminology, as shown here by the following comments:

Doug, 1st-year, inorganic: […] I think if someone is interested in inorganic chemistry or, if he or she doesn’t know about, anything about inorganic chemistry, and then main thing that he/she has to do is, is take some classes and which helps me to the background knowledge, … so, taking classes and reading is the major thing I think.

Here, Doug is referring to how he gains knowledge about inorganic chemistry through courses and reading during his beginning years of graduate school.
It is important to note that the depth of this knowledge tends to be superficial; not particularly well-developed. Although the quotes suggest deep conceptual development, the tenor of the interviews suggests that their conceptions of the “basic ideas” is not as sophisticated as these quotes may imply. This disconnect is illustrated in the following sets of comments by Rich, a third-year physical chemistry student. Initially, he talks about his assumption that he and his peers entered the graduate program with a solid background in their understanding of basic chemical concepts:

[...] every one of us here has gotten an undergraduate degree in chemistry, and we all have an understanding of chemistry, you know, we all know what a covalent bond is, you know, we all have that understanding... so it’s about knowing that language and knowing those terms and those concepts...

However, upon being probed about what concepts he uses, he offers “electrostatics”, only suggesting a cursory role in his research:

Yeah, probably electrostatics is probably the thing I use because I work with DNA and DNA is very electronegative so its charges are very important in my research.

The basic knowledge acquisition category also includes the acquisition of some elemental problem solving methods. Jared, a first-year physical chemistry student describes, for example, his experiences with learning interpretative spectroscopy:

[...] but I think that there’s a lot to be learned in the classroom, too, especially when it comes to like, um, interpreting NMR spectra and stuff like that, you know, I mean, if you’re doing, if you’re doing uh, pretty complex like natural products with a lot of stereocenters um, you gotta learn how to interpret the NMR data from somewhere, but that’s not going to happen in a lab.
Individuals proceed in the process of professional development when these initial learning experiences lead to defining an area of interest, which often includes choosing a specific area in the field of chemistry. Thus, the individual moves from having a general interest in the undefined field of chemistry to an initial interest in a particular aspect of the subject. Consider the following comments:

Luke, 3rd-year, analytical: [… ] first semester, I did, I did very well in [analytical chemistry course], like right away, like the first quiz, I remember, I got a 100 and most people failed it so that just told me, that, that was like my thing to do, you know, so.

Damian, 4th-year, analytical: When you find something interesting and you want to learn more about it. I think that’s when you have the drive to want to understand to learn more, like you have a good project, and you’re like “Oh that’s neat” and you want to see how does that work, how does this work?

It is interesting to note that Luke’s success in analytical chemistry motivated him to learn more about the field. This sense of self-efficacy, discussed in a later section, is a fundamental driving force of identity development.

The last sub-dimension of foundation category is making a preliminary determination whether the chosen field could coincide with personal goals. This component – formation of future self-image – has several attributes. Consider, for example, Zack’s comments regarding his future career goals:

Zack, 5th-year, inorganic: I’ve really always, that’s almost like a personal thing of mine, I’ve, when I was growing up, I always wanted to, I wanted to make something that was going to benefit someone else, […] I think it’s what even attracts me to the inorganic, the solid state, is we’re building scaffoldings, we’re building structures like that and it’s just kinda like, that’s just almost like a personal, personal model, make things, you know, make the world better.
Future self-image also includes the perception of potential fulfillment that the choice of profession offers. For example, Heather describes employment prospects upon completion of the Ph.D.:

Heather, 4th-year, analytical: Well, like my prev-, previous group members have been, most of them have been pretty successful, and I kinda took about trying to follow their work, and their ethics, I guess and they've all gotten good jobs and that’s what I want to do, that’s what I want to try and get a job that pays well. And I think there (inaudible) working with them helped me decide where I want to go when I get my degree.

**Experience**

With the formation of some or all of the foundational components, the individual seeks experience in the field. Experience is a developmental category in which chemists learn about themselves and others in the chemistry field simultaneously. The experience category is broad and includes the following subcategories: engagement in an activity with personal relevance, incorporation into a Community of Practice (CoP), conquering personal challenges, and reflection.

Engaging in an activity promotes the belief of personal relevance, which implies doing something that corresponds with one’s interests. This can include viewing the activity as pertaining to the “real world”, as described by Luke, Sean, and Jenna.

Luke, 3rd year, analytical: Um, I learn it from a book and then it gets solidified if I have to use it in real-life.

Sean, 2nd year, inorganic: [...] I think when you run an experiment, you kind of understand the experiment better than being taught, it’s more hands-on so, you understand better.
Jenna, 1st year, analytical: Um… I guess it’s more of, so you’re in class, you might be given an equation or a reason why these things happen and then in the lab you can see it. [...] Or more, you’re thinking scientifically might come in a lab because you actually have to deal with things. You can see problems that occur, you can see whatever your process is occurring, and then work around them and stuff like that.

It is important to note here that having application to real world experiences, at least for graduate students, primarily means seeing its application in the laboratory setting, as described by all three participants above. It does not necessarily extend beyond the research laboratory environment.

Being incorporated into a CoP includes many components. For example, being mentored and mentoring are two of these aspects. The newer graduate students, such as Jenna, speak about learning from senior group members.

Jenna, 1st-year, analytical: I’m a lot better [at learning techniques] if someone’s, if I’m trying to learn something new, if someone stands behind me and directs me while I do it instead of them showing me how to do it and like, so…

Although Jenna realizes she is going to learn the techniques from senior students in her research group, she takes action by playing an active role in her own learning process. By having the process in her own hands, she is already gaining experience, even during her first year of research. This leads to confidence, which will allow her to develop professionally throughout her graduate student career.

However, even senior students, such as George, recognize that having senior students is an essential part to learning from students who have more research experience in your area. Professional identity formation precedes conceptual learning, as shown from our previous results (Bhattacharyya, 2008),
and thus George realizes that learning from senior people who possess more
developed professional identities may be good resources.

George, 4\textsuperscript{th}-year, organic: Yeah, I think, uh you know, it's very important, you know, like for in your group you have like a senior student and they have more experience than you or so you can learn a lot from them because they have more experience and sometimes, you know, running reactions or working in a lab, you do need experience.

As students become senior members of their groups, they talk about the role reversal; i.e., it is now their turn to assume the mentoring role to new members of their research group. Sara and Danielle explain this.

