Finding a new continent versus mapping all the rivers: Recognition, ownership, and the scientific epistemological development of practicing scientists and engineers

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FINDING A NEW CONTINENT VERSUS MAPPING ALL THE RIVERS: RECOGNITION, OWNERSHIP, AND THE SCIENTIFIC EPISTEMOLOGICAL DEVELOPMENT OF PRACTICING SCIENTISTS AND ENGINEERS

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Chemistry

by
Andrea Marie Verdan
May 2012

Accepted by:
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ABSTRACT

Maintaining our nation’s standing as a leader of innovative and premier science and engineering research requires that those on the trajectory of these careers receive both rigorous and exceptional training. In addition to educating students in the content knowledge of these disciplines, it is also necessary to train them in the professional skills associated with being competent and conscientious scientists and engineers. In the attempts to understand the best strategies to teach these skills, research during the past few decades has shown a steadily increasing interest in improving the scientific literacy of students in science and engineering disciplines. Researchers agree that fostering this literacy—particularly with respect to understanding the nature of science, i.e., scientific epistemology—is an important component in developing students’ abilities to become successful practitioners of science and engineering.

This research was motivated by the need to further elucidate the formative experiences that contribute to science and engineering faculty members’ personal epistemologies of science. To examine the development of these epistemologies, a phenomenographical study was designed to elucidate academic scientists’ and engineers’ understandings of contributions, collaborations, and credit assignment. The results and inductive, grounded-theory analysis of interviews with faculty members in the College of Engineering and Science at a large, southeastern institution revealed a model of scientific epistemological development and its possible ties to professional identity development. This model can help inform changes in mentorship and training practices to better prepare students to manage the challenges posed by being scientists and engineers in the 21st-century.
DEDICATION

To Andres, Rowena, and Alden Verdan, whose unwavering love makes anything possible.
ACKNOWLEDGEMENTS

My heartfelt thanks to my research participants, whose sharing of experiences helped shape this research; your insights will continue to provide inspiration as I continue on my career path. Words cannot express my gratitude to my advisor, Dr. Gautam Bhattacharyya, for all his insights during this period of my professional and personal growth; thank you for being both a guide and a colleague while providing me with the opportunity and support to pursue my very own professional passions. Also, many thanks to my advisory committee, Dr. Melanie Cooper, Dr. Zahra Hazari, and Dr. Julia Brumaghim; I am grateful for your ongoing mentorship. And finally, I would like to thank all my pillars of strength—Circle Four, Tim & Marie Slottow, Barbara Lewis, Lindsey Cain, Dr. Nathaniel Grove, Barbara Bull and our fellow associates & conspirators at Moe Joe, and Michael K. Wazowski; this dissertation would not have been completed without your presence.
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CHAPTER I

INTRODUCTION

Over the past decade, the number of doctoral degrees awarded has been steadily increasing across all disciplines, from the humanities to the sciences (Bell, 2010). This growth in Ph.D. production is accompanied by an increase of talent and knowledge that ultimately benefits various communities, contributing to scholarship within academia, innovation within industry, and leadership within government. Doctoral graduates have one of the lowest unemployment rates in the working population—a rate of 2.5%, in comparison to 7.6% for all workers (Bureau of Labor Statistics, 2012)—and of those Ph.D. recipients with definite employment commitments post-graduation, approximately half find work in academia, a quarter encounter work in business and industry, while the remainder pursue work in other sectors such as government, non-profit organizations, or K-12 school systems (National Science Foundation [NSF], 2009a). With their degrees in hand, these doctoral graduates ideally possess the skills of navigating the literature, utilizing research methods and techniques, and solving the relevant problems within their knowledge disciplines. In fact, over 75% of both faculty advisors and senior doctoral students across the disciplines believe that graduate programs successfully prepare students for performing research with a high level of proficiency (Walker, Golde, Jones, Bueschel, & Hutchings, 2008). However, many recognize that because of the rate at which knowledge is becoming increasingly global, the continual blurring of boundaries between traditional knowledge disciplines, and the changing landscape of employment opportunities, graduate students must be prepared beyond basic research skills for the careers that follow their Ph.D. programs.
The State of Graduate Education in Chemistry

In 2007, the National Research Council (NRC) released a report on the state of chemistry research in the United States. The findings of this report claimed that the productivity of chemistry research in the U.S. was stronger than all other countries, though countries in Europe and Asia were becoming tough competitors. The report suggested that one important factor for the U.S. to maintain its standing as the world leader of chemistry research was the fostering and development of its future chemists, especially those pursuing doctoral degrees. This suggestion has also been made by various graduate students, chemistry academics, and professional societies, who all agree that while a chemistry Ph.D. prepares students for careers in basic research, it does not fully prepare them for the professional responsibilities associated with being faculty members in academia or leaders in industry (Commission on Physical Sciences, Mathematics, and Applications, 2000; Caserio et al., 2004; Golde & Walker, 2006; Shulman, 2008; Loshbaugh, Laursen, & Thiry, 2011). These groups have strongly advocated doctoral education reform, recommending that the quality of chemistry Ph.D. programs can be improved by fostering professional abilities outside of technical research. They suggest that providing more opportunities to develop the skills related to interdisciplinary work, collaboration, grant writing, leadership, management, and teaching can enhance students’ sense of responsibilities to their future professional communities.

Motivations and Personal Background

Preparing doctoral students for the responsibilities associated with their future professions requires a deep understanding of those professions. Therefore, the overall goal of the research presented in this dissertation is to elucidate conceptualizations of what it
means to be a full-fledged professional scientist and engineer. In particular, this body of work explores the formative experiences that contribute to academians’ understandings of knowledge development and research practice in the science and engineering disciplines. In addition to being rooted in the science and engineering communities’ current concerns in enhancing doctoral training, these research goals are also motivated by my interests in understanding my professional self. My lifelong struggles and experiences of trying to discover my identity as a student, a chemist, and an educator—my own journey to uncover how I am situated as a professional in society—has greatly inspired me to undertake this research goal. In turn, what follows is my current story of professional development and how this journey has influenced the research questions I have chosen to pursue.

My earliest recollection of my interest in a career in science was when I walked into my kindergarten class, dressed up as a doctor on “Career Day.” From that day forward, I fully devoted myself to my studies, being particularly meticulous in all my science courses. It was not until my junior year of college, working in a pre-med program towards a degree in chemistry, that I actually stopped and thought to myself, “Do I really want to do this, be a doctor?” Realizing that the answer was “no,” I had the immediate need to redefine myself, feeling the painful void of losing the identity of the girl-who-would-be-doctor.

It was not until a few years later, after having moved to Spain to simply relax and reflect, that I stopped struggling with the question of my career path. While working as an English language teacher in Barcelona, I discovered something I had never experienced before: an actual job in which I enjoyed investing my time, work for which I had a great passion. It always brought me utter joy to watch my students’ faces light up with understanding when they reached the “Eureka” moment, that one instant when something
previously incomprehensible would become obvious and clear. I had these amazing moments during my own education and realized during my teaching experience that this euphoric feeling can be shared between student and teacher. It was this feeling that inspired me to become another kind of doctor—an academic—with a research agenda to understand the journey of both students and teachers to similar “Eureka” destinations of discovering new knowledge and themselves.

Upon returning to the U.S., I decided to pursue a Ph.D. to gain the content knowledge and proper training to be a professor of chemistry, thus uniting my fascination with chemistry with my enthusiasm for teaching. Knowing that my passion was not in bench chemistry but in chemistry pedagogy, I was fortunate enough to search for a graduate program focused in chemistry education. I decided to work with Dr. Gautam Bhattacharyya at Clemson University because his research interests pertaining to science practitioner development were in line with questions I had in both my personal and professional life. After joining his Chemistry Education research group within the Department of Chemistry, I found myself struggling to find a niche in which I fit. I did not identify myself as a chemist, since I was not actively investigating the properties of atoms and molecules at a laboratory bench, nor did I identify myself as a full-fledged educator, since I was not fully participating in teaching practices. Though I believed that I possessed the foundational content knowledge of a chemist and the passion of a diligent educator, I constantly wondered, “Who am I? Where is my place and where do I belong in this community of academic chemists?” These were the personal questions that were closely related to the research questions I ultimately pursued in this dissertation work.
Therefore, to gain a deep understanding and rich description of what it means to be a professional academic researcher in science, this qualitative research investigated understandings of the formative experiences that strongly contribute to the development of scientists’ and engineers’ notions of scientific knowledge and practice. The outcomes of this work can help inform changes in training and mentorship practices, to better prepare students at all levels to manage the challenges posed by being scientists and engineers in the 21st-century.
CHAPTER II
LITERATURE REVIEW

In this chapter I will present a brief literature overview of two major themes related to science and engineering practitioner development. Ultimately, my research questions were embedded in the themes of scientific ethics and scientific epistemology. The review of previous research pertaining to scientific ethics will focus particularly on ethics training in the discipline of chemistry, which in turn guided my initial pilot studies with graduate students. The overview of research pertaining to scientific epistemology, i.e., the nature of science, will focus on research assessing the scientific epistemological views of undergraduate students, graduate students, and research practitioners in science and engineering disciplines, which helped inform the major body of my dissertation research.