Sara, 4\textsuperscript{th}-year, analytical: […] I am trying to help [new labmates] with the start in the lab because I know how things work in the lab […] so I am trying to help them because I know that the people that are coming had to go by the same process that I had to do. That is the way that I interact with them.

Danielle, 5\textsuperscript{th}-year, analytical: […] I went from being a first year to now I'm actually a senior student, so my interactions with people are very different now, um, uh, I would say that when I first got here, I was very naive, and I think that I thought that everybody above me knew more than me, and um, I have learned that that isn't true. I know certain things and other people know different things. It doesn't mean that you know more than me or you're smarter than me, it just means that we know different things.

Although Brendan also assumes the role of senior mentor within his research group, he does not mention feeling obligated to mentor, but rather the benefit he gains from helping the other graduate students in his group.

Brendan, 4\textsuperscript{th}-year, physical: Yeah, uh, I like teaching and helping people and uh, you know, I'll usually drop what I'm doing if I can to help other people because that helps me reinforce what I know, too, so there's a lot of usefulness in that so.

Many senior students spoke of the role they now play in their research groups. This includes becoming mentors to the new students, as junior students seek
them out for assistance (described above), but also that senior students now rely on their advisor’s views to keep them on track. Brian and Lauren both talk about relationships with their research advisors, and how they can learn from them.

Brian, 5th-year, analytical: […] as far as I’m concerned, we’re still under [advisor’s] wing. You know, he’s, he’s very present in the lab and that helps the majority of the time. Uh, you know, he keeps us on task definitely, because he’s always, everyday he’s checking on us to see what kind of results we get uh, and see if those sort of fit the ideas, or, the, the, the goals of the lab, of the project.

Lauren, 2nd-year, analytical: […] so a lot of it, [my advisor] lets you learn on your own, which is good for me, because that’s when I remember the most, and he’s always there, so you can go and say “Okay listen, this is what I don’t get. It didn’t work” or “this is what I got but it’s not what I expect” and so I can learn, like he’s always there to help me figure out what I’ve done wrong, or did it not work and he can guide me or explain why I’ve gotten answers that don’t make sense.

This is a step towards professionals viewing graduate students as peers in the research community. Thus, if professionals view graduate students as peers, they are more likely to start feeling like and acting as professionals. Since being incorporated into a CoP is a part of identity formation, this is a major step of the professional identity development. Further, the incorporation into one’s given community is essential. Ed describes his collaborative work with his advisor, a professional organic chemist.

Ed, 3rd-year, organic: Well to be quite honest, we’re doing a cooperation. [name of advisor] wants me to give him results and he also wants to teach me things. And for me, I want to learn things from him so we were trying to, you know, compromise with each other to reach to, to the same goal so, um, he wants me, he wants to, you know, learn from me and uh, you know teach me how to be a successful chemist so on the one hand, he teach me the actual knowledge, let’s say, this is an amine, it’s more reactive compared with this aldehyde or it’s just some sort of reactions. That’s one actual piece of knowledge. Another thing is method. I think you can’t just learn uh, basic knowledge from someone.
Another important component to being incorporated into a CoP includes the idea of socialization; i.e., how interactions with others affect the experiences of the graduate students. Brendan and Jared both describe their interactions with other graduate students as a means to explore other possible ideas, in addition to their own.

Brendan, 4th-year, physical: Okay. The interactions. I don't know, it's just the free-exchange of ideas. I help them on their projects if I can, and they help me on my projects if they can, um... and sometimes, looking at somebody else's research, I get ideas for my research. So, I try to be as interested, in whatever other people are doing, as I can, and uh, usually it doesn’t cost me much time...

Jared, 1st-year, physical: [...] I think, and talking to people about it, I think, that, that know what they're talking about and talking to people who are in the same boat as you learning about it, I think that helps a lot. That, that definitely helps me a lot to talk about things that I'm not quite getting just, yeah... even with people that, you know, don't necessarily get it themselves, there's kind of a meeting of the minds where you can, you know, as a group kinda get an understanding that you...

However, Brian speaks both about working with other scientists as a mechanism to solve problems and collaborating with his own group members to discuss results.

Brian, 4th-year, analytical: [...] And you've gotta know other people and be able to interact with them at a level that you can solve problems together. You know, collaboration's where it's going.

Brian, 4th-year, analytical: And with the, you know with labmates, we all work very well together and so, we have, we bounce ideas off of each other and we have a real good dynamic in the lab, so that, that helps a lot, um, talking to each other about the different results that we get and we have group meeting each week and so, another idea session where we bounce ideas off each other and the boss so that helps a lot.

Thus, it is shown here that new graduate students rely on senior group members for assistance in the lab, whereas senior group members normally seek guidance
from their advisors. It is interesting to note that they look up to whomever is the next knowledgeable person above them, and that new graduate students do not immediately jump to their advisor for seeking guidance.

Pursing experiences allows individuals to conquer personal challenges. These challenges include overcoming obstacles when conducting experiments and having the motivation and perseverance to keep trying when not getting many results. Brian talks about the necessity of overcoming problems when he encounters unexpected results, but also acknowledging that it is important to explain why you did get those results. Being able to do this is an essential step in identity formation, as it builds confidence by combating unexpected experiences.

Brian, 5th-year, analytical: […] well, there’s a lot of trial and error and I think one of the things that you learn in the lab is that, it doesn’t always work the first time, or the second time, or the third time, um, and so, perseverance is one thing that you really learn in the lab, and knowing how to not get frustrated when you don’t get the results that you’re looking for. Also, learning how to explain the results that you do get.

Further, Danielle discusses how challenges help her learn.

Danielle, 5th-year, analytical: Um, I learn the most being challenged, personally. My own personal things, I learn the most being challenged and being interested in something that I’m challenged with. I learn the least when it’s negative. Um, I learned that more I think in grad school than in undergrad. If it’s a negative atmosphere, I tend to not learn, and there is a very fine line between um, challenging someone and being negative um… you can challenge someone by being negative but it only, you only need a little bit of negative to challenge someone.

Don also supports Danielle’s views, which show that although different methods are used, the environment plays a role. Danielle focuses on having an
environment that is not excessively negative while Don discusses being successful when there is not immediate assistance within reach.

Don, 2\textsuperscript{nd}-year, physical: Facing problems. I mean, when you face problems, I mean, and you try to solve it by yourself, then you learn most. And when you have someone to help you very easily, then you learn the least.

Lastly, the reflection and reconstruction of knowledge dimension of experience deals with evaluating oneself as a developing professional. Kasey, who is able to reflect on her past experiences to alter the way she approaches new experiences and gather new knowledge, illustrates this.

Kasey, 5\textsuperscript{th}-year, inorganic: Yeah, I guess um, now, I know, I try to think more fully through it, where back in the day I wouldn't, I'd just be like oh I'll go do it and not really think about it, you know, but now I'm like okay, I'll stop and actually and you know, I'll want to do like a set-up so I know what I'll need so I won't be running around with my head cut off, you know, so I guess that's really changed, because I don't want to say I wasn't prepared back, you know, but it was, I didn't have the experience to think about the things that I might encounter or, like, how to interpret the data, you know, whether or not it's good, or why this is doing that, like, if there's problems I have a much higher likelihood of figuring out what it is rather than not, so, back then I couldn't do that.

This is consistent with the pilot study, where it was shown that senior students took ownership of their work. In addition to becoming more independent, these graduate student researchers are also learning to think independently. As Kasey noted, she now knows how to set-up her own experiments, where as before it can be inferred that someone else was doing the actual thinking for her, either her advisor or other resources she may have used. Thus, professional identity development has components of both being incorporated into a CoP and also developing independence.
Outcomes

Outcomes are the final component in the developmental model. This category is an important part of the professional identity development of chemists, as it is the time where individuals can notice that they are becoming professional. The outcomes of the cycle include components of identity learning, problem-solving, self-efficacy, and having a sense of professional self.

Identity learning considers the formation of concepts as applied to encountered problems, because the meaning of the concepts that the students have comes from learning. Rich and Brian describe how they must make a connection between math and science in order to solve problems.

Rich, 3rd-year, physical: Um, I think it’s just really grasping the concepts, when you’re like making a connection between the math, the actual system, and, you know, when you look at a giant equation and then you try and, make a connection between that giant equation and what’s actually going on, you know, it’s really hard to do that. Um, and I think that’s what I struggled with.

Brian, 5th-year, analytical: […] I like knowing that I can apply the concept that I’ve learned to something. It’s like with uh, math courses that I’ve taken. If it’s just pure math, I struggle. But if I have something to apply it to, like a concept or a problem that I need to know how to solve, um, it helps to be able to know that the math is being useful, and for me, it helps for me to know that the chemistry is being useful in that, oh, okay, I’ve learned this concept and I’ll be able to apply it to this problem and be able to solve this problem.

Peter and Luke both refer to their coursework when talking about transferring what material they learn in coursework to the laboratory setting, and how it has meaning to them when they can see the application.

Peter, 2nd-year, analytical: […] I really think I’ve gotten close because now you can tell me something and I will sit there and figure out, okay, what is really going on and try to base what I’ve learned from classes or the hands on, little hands on work that I’ve done so far in the lab and be able to come
up with an idea or a concept of why this really happens, and base an opinion on it pretty much, that’s logical, and I kinda feel like that’s knowing chemistry.

Luke, 3rd-year, analytical: It forces concepts that you learn in classes, like, I don’t know specifically because there are so many different things, but um, just whatever you learn in class, you are going to be using in lab.

Despite Luke’s choice of using the word “concepts”, consider this exchange regarding the use of his concepts in the laboratory:

I: What concepts do you think that you use the most in your research?

Luke: Concepts… um, even like little, simple things, you learn like uh, general chemistry, like \( M_1V_1 = M_2V_2 \), you know, like stuff like that. You learn it when you’re a freshman in college and you’re like, what’s the point of this, it’s stupid. But then you work in a lab and you use it every single day, all day, like little things.

Although he spoke of concepts, when further probed about the actual concepts he uses in his research laboratory, it turns out that Luke’s ideas about “concepts” are not as deep as previously thought.

Finally, Brendan describes that you know something when you are able to explain something in a variety of ways, implying that there is some deeper understanding than surface level. However, it is important to note that Brendan is not giving himself as a specific example, nor is he referring to specific concepts.

Brendan, 4th-year, physical: […] I don’t know, one of the Hallmarks I see of somebody who really understands it is being able to explain something not only one way, not only the way you’ve memorized it or the way it was taught to you, but to be able to crunch it down and break it up and explain it several different ways…
Problem solving may be best defined here by some of our participants comments, as shown here. Maggie, Paul and Luke talk about professionals being problem solvers, and therefore acknowledge that being able to tackle problems is an important component to becoming a professional chemist, and that they also strive to achieve this during their graduate school careers; i.e., before they become a Ph.D. chemist.

Maggie, 2nd-year, physical: I mean, I think you’re pretty much a problem solver as a chemist no matter what.

Paul, 5th-year, inorganic: Well, I mean, to me, anybody with a Ph.D., just should, a Ph.D. means you could solve problems. That’s what people wanted to solve problems. Chemists, it’s just, you know, you solve a certain type of problem.

Luke, 3rd-year, analytical: Well, I would say just chemists in general, ‘cause I don’t know if I can really say analytical is different than somebody else, ‘cause I don’t really know anybody else like that, but um, I would just say we both think at like, not necessarily outside of the box, but they’re able to solve problems [...] but that’s basically it, just I mean, that’s what the whole Ph.D. is about. That you can throw somebody in a situation and you don’t have to be worried about if they’re competent or not, ‘cause they were taught how to think.

Problem solving corresponds with the ability to solve a given problem, and in our model, is described as achieving a higher level of problem solving ability than previously held. Peter describes his research as a puzzle that he is trying to solve.

Peter, 2nd-year, physical: [...] Your research is almost like a puzzle where you’re missing a few pieces to put stuff together and my job is to try to figure out how to link them together and figure out the missing piece…

Paul talks about encountering new problems in a research laboratory setting that you may not have been exposed to in an academic undergraduate environment.
Paul, 5th-year, inorganic: Uh, I learned how to use, uh you know, the instruments that you learn how to use. You don’t really learn it, uh in the undergrad, ‘cause you don’t, they just… I mean, you learn how to use it but you don’t really learn how to analyze, and when you do it for real, you have to learn how to analyze because what they give you, what you have is not necessarily gonna be able to, like in lab they always give you something that works. When you’re not in lab, when you’re doing it for real, it might not work so you have to figure out why it’s not working…

Neville, however, discusses the way he transformed into a problem solver throughout his chemistry experiences, even referring back to his undergraduate organic chemistry course, and finally relating it to how he currently approaches problems in his research.