Scientific Ethics

As mentioned in the previous chapter, the call for reform in graduate education is widespread throughout the humanities and scientific disciplines. Within the science and engineering communities, many educators, researchers, and professionals societies agree that doctoral students need preparation beyond the research skills of posing good research questions, analyzing and interpreting data independently, and employing research techniques (Walker et al., 2008). In addition to improving training in areas such as teaching, communication, and collaboration, science and engineering professionals and leaders are calling for enhanced training in scientific ethics. In contrast to the colloquial definition of ethics, which involves the theory of the universal values and standards of behavior we follow
as members of mankind (Durkheim, 1957), scientific ethics pertains to professional ethics: a branch of moral philosophy concerning the system of values and standards of behavior for professionals engaged in a common pursuit (Kovac, 1996). Just as lawyers and doctors have their own codes of conduct to which they must adhere, scientists and engineers have their own ethical and normative values upon which they evaluate their professional behavior.

Concern for the teaching of science and engineering ethics has its origins in the 1970s, a decade in which there were growing realizations of the broader societal impacts of scientific research (Coppola & Smith, 1996; Pascal, 1999; Reiss, 1999). Though there was no immediate implementation of formal ethics training at that time, the founding of journals such as *Accountability in Research* (est. 1989) and *Science and Engineering Ethics* (est. 1995) demonstrated the increasing regard and need for a forum in which science and engineering practitioners’ could discuss and explore the issues pertaining to research integrity. Moreover, in the past few decades, science and engineering communities have been increasing their call for enhanced ethics training.

*The Call for Training in the Responsible Conduct of Research*

As members of the science and engineering research community, we are entrusted with the great responsibility to conduct rigorous research with integrity. Nonetheless, there are those who have abused this responsibility, which can threaten the progress of science and the sense of trust amongst scientists and the general public (Kalichman, 2007). In addition to high-profile cases of research misconduct—such as Bell Laboratories physicist Jan Hendrik-Schön’s fabrication and falsification of data in articles appearing in the prominent publications *Science* and *Nature* (Service, 2002), Korean scientist Woo Suk-Hwang’s fabrication of experiments in stem cell research (Holden, 2005), and University of
Wisconsin professor Elizabeth Goodwin’s falsification of data in National Institutes of Health (NIH) grant applications (Couzin, 2006)—there are reports of more “regular” research misbehaviors that often go dismissed and unpunished (Swazey, Anderson, & Louis, 1993; Anderson, 2000; Martinson, Anderson, & de Vries, 2005; Heitman, Anestidou, Olsen, & Bulger, 2006). For example, Martinson and colleagues (2005) found that a significant portion of early- to mid-career researchers funded by the NIH admitted to engaging in “common” unethical practices including assigning authorship credit inappropriately, omitting observations or data points from analyses, and keeping inadequate records of research projects. Additionally, Kirby and Houle’s (2004) survey of American Physics Society (APS) undergraduates, junior faculty, and department chairs revealed that these APS members admitted to partake in practices such as inappropriate assignment of authorship and unethical treatment of subordinates in the research laboratory. Beyond the typically highlighted misbehaviors of plagiarism, falsification, and fabrication (PFF), these other activities were, until recently, often overlooked as challenges to scientific integrity.

With the heightened awareness of these “regular” research misbehaviors, researchers, professional societies, government officials, and major funding agencies currently recognize that in order to maintain our nation’s standing as a leader of science and engineering research, rigorous training for students and professionals alike in the responsible conduct of research (RCR) must be implemented (Dalton, 2000; Titus & Bosch, 2010). There are various issues related to RCR (NIH, 2009) which include, but are not limited to:

- Data Acquisition, Management, Sharing and Ownership
- Mentor and Trainee Responsibilities
- Publication Practices, Citation, Plagiarism, and Responsible Authorship
- Peer Review
Additionally, both the NIH (2009) and the NSF (2009b) recently implemented new policies for applicants of federal research training funds, requiring RCR instruction for all research trainees. Due to this call to enhance RCR education, institutions have responded in various ways. These responses differ at each institution and have included the development of professional codes of conduct, the establishment of interventions and assessments of organizational climates, the formation of mentorship programs, and—most notably—the implementation of ethics and RCR educational courses, online training programs, and workshops (Brock et al., 2008). A wide variety of this ethics and RCR instruction has been reported and reviewed in the literature (Antes et al., 2009; Kligyte, Marcy, Sevier, Godfrey, & Mumford, 2008; NRC, 2009), a detailed analysis of which is out of the scope of this literature review. However, I will now focus on the training found in chemistry departments around the country.

Current Implementation of Ethics and RCR Training Programs in Chemistry

When ascertaining the content necessary for ethics and RCR training, the chemical disciplines are unique in that issues not only within academia but within private industry as well must be considered, since a significant portion of chemists have professional trajectories into private industrial positions (Bunnett, 1999; Bruton, 2003). In fact, many advocates of ethics and RCR training recommend that there cannot be a “one-size-fits-all” instruction, due to the differences in practice and culture in the various science and engineering disciplines (Bullock & Panicker, 2003; NRC, 2009; Kalichman, 2011). The studies that
address ethics and RCR training of chemists range from courses offered to high-school students in research experiences for undergraduates (REU) programs (Mabrouk, 2007; Fisher & Levinger, 2008) to targeting various entry points of teaching ethics during undergraduate (Coppola, 2000) and graduate school (McGuffin, 2008) instruction, to more focused studies investigating faculty members’ understandings of authorship assignment (House & Seeman, 2010; Seeman & House, 2010), some of which will be discussed below.

Instruction in scientific ethics and RCR has been implemented as early as training for high school students. In a summer REU program for high-school students, Mabrouk (2007) described an hour-long workshop which defined and focused primarily on PFF. Student groups held discussions on various case studies and identified strategies—along with the related consequences—to solve the ethical dilemmas of each case. A qualitative “assessment” of the course, based on students’ opinions of the workshop, suggested that students believed they “learned some useful things” (Mabrouk, 2007, p. 954) about dealing with ethical dilemmas. The author attributed this to the fact that most of the students initiated the course with minimal awareness of issues pertaining to plagiarism, theft of results, and the severity of consequences when making unethical decisions. Similarly, Fisher and Levinger (2008) also discussed the 2- to 3-hour long ethics workshops they presented to summer REU high-school students. In their curriculum, they used both real and fictional case studies of the aforementioned RCR issues—in addition to dilemmas surrounding resource allocation and job searching—that were potentially encountered in scenarios ranging from high-school to post-doctoral studies. These authors claimed that their workshop was potentially useful for ethics and RCR training at all levels, since the case studies were applicable to students of differing background and experience; they also
concluded that in the student reviews of the workshops, 90% of the student participants rated it as “excellent.”

Numerous ethics and RCR training courses for chemistry undergraduate students also center on discussions and analysis of case studies. The previously discussed workshop of Fisher and Levinger (2008) was also presented to chemistry students enrolled in a senior capstone course and the authors reported outcomes similar to those of the REU students. Coppola (2000) reported on his ethics course for first-year chemistry undergraduates who earned Honors credit for taking the course. In weekly, 2-hour supplemental instruction sessions led by the instructor and junior and senior undergraduate students, students were assigned readings of chemistry-based case studies with ethical dilemmas, were asked to write a short personal reflection on the case, and were then required to discuss those reflections in class. From the student evaluations, Coppola concluded that students became more reflective with their RCR knowledge and further suggested that explicitly addressing ethical issues can heighten student awareness of ethical dilemmas in day-to-day laboratory courses and experiences. The same conclusions were made by Kovac (1996), in a course for undergraduate students titled “The Ethical Chemist.” During the course he taught the students that ethical decision-making is similar to solving a design problem, demonstrating that one must observe and consider all the facets of the problem and consider all the outcomes and consequences of a particular course of action. Kovac concluded that students “appreciate” the course and that students claimed they became more mindful of ethical issues due to the decision-making activities.

The reported ethics and RCR instruction for chemistry graduate students is similar to that which has been presented to REU and undergraduate students. In a one-semester
course for graduate students in a department of pharmaceutical chemistry, Rytting and Schowen (1998) focused on various issues of scientific integrity. The course was designed as a series of weekly, one-hour lectures given by various faculty members—including a professional ethicist—with expertise in scientific writing, grant administration, and regulating institutional and government issues. These lectures were followed by a class discussion which related the presented topics to graduate student experiences. Though no formal assessment of the course was made, the authors claimed that students were “generally satisfied” with the course. In another course titled “Research and Ethics Skills,” Bruton (2003) described a one-semester course open to all graduate students, with a high enrollment of chemistry students. In addition to studying case studies, the instructors had students relate their research experiences to codes of conduct from various professional societies’, including the American Chemical Society’s *The Chemists’ Code of Conduct*. Evaluation of the course demonstrated that students viewed the code as a declaration of ideals to which chemists should adhere, a public relations statement to show the trustworthiness of chemists, or a guidebook for chemists encountering difficult decisions. Interestingly, the author noted that students did not realize that the code could be used to define professionalism and ethical behavior in chemistry. Finally, Danowitz and Taylor (2011) described an ethics instruction module presented to first-year graduate students, which were led and moderated by senior graduate students. These first-years participated in two 2-hour graduate school orientation sessions, centering on discussions of case studies that addressed potential ethical dilemmas students could encounter in the first two years of their graduate programs. Since faculty involvement during the sessions was minimal, the peer-leaders consulted with faculty members to highlight important discussion points and solutions for each case. Although
there was no assessment of the training modules, the authors concluded that the sessions raised students’ awareness of the nuances of ethical decision-making. Additionally, they suggested that having senior graduate students as peer-leaders was important for incoming graduate students to be candid about their beliefs about the ethical issues.