Neville, 5th-year, organic: I’d have to say in order to know organic chemistry um, I found that for myself knowing organic chemistry came when I was able to not necessarily understand, or know an answer right away, but um, be really able to work through it with a mechanism. That was really when it hit. Um, because when I took organic chemistry, all I did was kinda just go to the back of the book chapter and just memorized, you know, every single of those reactions, and in retrospect, it would have been much easier to remember how it happened and so I think you really have a good grasp of organic chemistry when you look at a problem that you haven’t seen before and you sit down with uh, with a mechanism and work your way through, to an answer, whether it’s right or wrong, but work your way through.

Self-efficacy, which plays a major role in identity development, focuses on the beliefs chemists have as related to having the abilities to solve those problems. This includes having the will power to continue, described here by Maggie:

Maggie, 2nd-year, physical: [...] the major thing is actually doing research everyday. Like, working on a project and sticking to it and what has prompted me to think this, is that I’ve realized how hard it is to have the will-power to try and work everyday and try to keep, keep trying new things even when things aren’t working.
This also includes ideas like Brian’s about not getting held back by not initially being able to solve a particular problem.

Brian, 5th-year, analytical: […] well, going back to the last answer, problem solving. And being able to not get totally flustered and frustrated when you approach a new problem that you can’t figure out, being able to use all the resources that are available to you, whether it be literature or people.

By struggling through the problems he encounters, Brian increased his self-efficacy, which makes him a more successful problem solver. Finally, Chad acknowledges that not only do you have to have the motivation to conduct your research, but you must be able to think independently, which comes from having the confidence to do so.

Chad, 5th-year, inorganic: I think to be a successful graduate student you have to um, be willing to work, and not only work, but you have to be able to get results and think on your own.

Another component of self-efficacy is the idea that one fulfills the expectations of others, as discussed before by Jenna. Peter describes that he feels successful because he knows what other expects of him, which also increases self-efficacy.

Peter, 2nd-year, analytical: Now, I, I think it helps going to class thinking that this is going to help me and I really need to learn this for myself, I think that helps be successful. I think being able to do stuff on your feet without someone saying “do this, do that”, like someone, no one needs to tell you that you need to go to the lab and learn. No one needs to tell you to go to class, when to study, being responsible.

Brendan, however, talks about the confidence he gets when he helps other people in his group.

Brendan, 4th-year, physical: […] So, I try to be as interested, in whatever other people are doing, as I can, and uh, usually it doesn’t cost me much time, and it’s fine, and I get more practice at what I do, and it instills confidence too, when I’m like “wow, I actually know how to do that”.

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This confidence is essential to approach new challenges that may arise during research. Neville refers to being confident with some material as a means to build onto the knowledge he already has.

Neville, 5\textsuperscript{th}-year, organic: Hhhmm, um, I don't know. I guess I've only learned chemistry really, in the past year and a half, is really what I, I feel is, I've really started to learn chemistry um, it's so, it's so linear. There's so much to know um, I guess that, that the one common trend, for me, is in learning chemistry, is, is always adding to my background, to my foundation of what I do know and what I do have a firm grasp on and as little or as much as that is, really, to me, learning chemistry is applying what you know and adding to what you really feel confident with so...

Neville's views demonstrate how the cycle is propagated; i.e., one learns something new if their interest is sparked.

Thus, through this cycle, the students' sense of professional self is developed. Having a sense of professional self encompasses knowing what other professionals in one's field do, and knowing how one fits in with that group, in this case, professional chemists. Many students provided their views on what it means to be a professional in the chemistry field. These attributes include being successful problem solvers, thinking independently, and realizing that they have the self-efficacy to do these, as described here by Rich and Brian.

Rich, 3\textsuperscript{rd}-year, physical: You learn in-, like independent, um, study. In your first semester, second semester, I felt like, in my first semester and second semester, I felt like I was constantly going down to my, [advisor's] office, just like, at least two or three times a day I was down in his office, but now I'm at the point where I'm there maybe every two weeks. So, in, and that's only when, he's like a last resource. Um, and I think that's what you learn. You learn how to think for yourself, how to develop projects on your own, how to um, just come up with things on your own.

Brian, 5\textsuperscript{th}-year, analytical: [...] To be a successful graduate student, uh, at the end of my graduate student career, um, I should be able to know how to approach any sort of problem and set up an experiment to solve it, or set up, you know, set up a project to be able to address any sort of
questions about an experiment or some sort of physical problem I come across…

Although Jared has yet to experience much of graduate school, he realizes from the beginning that he wants to be viewed as a professional by the completion of his degree.

Jared, 1st-year, physical: [...] some people wanna just know enough to get through, and that’s fine, too [...] but yeah, if I’m going to be getting a Ph.D., I wanna be an expert at what I’m doing for sure.

Finally, there are perspectives such as those of Paul and Sara, who understand that professionals will have views of their abilities, but that one must also be content with their own professional life.

Paul, 5th-year, inorganic: [...] I don't know, I mean solve a problem, I think it’s problem solving. I mean, you can’t be able to uh, to uh, no one should expect you to know everything about chemistry [...] so usually you are just specific in one trait, you know, you’re just a master of one, but not a master of you know, of all of them.

Sara, 4th-year, analytical: You can’t pretend to be successful, [...] you have to be happy with your professional life, happy with your personal life. That gives you that idea that you fine in whatever you are doing.

Paul also describes that throughout his graduate school, he found where he belonged. Having a sense of belonging in a CoP is an essential part of professional identity development.

Paul, 5th-year, inorganic: [...] I mean, in the first few years I was just uh, trying to find where I belonged and then it kinda, you know, came, and now I found my niche.

Finally, Heather, a 4th-year analytical chemistry graduate student provided us with an overarching outcomes quote to encompass the Developmental Model of Sense of Professional Self in chemistry:
Heather: [...] in my opinion, it would be, well, identifying what you want to do or the problem they want to fix and coming about, coming up with a method of ways to solve that problem; be able to do it by yourself or be able to use the resources that you’ve learned to do that and just contribute a little bit more to the main goal, I guess.

This is also similar to what Neville describes.

Neville, 5th-year, organic: [...] there’s a lot, I guess there’s a lot of different chemists but from where I’m coming from, um, to be a really good chemist, to me, is uh, to have a really firm understanding of what’s going on around you. Not just the research that you’re doing but to, let’s say, be able to pick up a C&EN News and just be able to look through it and have a general idea of what they are saying. There’s stuff that I don’t understand at all but I still get a good idea, the work that they’re trying to do. Um, that’s what makes a really good chemist and part of what, for me, also makes a really good chemist is, this, getting into chemistry, I quickly realized how divided it all is. I mean, I don’t really know very much about inorganic chemistry and all that, those types of divisions, I think becoming a really good chemist also involves a lot of humility and being able to say you don’t know. But then knowing exactly where to look to find those answers or who to go to find those answers. And then being able to come back.

Although there are sub-dimensions to all of the dimensions in this model, the foundations, experience, and outcomes build from one another in a cyclical fashion. For example, Michael describes not ever acquiring enough knowledge because new science is always being developed, which is consistent with the idea that our model is cyclical:

Michael, 2nd-year, organic: [...] there are certain things that come in handy to you anytime in chemistry, like for example, the chemical equilibrium, chemical kinetics, all the reaction mechanisms or some inorganic things. So those are the things that no matter what material you want, will always be useful to you so, when I said basic knowledge, I meant those things [...] You know those things are not sufficient, just knowing the definition or just knowing a few equations that help you is not enough because science is continuously progressing and we have new areas and we need to look into them so it’s good to have a solid background but still we need to read a lot to go into new areas and do research over there.
In other words, once chemistry students have fulfilled some of the sub-dimensions in each major category, they tend to continue on to the next. It is not a requirement to fulfill all sub-dimensions within a given component of the model prior to continuing through the three stages, although it is proposed that the sub-dimensions tend to work synergistically within each dimension.

The model of sense of professional self, as well as the supporting quotes shown within this results section will be addressed and explained in the following chapter as they related to the guiding research questions.
CHAPTER V

DISCUSSION

This chapter will discuss the results given in the previous chapter, in a fashion in which the discussion answers the guiding questions of the research study. This model addresses the guiding research questions, as shown in Chapter II: Methodology, primarily focused on the question “How does one become a professional chemist?”, although our model’s dimensions and sub-dimensions also portray the graduate students’ views and experiences on chemists and chemistry.

What do chemistry graduate students believe is chemistry?

When answering the first guiding question of “what is chemistry?”, the primary theme that emerged from the responses is that the graduate students’ perceptions of chemistry were based on chemistry as a whole. Although the participants did not have a strong idea of what chemistry actually is at the beginning of their graduate school careers, they still were required to choose a discipline within chemistry. However, even students towards the end of their Ph.D. degrees did not have a well-defined idea of what chemistry is. This implies that students are choosing a discipline based on other considerations rather than deep understanding of chemistry and its subdivisions.

Developing an interest and choosing a domain may seem obvious for students who are enrolled in a graduate program; however, the reasons for choosing a domain varied among graduate students. Danielle, a 5th-year,
discussed “ruling out” organic chemistry research because it was “difficult”. By default, she chose something that was easier for her, despite the two having similar levels of interest to her, demonstrating that self-efficacy is an important aspect of choosing a discipline. Third-year student Luke had similar views, and that his domain was chosen by the fact that he was very successful on his first quiz in his analytical chemistry class (in graduate school) while his peers were not as successful. This experience told him that was his calling. Damian, a fourth-year student, spoke more directly about having an interest in something and how that relates to having a “good project”. All of these reasons to choose a discipline were common responses from our participants and thus comprise this sub-dimension of foundation. Thus, most students choose a discipline based on factors that do not always involve a deep level of processing about the field of chemistry, supporting the idea that students do not have a firm understanding of what “chemistry” actually is at this stage in their careers.

What do chemistry graduate students believe practicing chemists do?

There are primarily three components to the students’ beliefs of what practicing chemists do. These include the students’ ideas of what chemists are when they are young, knowing the language of chemistry so that they can communicate with other chemists, and most-common problem-solving techniques.

The future self-image quotes showed that the students had some long-term goal as it relates to chemistry. For example, Zack talked about always
wanting to be involved in activities that would “make the world better”. In his case, Zack sees himself improving the world by building inorganic “structures” and that being a personal model for him, as that is what he envisions professional chemists doing. Further, Ed, a third-year organic chemistry student talks about what professional chemists should be able to do. However, he does not yet acknowledge the fact that he will be a professional chemist in several years when he completes his Ph.D. The students also lack some of the deep understanding of the terms that they use when discussing their research, but rather use verbalisms that they have learned from their advisors and others in their field (Vygotsky, 1978).

It appears that for graduate students, “understanding chemistry” implies knowing the language of chemistry, as indicated by Rich’s statements. Rich identified basic knowledge acquisition as knowledge that they learned as undergraduates, but not before (e.g., primary or secondary school). Further, Rich realizes that there is a language used among chemists and it is one that only chemists know and use on a daily basis, but that it is essential to become familiar with. When one acquires the ability to speak and use the chemistry language, they gain the ability to use the language that allows them to communicate with chemists. This is a major step for becoming incorporated into the CoP, which is a component of identity development, and becoming a professional chemist.

Problem solving was a major outcome that emerged from our data, as based on the improvement of problem solving ability. Although not measured
quantitatively, the graduate students’ accounts of being able to solve problems was much more apparent by the end of the Ph.D. degree, but also that students in their earlier years of training acknowledged that to be a successful chemist, one must also be a successful problem solver, as defined by second-year Maggie, third-year Luke, and fifth-years Paul and Neville. Further, 5th-year Brian discussed having the motivation to get past the initial state of frustration when approaching a problem, by using available resources. Peter, a second-year analytical student discussed his research being like a puzzle and he is trying to find the missing piece to put the entire picture together. Others discussed trouble-shooting being a mechanism of problem solving, including Paul (5th-year), who was discussing the smaller picture in his research: figuring out a problem in a reaction, rather than his research project as a larger “problem”. Therefore, according to the graduate students, to be a successful chemist is to solve problems, and their emphasis is not on having a deeper understanding of what happens in a chemical system. Despite talking about creating new knowledge in chemistry, they do not prioritize having the fundamental theoretical knowledge in that process.