Together, these implemented methods of ethics and RCR training for chemistry students and others across all levels have primarily revolved around readings, discussions, and reflective writing relating to case studies of clear scientific misconduct (PFF) or the normative guidelines of the chemistry community. In addition to courses such as these, courses have also been developed which incorporate role-playing scenarios into the instructional setting. For example, in a colloquium for undergraduate students in a summer REU program, students participated in a role-playing scenario based on a real, ambiguous case of intellectual property issues (Hoggard, 2008). In this case study, a European graduate student studying in the U.S. refused to disclose details and provide research notebooks related to a potentially patentable process, wanting to claim the data as his own. Followed by the role-play, students and faculty discussed the ethical dilemmas and found no consensus on the proper consequences of the graduate student’s actions. No formal assessment of the colloquium was made, but the authors implied that students became more aware of the challenges of ethical decision-making. Additionally, this role-playing method of teaching RCR was also implemented with chemistry graduate students (Brummel, Gunsalus, Anderson, & Loui, 2010). Graduate students from the department of chemistry of a large, research-intensive public university participated in a single one-hour RCR training session. These students role-played a conflict-of-interest issue centering on a departmental advisor concerned with a student’s dissertation research project that was heavily associated with an
external business. The authors reported that students agreed that the role-playing method was an effective dialogue starter, since the complexities of the situation were far more evident than traditional case study analysis. The students believed the role-plays were more engaging and promoted a deeper understanding of ethical dilemmas, as compared to a lecture or case study covering the same topic. Together, these authors suggested that role-playing is an effective strategy to teach RCR, as it forces students to personalize the situation and actually make decisions as if faced with the real issues.

This literature demonstrates that there is plentiful ethics and RCR training being executed in chemistry departments across the country—all in addition to instruction offered in other science and engineering departments, institutions, and organizations. However, none of these courses and programs has undergone substantial, critical assessment. This assessment is challenging since there is little consensus on the goals of ethics and RCR training and the methods of teaching ethics and RCR that are most effective (Plemmons, Brody, & Kalichman, 2006), which is likely due to the different codes of conduct and varying principles within each science and engineering discipline, and perhaps even sub-disciplines (Anderson, Martinson, & de Vries, 2007). Moreover, research on the effectiveness of ethics and RCR training in science and engineering disciplines is mixed (Anderson et al., 2007); while some studies demonstrate that instruction results in only little to modest gains in ethics and RCR understandings (Macrina, Funk, & Barrett, 2004; Antes et al., 2009), others indicate that training indeed enhances ethical decision-making skills (Mumford et al., 2008; Klygite et al., 2008; Brock et al., 2008). In these latter courses reporting successful outcomes of ethics and RCR education, the authors emphasize that no matter what the
science or engineering discipline, it is imperative to use day-to-day research practices as a basis to understand ethical decision-making.

**Student Understandings of Ethics and RCR**

Of the literature presented addressing ethics and RCR instruction in chemistry, the majority indicates that students do develop an “appreciation” and “awareness” of issues surrounding ethics and RCR during training. However, these reports do not compare pre- and post-understandings of these issues and there is little to no research pertaining to chemistry students’ current or baseline notions of scientific ethics and RCR dilemmas as they enter undergraduate or graduate programs. Interestingly, one study has demonstrated that new graduate students in the biomedical sciences are lacking or uncertain in their RCR knowledge, regardless of their prior education or experience, and students with previous RCR training were found to have inconsistencies in essential ethics and RCR knowledge (Heitman, Olsen, Anestidou, & Bulger, 2007).

The reported lack of success of some ethics and RCR training may be attributed to the possible disconnect between students’ experiences and the case studies given during instruction. Students may have difficulty relating to the content of these case studies since the majority of the cases focus on the ethically ambiguous situations and potential decision-making dilemmas which professors and instructors believe are important for students to know as they transition to future careers as practicing scientists and engineers. To make this training more relevant and effective, it would be interesting to shift the focus of ethics and RCR instruction to students’ daily research experiences and practices (Plemmons et al., 2006), as promoted by those who have observed success in ethics and RCR instruction (Mumford et al., 2007; Klygite et al., 2008). Moreover, the actual understandings of chemistry students’
own normative values and the ethical challenges they face in their daily research has not been reported. Therefore, in the initial studies of my dissertation research, I decided to examine chemistry graduate students’ perceptions of scientific norms and ethical misconduct in the context of their daily experiences as students, teaching assistants, and laboratory researchers, which I will discuss in detail in the following chapter.

Scientific Epistemology

To gain an appreciation of scientists’ and engineers’ professional codes, ethical standards, and normative values, it is essential to understand science itself. This understanding is a concern of scientific epistemology, i.e., the nature of science. Though the field of engineering epistemology is slowly emerging (Pirtle, 2007; Figueiredo, 2008), there is no substantial research in this area. Therefore, the following discussion will focus solely on scientific epistemology since the practice of both scientists and engineers is concerned with the development of scientific knowledge. As stated by Sadler, Chambers, & Zeidler (2004),

… A person’s understanding about the epistemology of content knowledge will influence the application of the content knowledge. In other words, nature of science conceptualizations affect the interpretations of scientific knowledge upon which decisions about [ethical] issues are made (p. 390).

Thus, an understanding about the nature of science can enable science and engineering students, educators, and practitioners to understand the complexities of scientific knowledge and how it applies to ethics and RCR content.

Defining the Nature of Science (NOS)

Advocated by educators and scientists alike to enhance students’ scientific literacy (American Association for the Advancement of Science, 1990, 1993; NRC, 1996), the nature
of science (NOS) has been an active area of science education research for approximately a century. Though there is widespread consensus that an understanding of NOS is important for students, teachers, and practitioners in science and engineering disciplines, there has always been debate over what NOS actually entails (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). In its earliest promotion by the Central Association of Science and Mathematics Teachers (1907), NOS was defined as an understanding of “the scientific method.” Indeed, a significant number of articles published since that time, which claim to address NOS issues, have researched students’ notions of scientific inquiry and processes (Lederman, 2007). However, many counter that scientific inquiry is not a matter of NOS; rather, NOS is concerned with the philosophy of science—what science is and how science works (Schwartz, Lederman, & Crawford, 2004).

In the more recent literature, many utilize and refer to Lederman’s (1992) definition of NOS: “the epistemology of science, science as a way of knowing, or the values and assumptions inherent to the development of scientific knowledge” (p. 331). In general, the characteristics of scientific knowledge with which NOS is concerned include: the tentativeness of scientific knowledge; demarcating the boundary between scientific and non-scientific knowledge; the subjectivity and theory-laden quality of observation due to personal biases and experiences; the influence of human inference, imagination, and creativity in the progress of scientific knowledge; and the recognition that the development of scientific knowledge is socially and culturally embedded (McComas, Clough, & Almazroa, 1998; Osborne et al., 2003; Lederman, 2007; Schwartz & Lederman, 2008). Because of these varying foci and tensions in defining NOS, different researchers highlight different aspects of what is important to understand about NOS. Moreover, it is also difficult to find
consensus on what constitutes adequate NOS understandings and what methods are best for teaching NOS. Strategies discussed in the literature include, but are not limited to, implicit and explicit teaching of NOS principles (Abd-El-Khalick & Lederman, 2000b; Khishfe & Lederman, 2007), instruction through scientific inquiry and authentic research experiences (Schwartz et al., 2004; Russell & Weaver, 2011; Breslyn & McGinnis, 2012), training through the lens of analyzing socioscientific issues (Bell & Lederman, 2003; Zemplén, 2009; Nuangchalerm, 2010; Khishfe, 2012), and teaching through the history of science (Abd-El-Khalick & Lederman, 2000a).

**Student and Practitioner Understandings of NOS**

There is a deluge of research on NOS, the majority of which focuses on the development of courses and curriculum to enhance and/or assess NOS understandings of primary and secondary school students, pre-service teachers, and teachers. These research studies have been thoroughly reviewed in the literature (Abd-El-Khalick & Lederman, 2000b; Lederman, 1992, 2007; Deng, Chen, Tsai, & Chai, 2011), with these reviews highlighting the complex nature of both teaching and learning NOS. These reviews recognize that the difficulty in defining NOS and the debate surrounding the most effective methods of instruction of NOS contribute to the contradictory findings found throughout the literature. Since different studies focus on various teaching approaches and different aspects of NOS, some studies have found gains in learner NOS understandings, while others have not.