How do chemistry graduate students believe one becomes a professional chemist?

Becoming a professional chemist also had various components, as described by the graduate student participants. These elements include overcoming personal challenges, becoming incorporated into a Community of
Practice through scaffolding and other experiences, reflecting on one’s experiences, and actually having a belief that one is becoming a member of the chemistry community. These components all lead to an increased level of self-efficacy, which is essential to the overall professional identity development of chemists. Without this high-level of self-efficacy, it is difficult for professional identity development to occur and also to increase over one’s career.

Learning how to overcome personal challenges as they arise was a common factor in how students believe they can become a professional chemist. Danielle, a fifth-year, talks about learning the most when she is challenged, as long as the environment is not negative, but that she has to overcome some situations that are negative and out of her control to change. Don (2nd-year) also supports this, by adding that solving it “by yourself” helps him learn more, even if that is more challenging than seeking out the answer from another resource. Fifth-year Brian talked about struggling through points of failure if chemistry does not initially provide the expected results. Further, Brian acknowledged that you do not only have to accept the results that you get, but that you have to be able to understand and explain the results, despite them not necessarily being the results you wanted and that this is a common challenge within the field of chemistry.

It was evident that being incorporated into a Community of Practice (CoP) was essential to professional identity development, as shown by the variety of quotes given in the results section. This includes the idea of socialization, both within the research group and the chemistry department. Thus, mentoring
interactions follow the scaffolding model from Vygotsky and that chemists at all levels need people closer to their zone of proximal development (ZPD) (Vygotsky, 1978).

Outside of graduate student mentors, interactions with advisors are essential and show a form of apprenticeship. Lauren, a second-year student talks about her experiences with her advisor. She is able to consult her advisor for guidance if she needs it, however, he “lets you learn on your own” otherwise. This is important because she sees her advisor as a professional in her field, but also acknowledges that she can learn independently. This is consistent with our previous results and the development of using resources as a supplement as one progresses through their research (Walls et al., manuscript in preparation). In addition, Ed (3rd-year) acknowledged that his research is a “collaboration” with his advisor and that they work together to achieve a common goal. He even says that his advisor is teaching him how to be a “successful chemist”, supporting how Legitimate Peripheral Participation (LPP) can influence graduate students (Lave & Wenger, 1991).

When considering socialization in a laboratory environment, Brian (4th-year), Jared (1st-year), and Brendan (4th-year) all explain that being able to exchange ideas with other people is an essential component. It is important to note that these students are not talking about seeking out the answer or solution to a problem, but rather that they are sharing knowledge and ideas with each other as a means of using resources. This use of resources is also consistent
with the results from the pilot study and shows the transition of using resources is a function of time during the research phase of the Ph.D. degree.

A quote by Kasey, a fifth-year inorganic graduate student, provided an overarching quote for the reflection and reconstruction of knowledge component. Her account is of her transition from lacking the experience to set-up reactions, to interpreting the data and dealing with problems she may encounter to the point where she is now able to think about these situations prior to running an experiment. She would now be able to alleviate a problem she may encounter and learned this through years of training and experience in the laboratory setting. Thus, becoming a self-directed learner is essential to becoming a professional chemist. This is also consistent with the results from the pilot study.

As related to becoming a self-regulated learner, increasing self-efficacy is required in professional development of chemists. As defined by Bandura, self-efficacy is “people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives” and this determines how people think, are motivated, feel, and behave (Bandura, 2002). Thus, the responses given by the students regarding these emotions are aspects of self-efficacy. Peter, a 2nd-year, talked about “learning for [himself]” in classes that are relevant to his research, because he knows he will benefit from learning the material. Second-year Maggie discussed having the “will-power” to keep working when her experiments are not going as expected. Brendan (4th-year) realizes that he benefits from helping others in his group when they encounter problems. Since he is able to help his peers solve problems, it “instills
confidence” in him because they are using his knowledge as a resource. Lastly, Neville (5th-year) explained his view of learning chemistry as “applying what you know and adding what you really feel confident with”. Thus, having confidence in what you are doing is actually helping individuals learn.

Further, as graduate students progress through the research phase of their Ph.D. degrees, it is evident that they are starting to view themselves as becoming a professional in the field of chemistry. These accounts range from first-year Jared, through many fifth-year students, most of whom nearing the completion of their Ph.D. degrees. Even as early as his first year, Jared acknowledges that if he has a Ph.D., he should be an “expert” in chemistry. Others define themselves as professionals in less bold terms, as Paul did. Fifth-year Paul stated that it took him a few years of trying to find where he fit in, but that he found his “niche”. Further, Neville discussed that professional chemists are able to pick up a Chemical & Engineering News magazine and be able to understand the general ideas of the research being done. He has realized that chemistry is divided; yet there is still an overarching framework that holds the chemistry field together.

**How do chemistry graduate students believe that one learns chemistry?**

Graduate students describe learning chemistry by having a project that aligns with their personal goals and interests, having active engagement in their laboratory experiences, but also acknowledging that coursework related to their research is important in certain circumstances, like learning how to interpret NMR
spectra. Further, students learn chemistry by building upon their existing knowledge and also through the interactions they have with other members of their research group.

As with developing an interest in the foundation dimension of our model, working on a project that has personal relevance to the graduate student is essential. Luke, a 3rd-year student explained that learning from a book is not quite enough for him to understand, but that it “gets solidified if [he has] to use it in real life”. Using the concepts he learns from a book and transferring them into a lab setting is more beneficial to Luke’s learning experience, as it now has meaning to him. This is consistent with the results from our pilot study, where students learned most when there was meaning to the research activity. Second-year graduate student, Sean, enjoys the “hands-on” aspect of working in a laboratory and how that helps him understand better. Lastly, Jenna (1st-year) refers to learning an equation in class, but then being able to “see” it in the lab setting. She even talks about being able to “see” the problems as they occur in a lab setting, something that may not be explicit in a textbook or a class lecture. Thus, being exposed to active environments enhances learning, once the relevance has been established.

As should be expected, students in their first two years of graduate school talked more about how they learn from coursework and classes than their more senior peers. This is likely due to their involvement in coursework and taking cumulative examinations in addition to beginning their research. An account by Jared, a first-year graduate student, about learning NMR interpretation was of
interest to the researchers. He noted that NMR interpretation is essential to
natural products researchers, but that you have to have the tools to read an NMR
and that you are unlikely to pick that up in a laboratory setting. NMR
interpretation is a process that is focused on theory and principles, and thus the
ability to do this may be better learned in a classroom environment, prior to
applying it to one’s research.

Maggie, a second-year physical student, acknowledged that she learns
best when she knows a small amount of something prior to delving further into
the phenomenon of interest, but does not yet talk about relating them to more
complex ideas. This relationship to complex ideas may occur the next time
Maggie goes through the cycle, as she will build upon her existing knowledge.

Graduate students spoke about the “knowledge acquisition” stage in many
ways. Fourth-year Sara, for example, discussed that the material that she
learned during her undergraduate career was essential because it was part of
her foundation as a graduate student. Sara’s comments are consistent with
previous data in which advanced graduate students primarily refer to their
undergraduate training when discussing their conceptualizations of chemical
phenomenon (Bhattacharyya, 2006). These statements demonstrate how long it
takes for deeper aspects of concepts to be incorporated into the minds of
students.

First-year Jenna discussed how she learns something new best when
someone is standing behind her, advising her on what to do rather than showing
her what to do (referring to a fellow graduate student). Brendan, a 4th-year
student, explicitly says he enjoys helping others because it helps him ensure he knows what he is supposed to know. Sara, another 4th-year, realizes that it is her responsibility to help the new graduate students who join her group adjust to the new environment and learn the new instruments. All of these students recognize that there is a “Community of Practice” and that the old-timers help the newcomers, as in LPP (Lave & Wenger, 1991). An example of this is 5th-year Danielle, who explains her transition from being a “naïve” first year student to now being a senior member of her group and how that has helped her learn that each member of her group knows different things and that she can learn from others, even if they are junior members of the group.

**Final Remarks**

Although students in various disciplines and at various points in their graduate careers participated in these interviews, I was able to develop a model of sense of professional self that transcended any one of the four traditional areas in chemistry. This demonstrates the identity development that occurs across domains in chemistry and is related to the guiding questions that framed the research study. As shown in the results, despite giving different examples for each dimension, the graduate students displayed common goals in addition to the obvious goal of obtaining the Ph.D. degree. This is of particular interest to the researchers as the four traditional areas are also becoming even more specific, as they are transforming to those such as bio-organic, bio-analytical, physical-organic, etc.
As graduate students learn various research techniques, they are also developing their identities as chemists through foundation, experience, and finally seeing the outcomes of their work. These dimensions of our model are addressed by the answers to the guiding research questions, as discussed above. The answers to the guiding research questions include ideas of the graduate students’ perceptions of chemists and chemistry, based on how they learn chemistry, and what chemistry means to them. These answers are based primarily on their experiences in their research laboratories and include components such as becoming self-regulated learners and building the self-efficacy that they need to be successful chemists. Once they establish an identity for themselves professionally, they can build deeper conceptual understanding, similar to that of their research advisors and other professional chemists.
Based on the results given from the pilot study and the primary research study, *Graduate Students Perspectives on Chemists and Chemistry*, we have concluded that students in all disciplines of chemistry have similar views on what it means to be a chemist and the manner in which one establishes his/her professional identity. The Developmental Model of Sense of Professional Self (Figure 4.1) is a diagram that contains the primary components that emerged from the interviews with graduate students. The assertions generated from the data include the three dimensions of the model: foundation, experience, and outcomes.

Developing a foundation for a future in the chemistry field is an essential step and is shown by numerous students who recounted that you have to have an interest in your research, but also have a basic knowledge base and have an idea of what your future will be. The experience stage, at least during the graduate school experience, is focused around the research group environment, where students are being incorporated into a CoP, conquer personal challenges, and then are able to reflect on their experiences as a member of this CoP. Lastly, the outcomes component of our model depicts what the foundations and experience dimensions lead to. The students feel as though the major outcome of their graduate school experiences leads them to be successful problem solvers and also that they have a significant increase in self-efficacy.
Although our results support our model based on graduate students’ experiences, we propose that this model is cyclical, and that the model may be applicable in other time periods in the development of a professional chemist. For example, further research can be conducted to see if this model holds for undergraduate students, Post Doctoral chemists, and Ph.D. chemists entering the professional world for the first time (e.g., in industry). In addition to determining the applicability of this model to other important stages of the professional development of chemists, a quantitative instrument is being developed. It is our hope that this instrument will be used first at other colleges and universities and eventually as a universal instrument to assess professional identity of chemists at all levels in a quantitative manner.

**Implications in Chemistry Education**

The following section will address the implications for chemistry education, as related to the model of sense of professional self of chemists. These implications include exposing students to chemistry at young ages and showing how it is useful to them. By engaging children in chemistry at an early age, and by teaching children about how chemistry plays a role in their life, we can get them interested in chemistry before they are exposed to the fundamentals of chemistry during a traditional high school chemistry course. Since typically students do not take a chemistry course until high school, this is an important step in the professional identity development of chemists. In general, this would
initiate the cycle of professional identity development in chemistry earlier than it currently exists.

In addition, graduate students should set realistic learning goals and monitor them over time and evaluate progress. It is essential for professional identity development to occur, that students not only possess a list of goals, but a set of *realistic* goals. By attaining these goals, students will be able to reflect on their progress as developing chemists and can modify their identities as chemists based on their progress.

It is important to create an environment in which students are encouraged to overcome obstacles. This will help them to build greater self-efficacy, as they acknowledge their successes and gain motivation as a result. This is especially important during times of failure or few results. The positive environment should be established within a research group, as well as in the entire CoP.

Lastly, we should encourage members of CoP’s to engage with chemists at all levels. This includes active participation in research groups during graduate school, as well as including chemists of all levels in professional events. These events can include conferences, as well as social events within the CoP, as socialization plays a role in identity development. These interactions among chemists can lead to significant outcomes and allow the cycle to continue, thus constantly increasing the professional development of chemists.
Appendix A

IRB Consent Form: Learning in the lab: What organic chemistry graduate students learn during the research phase of the Ph.D.

Consent Form for Participation in a Research Study
Clemson University

Gautam Bhattacharyya – Department of Chemistry

Learning in the Lab: What graduate students learn during the research phase of the Ph.D.

Purpose of Research
The purpose of this research is to explore how organic chemistry graduate students learn organic chemistry.