Surprisingly, even less prevalent in the literature are studies on NOS views of science and engineering college and university students and science practitioners, though research with this population has been steadily increasing in the past decade. For undergraduates,
there have been studies comparing the epistemic development of science and humanities students (Palmer & Marra, 2004) and studies investigating NOS understandings of novice physics students (Hammer & Elby, 2003; Lising & Elby, 2005; Redish & Hammer, 2009; Ibrahim, Buffer, & Lubben, 2009), students participating in senior research projects (Ryder, Leach, & Driver, 1999), and students involved in various types of laboratory curricula (Russell & Weaver, 2011). Research with graduate students has centered on students enrolled in history of science courses (Abd-El-Khalick & Lederman, 2000a) and those immersed in Ph.D. research programs (Thoermer & Sodian, 2002). In addition, there has been research on NOS conceptions of university professors and well-established research scientists (Bell & Lederman, 2003; Samarapungavan, Westby, & Bodner, 2006; Schwartz & Lederman, 2008).

The NOS conceptions of undergraduates have been investigated both in and out of the context of research activities. Outside of the research and teaching laboratory, Palmer and Marra (2004) investigated undergraduate students in both science (chemistry, biology, physics, math, and engineering) and humanities (sociology, psychology, literature, and history) disciplines. The authors compared the science students’ epistemic views with the humanities students’ epistemic views and found that the science students possessed impoverished views of NOS. Almost two-thirds of those within the science cohort demonstrated limited “science-as-fact” or slightly complex “science-as-theory-or-fact-with-exceptions” NOS views, though the authors noted that the science students more naturally transitioned to enhanced epistemic views than their humanities counterparts. In contrast, another study investigating undergraduate physics students’ views of NOS characteristics—including demarcation of science and non-science, the purpose of experiments, the role of creativity in science, and the precedence of experimental data over theory—suggested that
students did indeed have sufficient views of NOS (Ibrahim et al., 2009). After classifying the physics students in four distinct groups, the authors found that 44% of the students held views consistent with the authors’ ideals of sophisticated NOS understandings. Finally, in another group of studies with undergraduate students enrolled in introductory physics courses, researchers investigated the effect of students’ scientific epistemic views on their learning of physics, showing that these students did not often utilize their scientific epistemologies in their learning of physics concepts (Hammer & Elby, 2003; Lising & Elby, 2005; Redish & Hammer, 2009). Together, these studies suggested that curriculum that explicitly addresses students’ scientific epistemologies—particularly their views on the tentative nature of scientific knowledge—can help strengthen students’ conceptual understandings of physics.

Undergraduates’ conceptualizations of NOS have also been studied in the context of research and instructional laboratory experiences. In their interviews with undergraduate students conducting senior research projects in the disciplines of chemistry, biochemistry, earth science, and genetics, Ryder and colleagues (1999) found that despite the research experience, students still held inconsistent NOS views. While students gained a greater understanding of the notion that scientific pursuits are influenced by theoretical developments within a discipline, they did not recognize or discuss the socially embedded nature of science, i.e., how science is practiced within a community. In addition, the authors postulated that NOS views may vary amongst disciplines, since disciplinary research approaches and methodologies vary considerably. Another study by Russell and Weaver (2011) compared the NOS understandings of college general chemistry students participating in verification, inquiry, or research laboratory curriculum. The authors found that students
with research laboratory experience demonstrated more sophisticated NOS conceptions, as these students were better able to define the nature of scientific theories and the role of creativity in the scientific process through their own research experiences. Together, these studies implied that authentic research practice helped to enhance undergraduate student understandings of NOS.

In contrast to the conclusions from studies with undergraduate students suggesting that authentic research practice enhances NOS views, research elucidating the NOS conceptions of graduate students has demonstrated that these more advanced students possess impoverished NOS views. For example, in their assessment of biology, chemistry, and physics first-year undergraduate students and second- and third-year Ph.D. students engaged in active research, Thoermer and Sodian (2002) found no difference in NOS understandings across the student levels. Though neither group demonstrated a clear understanding of the necessity of framework theories for the scientific research process, the authors noted that physics students held more sophisticated NOS views than the students in chemistry or biology. The notion that science graduate students possess under-developed NOS understandings was also suggested by Abd-El-Khalick and Lederman (2000a). These authors conducted an investigation of both undergraduate and graduate biological and general science students and pre-service teachers enrolled in courses teaching the history of science. The authors found that the participants who held initially limited views about the empirical, inferential, tentative, subjective, and creative aspects of NOS did not significantly change their views after the history of science courses. Only those students who started the course with more mature NOS views—who were primarily the pre-service teachers and surprisingly not the graduate students—demonstrated gains in their NOS views after the
history of science instruction. Though these studies were investigating different groups of graduate students and different characteristics of NOS, they both arrived at similar conclusions suggesting that graduate students have limited understandings of NOS.

In addition to the research on the NOS views of undergraduate and graduate students, a few studies have also revealed science professors’ and practitioners’ conceptualizations of NOS. For example, Bell and Lederman (2003) did a comparative study investigating how the NOS views of university professors and research scientists influence ethical decision-making. The authors separated these professors and scientists into two groups: those believed to have sufficient opportunities to reflect on NOS concepts, such as science educators, science philosophers, and research scientists, and those who the authors believed did not, such as historians, English professors, and business professors. The authors studied how and if these conditions influenced decision-making on science and technology-based issues and discovered that no differences were found between the decisions of the two groups, despite the groups’ disparate views of NOS. Professors and scientists in both groups primarily based their decisions on personal values and norms, with minimal to no consideration of NOS understandings in their decisions. In their conclusions, Bell and Lederman stated that their work brought into question the relationship—if any—of NOS and ethical reasoning. Schwartz and Lederman (2008) also investigated the NOS views of well-established practicing scientists in chemistry, life science, physics, and earth and space science disciplines, whose research varied in experimental, descriptive, and theoretical approaches. Collectively, the research participants had an average of twenty-five years of experience in their research careers. The results from interviews and open-ended surveys revealed that the empirical, inferential, tentative, subjective, and creative aspects of NOS
were held by and relevant to scientists across all of the disciplines and research approaches. Thus, the authors argued that NOS characteristics are not discipline specific, countering previous conclusions made by Ryder and colleagues (1999). Schwartz and Lederman also found that across the science disciplines, the experienced research scientists adhered to NOS views that were neither fully naïve nor fully informed; they found that the participants understandings “were neither all here nor all there—but everywhere” (p. 763). These studies together demonstrate the varying and complex implications of NOS understandings.

Finally, researchers have also examined the relationship between discipline-specific epistemology and scientific epistemology (Samarapungavan et al., 2006). To study how chemistry content expertise and research experience influences views of NOS, the authors interviewed various levels of chemists, ranging from high-school students to practicing research chemists. The study found that the practicing scientists had much more sophisticated NOS views than all other groups, including graduate students, undergraduate researchers, lower division chemistry students, and high-school students. In addition, though the research revealed that students with authentic chemistry research experience held NOS conceptions significantly more mature than those without, there were still limitations in experienced students’ NOS understandings. For example, the chemistry graduate students—in contrast to the research chemists—only understood the pursuit of research questions in the context of that determined by advisors or laboratory directors; these students did not realize the pragmatic or cultural factors that often shape research programs. In addition, the graduate students held negative connotations towards experimental error, rather than recognizing this error as a source of potentially fruitful, new discovery. The authors stated that “even graduate (doctoral) students, who are one step away from becoming independent
researchers, articulated a much more limited range of criteria for knowledge evaluation, focusing primarily on empirical adequacy criteria and methodological standards” (Samarapungavan et al., 2006, p. 487). The authors’ conclusions suggested that despite students’ rigorous training and rich research experience provided by Ph.D. programs, NOS conceptions still may not fully develop.

Though the science education community has given its attention to NOS for the past century, the clear lack of consensus on how to define, teach, and assess NOS suggests that there is still much to be learned about understandings of scientific epistemology. The abundance of research pertaining to NOS demonstrates that all members of the science and engineering communities—the novice high-school student, the graduate research apprentice, and even the expert practitioner—have gaps in their personal epistemologies of science. While most of the previously discussed research focuses on NOS understandings that these practitioners are lacking, it often dismisses the fact that despite these existing gaps, academic scientists and engineers are still able to function successfully as scientific researchers. Rather than continuing on addressing the lack or gaps of NOS understandings, this research will focus on the scientific epistemological understandings that science and engineering academians do possess. As I will present in the following chapter, my overall research questions addressed the development of NOS views, particularly elucidating the formative experiences that contribute to practitioners understandings of scientific epistemology.
CHAPTER III
METHODOLOGY

As previously stated, the overall goal of the research presented in this dissertation is to elucidate and explore understandings of the formative experiences which help develop science and engineering academians’ understandings of scientific knowledge and practice. At the beginning of my graduate work, I decided to focus on the domain of scientific practice related to responsible behavior, uncovering beliefs and understandings of issues related to ethics and RCR. Thus, my initial research centered on questions pertaining to chemistry graduate students’ understandings of the normative and ethical values they encounter in their daily research activities. Following the evaluation of this pilot work, I generated further questions regarding faculty members’ development of understandings of concepts related to scientific epistemology. The evolution of my research questions will thus be presented in this chapter, along with the theoretical frameworks and methodologies that guided me toward achieving my final research goals.

Pilot Study

Guiding Questions

An exploration of students’ understandings of the challenges they face as both student and chemist may help inform innovative avenues in their training toward becoming professional scientists. As mentioned in the previous chapter, though training in scientific ethics and RCR is progressively becoming part of chemistry curricula, there has been little to no substantial research conducted that investigates the actual ethical dilemmas students
believe they face in their everyday research practices. Thus, we decided to explore chemistry graduate students’ understandings of scientific norms and ethical misconduct as related to their daily experiences as students, teaching assistants, and scientific researchers. Our initial studies were therefore guided by the following questions:

- What are chemistry graduate students’ definitions of appropriate and inappropriate conduct in scientific research?
- What particular experiences have shaped these students’ learning of the normative and ethical values related to scientific research?
- How do students make decisions when evaluating and validating their research data?

Since the concepts of scientific norms and ethics are rather abstract, we decided to elicit students’ understandings of these concepts through the lens of their decision-making processes in their daily research activities. We believed students’ processes of validating and evaluating their research—where it was assumed that students make decisions to include or exclude data—may serve as a basis of understanding acceptable and unacceptable behavior in scientific research and would help reveal their practices as well as their conceptions. Since this research is published elsewhere (Verdan, Ingallinera, & Bhattacharyya, 2010), I offer an abridged description to serve as a background for the main study of this dissertation.

**Participants and Setting**

To uncover understandings of these phenomena, we interviewed a group of seven chemistry graduate students from the four traditional disciplines of chemistry: organic, inorganic, physical, and analytical (Table 3.1). The Department of Chemistry from which the students were recruited did not have a division of biochemistry, although three of the students’ research projects focused on chemical biology. The participants included two females and five males; each participant had a few semesters of undergraduate research
experience, no experience in industry, and had completed at least four years of their Ph.D. program. We chose students at this point of their programs since they were finished with graduate school requirements such as courses and comprehensive exams; thus, they were primarily immersed in laboratory research experiences from which they could derive their responses. International students and students within the division of Chemistry Education were not solicited to participate in these studies due to cultural confounders and potential conflicts of interest, respectively. The students who volunteered to participate came from the Department of Chemistry of a large, research-oriented, public university in the southeastern United States.

**Data Collection and Analysis**

Each participant was interviewed once, following a semi-structured interview protocol (Appendix A), with each audio-taped interview lasting 30 to 45 minutes. Questions focused on three major themes: personal information and background, beliefs and understandings of scientific standards within the scientific community, and beliefs and understandings of ethical conduct in the research setting. The interviews were then transcribed verbatim and were evaluated along with interview field notes and post-interview observations. To protect the participants’ confidentiality, each student was given a pseudonym upon data analysis.

<table>
<thead>
<tr>
<th>NAME</th>
<th>GENDER</th>
<th>YEAR</th>
<th>DISCIPLINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeff</td>
<td>Male</td>
<td>6th</td>
<td>Inorganic</td>
</tr>
<tr>
<td>Felicity</td>
<td>Female</td>
<td>5th</td>
<td>Analytical</td>
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<tr>
<td>Sandra</td>
<td>Female</td>
<td>5th</td>
<td>Inorganic</td>
</tr>
<tr>
<td>Daniel</td>
<td>Male</td>
<td>4th</td>
<td>Inorganic</td>
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<tr>
<td>Roger</td>
<td>Male</td>
<td>6th</td>
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<tr>
<td>Gary</td>
<td>Male</td>
<td>4th</td>
<td>Physical</td>
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<tr>
<td>Ray</td>
<td>Male</td>
<td>5th</td>
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The purpose of the pilot study was to reveal a general description of how chemistry graduate students conceptualize scientific norms and ethics in the context of their daily research activities. Given that previous research has not revealed these conceptualizations, we chose constant comparative grounded theory as a fitting analytical methodology. Using this inductive analysis strategy, we used the understandings of a particular group of participants—the chemistry graduate students in this case—to develop a general explanation, *i.e.*, a theory, of an experience (Creswell, 2007). The collected data was then analyzed by two researchers, who independently coded and interpreted the interview transcripts for trends (Strauss & Corbin, 1990). These trends were further grouped into categories, and major assertions and themes describing the overall data were then generated based only on the categories shared by the two researchers.

**Results and Discussion**

Overall, the data from the participants suggested that chemistry graduate students’ conceptualizations of scientific norms and ethical conduct were quite limited, arising from the implicit learning of these concepts in informal interactions and environments, students’ lack of understanding of the nature of science, and the reluctance and absence of opportunity for the students to take ownership of their own research.

With respect to appropriate and inappropriate conduct, the students could articulate their conceptions of scientific misconduct with more ease than their notions of appropriate scientific conduct and normative values. In their definitions of scientific misconduct, all of the participants focused on two aspects: plagiarism and data falsification. Consider the following answers from Felicity and Jeff, regarding their views on the definition of scientific misconduct:
Felicity, 5th-year, analytical: Uh, scientific misconduct. I would probably say plagiarism, umm, plagiarizing of papers. In many different ways people could help you out with data as well. Umm, if not, at least acknowledgement in a paper. Umm, sometimes author but... sometimes you go too far with author. They really have nothing to do with the evaluation of the data, they only gave it to you. So I think that is bad ethic... the only other is, umm, stealing other people’s data. You know, or taking something that wasn’t yours, you know?

Jeff, 6th-year, inorganic: Scientific misconduct? Would be, um, I don’t know. I guess, umm, not reporting something would not necessarily, not necessarily be misconduct. But if, umm, if you specifically found some data that didn’t fit into your... and then you just ignored it or threw it away. That, you know, misconduct. Umm, obviously, misrepresenting your data, just making stuff up, would obviously be a little... you know, good old plagiarism is always good.

Since publicity about ethics more often focuses on misconduct, rather than normative values, this result is not surprising, as demonstrated by the following statement by Daniel, a 4th-year student in the inorganic division:

Uh, on top of that [referring to his definition of plagiarism as misconduct], um, misconduct would be...[long pause]. I can’t think of a type of scientific misconduct, I mean that’s the one that everyone always talks about when they are talking about ethics, um [long pause] falsification, I guess, of data would be another big misconduct...

These responses demonstrate that students have a rather narrow understanding of what constitutes inappropriate conduct in science, as their definitions centered on the typically highlighted definitions of plagiarism and data mishandling. As a consequence of these limited definitions, the graduate students had a more difficult time articulating their notions of normative values and appropriate scientific conduct. Sandra and Daniel, 5th- and 4th-year inorganic students, respectively, made statements similar to that of the other
participants, referring to their definitions of scientific misconduct to construct their views of normative values:

Sandra: Umm, well, I mean, of course it would be the opposite of what I said [referring to her characterization of scientific misconduct], basically, umm, if you work in a cooperative environment, that you stand up and take credit for what you do, but not what somebody else does. So I mean, I think that, you know, the whole point in a scientific, when you're doing scientific research is you're in pursuit of something and I just think it’s very important that you don’t take credit for what’s not yours. So…

Daniel: Uh, good scientific [conduct] would be, umm… proper citations, throughout all your papers that you write, uh, I would say that um, good scientific conduct would be… in the opposite end of the spectrum for plagiarism is to cite obviously, and to not copy, uh, another one was um, falsification, I mean, make sure that your data is right, would be, considered, I mean double to, ya know, triple checking your results, ya know, ensuring that your results are not, ya know, skewed in any way, shape or form. So I would take that that is good scientific conduct.

In addition to using his understanding of misconduct to define his notions of normative values, Daniel’s definition revealed the interesting notion that proper scientific conduct involves accuracy, that one must “make sure that your data is right.” Two other graduate students, Roger and Ray, also demonstrated views of scientific normative values that went beyond the opposite of their previous responses on misconduct:

Roger, 6th-year, organic: Uh, really just, really prescribing, ascribing yourself to, um, to being responsible. To the information that you put out is real, um, that you are not racing just to try and find something. To really honestly believe that the results you are putting out are real and not, and have that without a reason, a doubt at all. And more specifically, um, not publishing results that you have any question of, you know, making sure that the results, you’re the first line of confidence, you know, and making sure you have it in your own research. That really, that responsibility is really what leads to good conduct.
Ray, 5th-year, analytical: Um, I, I guess it would be some more answers, just trying to make sure that your methods are correct. Uh, and if they are scientifically sound, and not, trying to create the answer that you want, or, um, you know, get, get data that fits with a model that you’ve made. No, you should try do your experiments in the correct manner, and then whatever the data turns out to be, you just, that’s what you get. And that’s the way to find out how physical processes actually work. You don’t dictate the way things work, we’re trying to discover how things work.

The students developed these definitions of inappropriate and appropriate scientific conduct in a variety of ways. Daniel and Felicity explained that their understandings of scientific misconduct arose from prior instruction, while Felicity also demonstrated that her teaching assistantship experiences helped inform her views.

Daniel: …And then falsification of data just is one of those things, uh, I think I probably learned it in undergrad probably, and then going through your, just, your—actually beginning lab courses where they’re always telling you to check your numbers three times, you know. Duplicate your results, and there’s reasons for that, so, and they go over the reasons and that’s where I get that from probably.

Felicity: Umm, I guess the plagiarism comes from, you know, from your grade school, you learn about that. Umm, I think I really figured it out, you don’t really understand the breadth of it until you either know someone or you have problems with it. And uh, actually I had a student who, I had a student and I had a friend’s student… they, one person actually had the same exact report. And the other person she plagiarized from the internet… So it wasn’t, you know, I mean it wasn’t our part, we weren’t trying to find it, but we were trying to figure out where they got it from ‘cause we knew we didn’t tell you that. So, I think a lot of it is just, learn to really look at the significance of it when you start to do it.