Specific Procedures to be Used
The research will consist of two, taped interviews. The first interview will be used to probe your experiences as a graduate student. The second interview will aim to probe your ideas about chemistry and chemists. The interviews will take place in 363 Hunter Labs or in another room in Hunter Labs in which your confidentiality can be protected. The interviews will be tape recorded for the sole purpose of the accurate transmission of the interview. Any written artifacts will be kept by the researcher for the sole purpose of data analysis. Federal regulations require all research records to be maintained for at least 3 years after the completion of the study. After this time, all tapes and written artifacts will be destroyed.

Duration of Participation
You are asked to participate in two interviews. Interviews are expected to last 30 to 45 minutes in length.

Benefits to the Individual
There will be no tangible benefits to you as a participant.

Risks to the Individual
The risks to you, as a participant, will be minimal. You are free to terminate your participation at any time during the interview. This interview is not a test. The researcher is not concerned with your ability to correctly respond to questions. If, at any time, you feel uncomfortable, you are absolutely free to terminate your participation or skip a particular part of the interview without any penalty or risk to your standing in the Division of Organic Chemistry, the
Department of Chemistry, or Clemson University. Volunteering to participate does not obligate you to the researcher or the research in any manner.

Confidentiality
Data collected from the interviews will be kept confidential. A pseudonym will be used for you throughout this study and in the dissemination of the results. Only the researcher will know the identity of the student participants. The interviews will be tape recorded for the sole purpose of the accurate transmission of the interview. The tapes will be destroyed upon completion of the project.

In rare cases, a research study will be evaluated by an oversight agency, such as the Clemson University Institutional Review Board or the federal Office for Human Research Protections, that would require that we share the information we collect from you. If this happens, the information would only be used to determine if we conducted this study properly and adequately protected your rights as a participant.

Voluntary Nature of Participation
You do not have to participate in this research project. If you do agree to participate you can withdraw your participation at any time without penalty. Furthermore, you may decline to answer or address any question or any set of questions. Declining to answer a question or withdrawing participation will, in no way, affect your standing in the Division of Organic Chemistry, the Department of Chemistry, or Clemson University. You are not obligated to the researcher or the research in any manner.

Contact information
If you have any questions about this research project or if any problems arise, please contact the researcher, Gautam Bhattacharyya at: Department of Chemistry, Clemson University, Clemson, SC 29634; phone: 864.656.1356. If you have any questions or concerns about your rights as a research participant, please contact the Clemson University Institutional Review Board at 864.656.6460.

Consent
I have read this consent form and have been given the opportunity to ask questions. I give my consent to participate in this study.

Participant’s signature: ___________________________ Date: ____________

Participant’s Name: ______________________________

Researcher’s signature: ___________________________ Date: ____________

A copy of this consent form should be given to you.
Appendix B

IRB Consent Form: Graduate students perspectives' on chemists and chemistry

Consent Form for Participation in a Research Study
Clemson University

Gautam Bhattacharyya and Bethany M. Walls – Department of Chemistry

Graduate students' perspectives on chemists and chemistry

Purpose of Research
The purpose of this research is to explore how chemistry graduate students learn chemistry in the four traditional areas of chemistry.

Specific Procedures to be Used
The research will consist of a single taped interview. The interview will be used to probe your experiences as a graduate student, as well as your ideas about chemistry and chemists in your discipline. The interviews will take place in 385 Hunter Labs or in another room in Hunter Labs in which your confidentiality can be protected. The interviews will be tape recorded for the sole purpose of the accurate transmission of the interview. Any written artifacts will be kept by the researchers for the sole purpose of data analysis. Federal regulations require all research records to be maintained for at least 3 years after the completion of the study. After this time, all tapes and written artifacts will be destroyed.

Duration of Participation
You are asked to participate in one interview. Interviews are expected to last 30 to 45 minutes in length.

Benefits to the Individual
There will be no tangible benefits to you as a participant.

Risks to the Individual
The risks to you, as a participant, will be minimal. You are free to terminate your participation at any time during the interview. This interview is not a test. The researcher is not concerned with your ability to correctly respond to questions. If, at any time, you feel uncomfortable, you are absolutely free to terminate your participation or skip a particular part of the interview without any penalty or risk to your standing in the Division of Organic Chemistry, the Division of Inorganic Chemistry, the Division of Analytical Chemistry, the Division of Physical Chemistry, the Department of Chemistry, or Clemson University. Volunteering to participate does not obligate you to the researchers or the research in any manner.
Confidentiality
Data collected from the interviews will be kept confidential. A pseudonym will be used for you throughout this study and in the dissemination of the results. Only the researchers will know the identity of the student participants. The interviews will be tape recorded for the sole purpose of the accurate transmission of the interview. The tapes will be destroyed upon completion of the project.

In rare cases, a research study will be evaluated by an oversight agency, such as the Clemson University Institutional Review Board or the federal Office for Human Research Protections, that would require that we share the information we collect from you. If this happens, the information would only be used to determine if we conducted this study properly and adequately protected your rights as a participant.

Voluntary Nature of Participation
You do not have to participate in this research project. If you do agree to participate you can withdraw your participation at any time without penalty. Furthermore, you may decline to answer or address any question or any set of questions. Declining to answer a question or withdrawing participation will, in no way, affect your standing in the Division of Organic Chemistry, the Division of Inorganic Chemistry, the Division of Analytical Chemistry, the Division of Physical Chemistry, the Department of Chemistry, or Clemson University. You are not obligated to the researchers or the research in any manner.

Contact information
If you have any questions about this research project or if any problems arise, please contact the researchers, Gautam Bhattacharyya or Bethany M. Walls at: Department of Chemistry, Clemson University, Clemson, SC 29634; phone: 864.656.1356. If you have any questions or concerns about your rights as a research participant, please contact the Clemson University Institutional Review Board at 864.656.6460.

Consent
I have read this consent form and have been given the opportunity to ask questions. I give my consent to participate in this study.

Participant’s signature: ___________________________ Date: ____________

Participant’s Name: ____________________________

Researcher’s signature: ___________________________ Date: ____________

A copy of this consent form should be given to you.
REFERENCES


Walls, B., Clark, J., & Bhattacharyya, G. (*manuscript in preparation*). Learning in the lab: What organic chemistry graduate students learn during the research phase of the Ph.D.