Felicity’s comment suggests the value of teaching, as it aided in her ethical development and understandings of plagiarism. With the responsibility of monitoring students’ lab reports and homework assignments to combat academic dishonesty, Felicity
believed she was able to see the significance of plagiarism and broad spectrum of actions that constitute it.

Another primarily mechanism through which notions of scientific misconduct and normative values were developed was informal interactions with group members, peers, and professors. This was demonstrated by the explanations of Jeff, Ray, and Daniel:

Jeff: Hearing stories about other grad students… At lunch, we were talking about a guy who would use white out and cover up the, any impurity peaks in his NMR spectra. Right, yeah, it’s usually just informal, sitting around with friends and other grad students. And you know, just hearing stories that… I can’t really remember how, how it comes up in conversation, but, uh, just things of that nature.

Ray: Well, learning by example, as far as good conduct, I’m not sure that I’ve [experienced] a lot of misconduct, thankfully. Um, but just watching post-docs, undergrad students, senior grad students, um, and some common sense as well.

Daniel: Since I’ve been here, you know, I’ve talked to people and friends or even professors, and talked about different things about how citations work or when plagiarism occurs. One thing I think uh, I’ve talked to some friends a lot about was, Wikipedia, you know…

These experiences indicated that the learning of scientific misconduct and normative values was typically occurring in informal or unstructured settings. This has also been found to be the case in other studies with chemistry graduates (Caserio, 2006) and students in the physics (Kirby & Houle, 2004) and biological science (Bird, 2001) communities. These graduate students were developing their understandings of scientific conduct in situations similar to soldiers exchanging war stories (Lave & Wenger, 1991; Knorr-Cetina, 1983, 1999). In these informal exchanges, which have previously been described as a mechanism of passing organizational knowledge from established members to newcomers, the graduate
students were being incorporated into their communities of practice (Brown & Duguid, 1991; Ibert, 2007).

To further elucidate their understandings of acceptable and unacceptable behavior in scientific research, we inquired about students’ processes of validating and evaluating their research. Like their understandings of normative values, all the participants had difficulty articulating how they made claims and conclusions when validating and evaluating their own research data.

Felicity: How do I know that they’re valid? Umm… so you take the data, and of course you have to duplicate the data, when it’s duplicated then you can make sure that you can at least start to understand what it means.

Roger: Um, you know that your results are real when the results you get are close to what you think your hypothesis should be. Um, and also when you can reproduce those results. Um, just because you get a result that’s close to what you think… reproducing those, those numbers, that data, um, really does help out.

Gary, 4th-year, physical: Well, I mean, a lot of the time you really don’t. Umm, you can’t ever say for sure that they’re valid. You can, you can compare them to other results that you feel are valid and you can compare them to results that are not, that you feel are not valid. And just repeat that process over and over again and, you know, say, well I’m confident in these results, I can’t say for sure that they’re valid, but, they’re close enough to these results, so, umm, that’s why we have statistics. You know, I mean, with, with a statistics and error calculations that helps to validate your, uh, conclusions.

These explanations, similar to those given by all the graduate students, showed the belief that validation centers on the reproducibility of results. When asked about how they determined the appropriate number of repetitions, the participants had responses like Jeff:

Uh, I think time is the biggest factor. That you really can’t, you don’t have the time to do the same, the same experiment, you know, four or five or ten times. So, that over the course, over the course of your work you do it two or
three times and it works the same, roughly the same, pretty much every time, I think that’s acceptable enough.

While students recognized the importance of repeating experiments and statistical analysis, they were not able to explain why two or three trials were sufficient for a measurement or whether or not they were simply reproducing the same error. This demonstrated that the participants had a limited understanding of scientific epistemology, i.e. the nature of science, since they could not explain the standards of validation within the scientific community. In contrast, Sandra was the only student who revealed a slightly more sophisticated understanding of how data is validated:

Well, that would be when you can really, in terms of our experiments, you of course want to repeat those experiments. Umm, of course, you know, the whole point of group meeting and, you basically get other scientific input. You know, if they think that you’re doing something wrong or you’re coming—so if everybody basically agrees that what you’re doing is good, you could repeat the experiment on several different occasions, then I would say that you can form a, a conclusion, at that point.

In addition to alluding to reproducibility, Sandra’s notions also acknowledged the social nature of science and importance of input from the scientific community, which in Sandra’s case was the community of her group members.

The final theme emerging from the interviews revealed that student were reluctant or lacked opportunities to take responsibility for the claims and conclusions they made in their own research. This was demonstrated by the participants when describing their experiences with validating their data and assigning credit through authorship in papers.

Jeff: And then obviously when you go to your advisor and show him the data and say, you know, I, you know, from this data I’ve concluded this and he says, you know, that’s, that’s good or you’re way off, try again, so...
Ray: If it’s something that, that you’ve gone through and you’ve repeated at least two or three times, um, and, you know, for me of course I always check with [name of advisor] to make sure that my procedures seem to be correct and that I’m trying to cover all of the bases, um, and he’s good about playing devil’s advocate.

Felicity: I don’t make that call [of assigning credit on publications]. I let my boss make that call. ‘Cause that little star next to his name is the reason he takes all the blame.

These participant responses indicated that they abdicated or transferred the responsibility of validating data and assigning credit to their advisors. This may be due in part to the students’ aforementioned under-developed notions of how scientific claims and conclusions are made. Once again, this highlights the participants’ limited scientific epistemologies and understandings of the nature of science.

In contrast, some participants like Daniel and Sandra expressed the desire to take ownership of their scientific conclusions in published manuscripts. However, they believed that they were not allowed to have this responsibility.

Daniel: Uh, yeah, I think, I mean, obviously the ending [ordering of authorship] will be up to the advisor, I think, I, I think, like, at the very end, regardless if you want to be first author or not, it’s up to your advisor, I mean the paper is going to have his name, he will be the corresponding author, it comes down to him. So he makes the ending choice.

Sandra: I had a paper, which I published, that, umm, there was a collaborator that we had, that worked, in my opinion, he, you know, obtained several measurements and things for us and we published his data. And, I did not do that data. But if I’m first author on that paper, then everyone assumes that I am the one that collected that data and I am the one that should be responsible for if there’s a problem with that data, if that makes sense… And my boss refused to put [the collaborator’s] name on the paper, which I fought against, but what it boils down to is that you don’t have a choice. If you wanna get the paper published you have to listen to what your boss says or you can fight it and not get it published.
These reflections indicated that some graduate students did have interest in taking responsibility over their data and conclusions; however, they believed they were not being given the choice and opportunities to do so.

Emerging Research Questions

The results from this pilot study indicated that students, well into their Ph.D. programs, had difficulty articulating their views of appropriate and inappropriate conduct in science. In elucidating the graduate students’ conceptualizations, the students also believed that they had little first-hand experience in collaborative efforts and assigning authorship, which may have contributed to their limited and naïve understandings of scientific ethics and normative values. Thus, an understanding of these concepts was difficult to reveal because the population we were investigating was not appropriate. However, the understandings of ethics and norms the students possessed revealed their under-developed epistemologies of science, which we believed stemmed from a limited sense of professional identity.

My research then started turning toward investigating the concept of scientific epistemologies. In particular, I was interested in investigating experiences following graduate studies, i.e., experiences as academic researchers, to elucidate “where” and “when” these personal epistemologies of science become more sophisticated. In turn, my primary research question emerged:

To what extent do scientific epistemologies develop for academic scientists and engineers through their engagement in professional practice?

This research question addressed professional practice for a specific reason. As discussed in the previous chapter, the body of research on scientific epistemology often reveals the gaps in students’ and practitioners’ understandings of NOS and focuses on the
effect of pedagogical practice on NOS views. For those who are identified as possessing mature personal epistemologies of science, the literature attributes these developed NOS views to authentic research practice. In turn, my primary research question probed deeper into this attribute, investigating how doing scientific research—\textit{i.e.}, being engaged in professional practice—influences scientific epistemologies. Thus, to elicit professional practice experiences through which science and engineering faculty could reveal their epistemic development, my research was guided by the following questions:

- What are engineering and science faculty members’ current understandings of contributions, collaborations, and credit assignment in scientific research?
- What specific experiences have led to those particular understandings?
- Have those understandings changed over time? If so, how and why?

I chose to uncover conceptualizations of contributions, collaborations, and credit assignment because I believed the interactions of these three phenomena in the context of professional practice could ultimately reveal academic researchers’ personal epistemologies of science. Unlike graduate students, faculty members are required to partake in collaborative efforts in their professional positions as academic researchers. Therefore, I believed they would have authentic experiences in research collaborations. Given the nature of collaborative work, faculty members must explicitly think about credit assignment as they judge who deserves credit when disseminating research. In their discernment of who deserves credit, it is necessary for researchers to consider the contributions of those involved in the collaborative effort. Through this consideration of contributions, faculty members’ scientific epistemologies can implicitly be revealed—their understandings of what constitutes a contribution could reveal what they deem worthy of being scientific knowledge.
Theoretical Frameworks

Because of the exploratory nature of my guiding research questions, it was not possible to generate meaningful hypotheses \textit{a priori}. Therefore, I pursued a qualitative research approach to create a rich and thick description of the development of faculty members’ scientific epistemologies. The use of qualitative strategies requires theoretical frameworks—sets of beliefs, assumptions, and goals about learning and knowledge which help guide the appropriate questions, data collection, and data analysis of research (Bodner & Orgill, 2007). In the following sections I will describe the various epistemological and methodological frameworks which guided the stages of this research. In my presentation of epistemological frameworks, I will discuss a set of theories describing how people learn. Additionally, my presentation of methodological frameworks will help to inform my chosen data collection and analysis procedures.

\textit{Epistemological Frameworks}

\textit{Constructivism}

In contrast to behaviorist theories of learning, which assume that abstract knowledge is transferred wholly and directly from the mind of the teacher to the mind of the student, constructivism is a learning theory which claims that “knowledge is constructed in the mind of the learner” (Bodner, 1986, p. 873). As described by Driscoll (2005), constructivism posits that learning is an active process in which knowledge is generated from the accumulation of an individual’s life experiences.

These tenets of constructivist theory have interesting implications. First, each individual builds his or her understandings of phenomena from the unique interactions with his or her surrounding world. Therefore, one’s knowledge is constantly changing and being
modified with his or her accumulation of experiences. In addition, since each individual has distinct experiences with the world, various constructs of knowledge are allowed to exist. Thus, there are no absolutes of “true” and “false” in knowledge; the construction that is the most valid is that which allows an individual to “cope” with the world (von Glasersfeld, 1989).

Constructivism also comes in various “forms” that differ on where the meaning-making process is focused (Geelan, 1997). These forms include personal and radical constructivism, which focus on an individual’s own building of knowledge from his or her experiences (Bodner, 1986; von Glasersfeld, 1995), and social constructivism, which focuses on the building of knowledge from social interactions that develop shared understandings among a group (Bodner, Klobuchar, & Geelan, 2001). Though these forms of constructivism could be considered distinct and separate, Bodner (2007) states:

It is tempting to think about radical constructivism and social constructivism as opposite ends of a continuum. At one end, learners construct knowledge in isolation, based on their experiences of the world in which they live. At the other end, learning is embedded in social and cultural factors. Most situations in which learning occurs, however, fall somewhere between these two extremes. Learning is a complex process that occurs within a social context as the social constructivists point out, but it is ultimately the individual who does the learning, as the radical constructivists would argue (p. 13).

As described by Patton (2002), a research study guided by constructivist principles examines the multiple realities constructed by individuals and the implications of those constructions on the individual and his or her surroundings. Thus, based on all of these constructivist principles, I believed that the faculty members’ understandings of contributions, collaborations, and credit assignment would be derived from their experiences in research, particularly as they interact with their science and engineering communities.
Though the participants may have shared meanings of some phenomena, the unique experience of each faculty member contributes to his or her individual constructions of knowledge. It was for this reason that one of my guiding research questions focused on participants’ description of their practices and lived experiences as researchers.

**Situated Cognition and Communities of Practice**

Closely related to the principles of social constructivism mentioned in the previous section, situated cognition is a theory concerned with the social and cultural nature of learning. Situated cognition challenges the traditional pedagogical idea that successful learning can occur in a classroom, through discrete and decontextualized activity. Situated cognition theory—which is also sometimes referred to as situated learning—posits that “knowledge exists not as a separate entity in the mind of an individual, but that knowledge is generated as an individual interacts with his or her environment (context) to achieve a goal” (Orgill, 2007a, p. 187). In other words, learning is located, *i.e.*, situated in one’s experience and engagement with the people and practices of his or her surroundings.

Though a wide range of theoretical perspectives—such as anthropology, critical theory, and the social formation theories of Bruner (1960) and Vygostsky (1978)—acknowledge the relationship between an individual and the environment with respect to its influence on learning, the hallmark of situated cognition theory is its focus on context and the learning process (Brown, Collins, & Duguid, 1989). Knowledge is not only constructed from one’s interactions with the tangible objects of an experience, but is also generated from a learner’s observations of and interactions with the people and culture of that experience. This culture includes the social, ethical, normative, and historical beliefs that guide the behaviors of those people. Moreover, in parallel with constructivist learning theory, situated
cognition also recognizes that knowledge is under constant modification, since every interaction an individual has within a context will influence his or her knowledge.

The culture and context in which one constructs knowledge is also known as a community of practice (Lave & Wenger, 1991). As described by Wenger (2000), a community of practice is a group of individuals with common concerns and beliefs, constantly interacting and engaging in the learning process to deepen their knowledge and expertise. Within these communities, members are mutually engaged in relationships and behavioral norms that bind the community together; have a joint enterprise that is continually negotiated amongst the members to define the goals and pursuits of the community; and use a shared repertoire of communal resources such as language, practices, protocols, and tangible artifacts (Wenger, 1998). Therefore, one can consider the various disciplines of science and engineering—and the science and engineering enterprise as a whole—as both individual and overlapping communities of practice.

As indicated by my guiding research questions, the science and engineering enterprise as a whole is the community of practice that I have chosen to investigate. Moreover, my choice to focus on the culture of academia, not industry, further narrowed down this community of scientists and engineers, allowing for a richer and thicker description of the scientific epistemic development of this particular group. Situated cognition theory and communities of practice were appropriate theoretical frameworks for this research because the phenomena I was investigating—scientists’ and engineers’ conceptualizations of contributions, collaborations, and credit assignment—were inherently influenced by and embedded in social interactions.
Synthesis of Epistemological Frameworks

On the surface, the theories of constructivism and situated cognition may seem incommensurable. While constructivism posits that knowledge construction occurs strictly within the mind of the learner, situated cognition suggests that knowledge is generated outside of the learner, from social and contextualized activity. However, constructivism and situated cognition can indeed be integrated. To do this, one must consider situated cognition as a perspective of learning rather than as an epistemology or model of learning (Carr, Jonassen, Litzinger, & Marra, 1998). One must recognize situated cognition theory as offering the circumstances under which learning occurs (Cobb, 1994). Within the situation or circumstance of situated cognition, constructivism then provides an explanation of the process of how an individual learns. In other words, situated cognition describes the authentic, contextual activity for learning and constructivism explains how the individual is active within the process of learning. Thus, an individual constructs knowledge by active engagement in an authentic, situated activity.

Methodological Frameworks

Phenomenography

Since the primary aim of this dissertation was to explore academic scientists’ and engineers’ own experiences and understandings of concepts that would reveal the development of their scientific epistemologies, I chose phenomenography as a methodological lens. Phenomenography, as defined by Marton (1994) is “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” (p. 4424). In addition, phenomenography is described as a second-order
approach, not actually examining the phenomenon itself, but investigating how individuals conceptualize said phenomenon (Orgill, 2007b).

Due to the somewhat abstract nature of the concepts I wanted the participants to describe, interviews guided by a phenomenographical framework assisted in uncovering faculty members’ understandings that were perhaps implicit or subconscious. Through the interview process, Marton (1994) explains:

The experiences and understandings are jointly constituted by interviewer and interviewee. These experiences and understandings are neither there prior to the interview, ready to be “read off”, nor are they only situational social constructions. They are aspects of the subject's awareness that change from being unreflected to being reflected (p. 4427).

Therefore, both myself as the interviewing researcher and the faculty member participants worked together to arrive at a mutual understanding of the meaning of their experiences.

Based on these principles guiding phenomenography, this research was not trying to understand the absolute essence and meaning of contributions, collaborations, and credit assignment; rather, it elucidated how the various faculty participants experienced and conceptualized these phenomena. This distinction acknowledges that there would be differences in the participants’ experiences and their conceptualizations. Moreover, given the constructivist assumption that these participants learned these concepts from their own unique experiences, phenomenography allowed for the recognition and revelation of multiple understandings of these concepts. Thus, phenomenography was an appropriate methodological framework, fitting nicely with the constructivist framework and research questions that guided this investigation, as it allowed the research to focus on the
participants’ experiences and understandings of the phenomena of contributions, collaborations, and credit assignment.

*Grounded Theory*

With my exploratory research questions and the theoretical frameworks that guided this study, I was able to generate a rich set of data, which was used to reveal a general description of science and engineering faculty members’ understandings of concepts related to the development of their scientific epistemologies. This was accomplished by evaluating all of the collected data with constant comparative grounded theory analysis. Established by Glaser and Strauss (1967) in the discipline of sociology, this systematic method helps reveal relationships amongst concepts in the data and uses these relationships to develop a theory directly grounded in data. Creswell (2007) claims that this inductive analytical strategy “generates a general explanation (a theory) of a process, action, or interaction shaped by the views of a large number of participants” (p. 63).

The process of generating a theory is described by Glaser and Strauss (1967). First, the researcher must establish a phenomenon of interest and identify concepts, principles, and features of the phenomenon. Based on the researcher’s initial understanding of the phenomenon, he or she purposefully makes decisions regarding the collection of data. Upon initial data collection, the researcher immediately analyzes the data and identifies preliminary categories through open coding (Strauss & Corbin, 1998). In turn, the researcher uses these preliminary categories and collects more data through theoretical sampling, choosing data sources “on the basis of their potential manifestation or representation of important theoretical constructs” (Patton, 2002, pg. 238). The researcher then compares the new data to the preliminary categories and, if necessary, modifies the categories appropriately. This
data collection continues until the modification of categories is no longer needed, thus reaching theoretical saturation (Strauss & Corbin, 1998). As described by Creswell (2007), “this process of taking information from data collection and comparing it to emerging categories is called the constant comparative method of data analysis” (p. 64). Finally, upon discovering the relationships of the categories generated from all the data, the researcher develops an emerging theory.

Relating these grounded theory principles to my guiding research questions, the development of scientific epistemologies was my phenomenon of interest and contributions, collaborations, and credit assignment were the avenues by which I chose to investigate the phenomenon. Based on evidence from my pilot study—demonstrating that graduate students do not possess sufficient experiences to conceptualize these phenomena—I purposefully turned towards the perspectives and experiences of faculty members within various departments of science and engineering to elucidate understandings of these concepts.

METHODS

Participants and Setting

Fifteen individuals comprising a diverse group of scientists and engineers in academia were asked to partake in this research (Table 3.2). These individuals were recruited from various departments of science (biology, computer science, material science, mathematics, and physics) and engineering (biological, environmental, industrial, and mechanical engineering) in a research-oriented, publicly-funded university in the southeastern United States. Faculty members from the Department of Chemistry were not
solicited to participate in these studies due to potential conflicts of interest. The initial set of participants was recruited from the College of Engineering and Science, those identified as female junior faculty members. As themes emerged from the initial data set, male junior faculty members and then female and male tenured faculty members were solicited to participate in the research. Of all those who agreed to participate, there were eight females and seven males. The participants varied in their research experience prior to their faculty positions; some had work experience in industry, some had a few years of post-doctoral experience, and some went directly from their graduate programs to their faculty position. Eleven of the fifteen participants were junior, non-tenured faculty members, having six or
less years of experience in their positions. The remaining four participants held tenured faculty positions, three of them having approximately twenty years of academic research experience.

The faculty members recruited for this research comprised a purposeful sample (Patton, 2002). The majority of participants were junior, non-tenured faculty members who were still transitioning into their careers as academic researchers. Since the guiding questions of this study attempted to elucidate conceptualizations of contributions, collaborations, and credit assignment—conceptualizations which were revealed to be limited for graduate students—I believed that junior faculty members were at a point in their professional development where their understandings of these concepts were more explicitly considered in the context of their research practice. In addition, these individuals were still relatively close to their graduate or post-doctoral experiences, so they could more easily describe any change in understandings of these phenomena as they transitioned into their academic careers. Thus, junior faculty members would provide information-rich cases, with relevant and current experiences from which they could derive their responses.

Given the constant comparative grounded theory methodology of this research, I also included a few tenured faculty members in this study, as their presence was to help provide and ensure saturation of the emerging categories (Strauss & Corbin, 1998). However, since the faculty members were participating solely on a volunteer basis, it must be noted that I was unable to recruit full professors. Therefore, the categories and themes that emerged from the data may potentially be limited from the lack of full professors’ perspectives.
Data Collection

Each faculty member volunteer was asked to participate in a single interview lasting 45 to 60 minutes. The interviews were based on a semi-structured interview protocol (Figure 3.1), focusing on the participants’ general background and beliefs and perceptions of what constitutes a contribution in science, the nature of collaborations in scientific research, and assigning credit for contributions and collaborations during research. The benefits of using a

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**Background**
1. In what year of your faculty position are you currently?
2. Before coming to this university, did you work in any other faculty or industry positions? If so, can you please explain what you did and for how long?
3. Prior to coming to this university, what types of experiences did you have with scientific research? How long did each of those last?
4. Why did you choose to pursue a Ph.D. degree? What do you think is the purpose of a Ph.D. degree?

**Scientific Contribution**
1. Can you please tell me your understanding of what constitutes contribution in science?
2. What experiences led you to develop your current understanding of this definition of scientific contribution?
3. Before these experiences you have just discussed, what were your early understandings of what constitutes scientific contribution?
4. Do you believe that your ideas about what constitutes scientific contribution have changed over time? If so, how have they changed? Why do you think they changed?
5. Based on your definition of scientific contribution, how do you think that you have contributed to science?
6. How do you choose your research ideas?

**Scientific Collaboration**
1. Can you please tell me your understanding of what constitutes collaboration in scientific research?
2. What experiences led you to develop your current understanding of scientific collaboration?
3. Are you currently involved in any collaborations? What is the nature of these collaborations?
4. Before these experiences you have just discussed, what were your early understandings of what constitutes a collaboration?
5. Have your ideas about what constitutes collaboration changed over time? If so, how have they changed? Why do you think they changed?

**Assigning Credit to Contributions and Credit in Collaborations**
1. Please tell me your understanding of how credit is given for scientific contributions. How did you come to this understanding?
2. How do you feel about the way credit is given in your field of scientific research? Do you have any personal conflicts with the manner in which credit is assigned?
3. What is your understanding of how credit is given for scientific collaborations? How did you come to this understanding?
4. How do you feel about the way credit is given in collaborative efforts? Do you have any conflicts with how credit is given in collaborative work in science?

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**Figure 3.1** The semi-structured interview protocol
A semi-structured interview format gave the participants the freedom to express their understandings in their own terms and allowed me to ask follow-up questions so that they could elaborate or clarify a previous response, which also provided opportunities for identifying new ways of seeing and understanding the participants’ conceptualizations of their experiences (Bernard, 1988). I was the only investigator who conducted the interviews, which were recorded with an audiotape recorder visible to the research participant. During the interviews salient observations were noted, with my writing implements visible to the participants. If necessary, after the initial data analysis of the primary data collection session, follow-up, member-checking email communication helped clarify any ambiguous statements given by the participants (Creswell, 2007). Following the transcribing of interviews, the data were analyzed using constant comparative grounded theory analysis.

Data Analysis

All interview transcripts and accompanying data sources, such as salient observations and member-checking emails, were first analyzed for trends through open coding (Strauss & Corbin, 1998), where each trend was given a unique code. From this open coding,
approximately fifteen unique codes were generated. These codes were then further grouped into three major categories through axial coding (Strauss & Corbin, 1998), where relationships between the fifteen codes were established and elaborated. Major assertions and themes describing the overall data and the main categories were then generated, from which an overall theory emerged (Figure 3.2).

Methodological Considerations

To protect the identity of the participants, a number of precautions were utilized when collecting the data. First, during the recruitment process, I requested that individuals interested in participating in the study contact me privately through email, allowing for the absence of other individuals outside of the study. The recruitment script and institutional review board (IRB) informed consent forms (Appendix B), explicitly stated that refusal to participate in the research would in no way jeopardize a participant’s standing in his or her department or at the institution. Those who agreed to participate then scheduled a primary data collection session, at the beginning of which I told them about the minimal psychological and social risks expected for the research. I also told the participants that they could terminate their interview at any time, for any reason. Additionally, I made it clear that they were not being tested or judged in any way; rather it was I, the researcher, who was there to learn about their views on scientific contributions, collaborations, and credit assignment. Based on my prior interview experiences, these techniques were found to be highly effective in assuaging participants’ discomfort or concerns.

Once the interviews were conducted, I was the only researcher with access to the raw data: recorded audiotapes, electronic documents of the interview transcriptions, interview notes of salient observations, and email correspondance with the participants. All
of this data, in printed form, was stored in a locked filing cabinet in my office and no one else had access to this raw data. To protect the confidentiality of the faculty members, each participant was given a pseudonym which was applied immediately to the raw data for that participant including audiotapes, transcripts, and any other written material; no raw data contained a participant’s real name.

Role of Researcher and Researcher Bias

As a graduate student with a disciplinary focus in chemistry education, my role as researcher was that of a participant observer (Patton, 2002). Being a graduate student in a scientific discipline gave me a background that I shared and through which I could relate—i.e., participate—with the faculty members. In addition, given the phenomenographical framework guiding this research, I participated in the interviews, by engaging the interviewees in their meaning-making processes. My participation while collecting data was in uncovering the faculty members’ personal understandings; as Geertz (1973) describes, “our data are really our own constructions of other people’s constructions of what they and their compatriots are up to” (p. 9). Additionally, I was also an outsider—i.e., observer—in this research, attempting to gain an inside understanding of the participants’ experiences as faculty members.

My standing as a chemistry graduate student, with a great interest in pursuing a career in academia, also contributed to researcher bias. Though this research sought to better understand the faculty participants, I had my own ideas—and perhaps even misconceptions—of what academic life is like. Thus, I had to carefully avoid superimposing my perceptions into the data. Another potential drawback of my researcher role was the implicit power-dynamic present between me and my interview participants. The faculty
members acknowledged my researcher role, but they also recognized that I was a graduate student. Though all the faculty members appeared open and honest during the interviews, some may not have been completely truthful in their responses because of the (potentially) ethically sensitive nature of some of my interview questions. Moreover, the integrity of participants’ responses could perhaps be affected by modification in their statements to match what they believed I was seeking as the researcher.

I took a few measures to counter these biases. First, to prevent myself from prescribing my own views, opinions, or expectations into the data, I acknowledged my own subjectivities by writing my personal reflections in an electronic notebook, physically separate from the recordings of my data coding and analysis (Appendix C). By writing these reflections, I heightened my awareness of my own biases and was therefore better able to detach my perceptions from the data. Second, during the entire recruitment and interview process I ensured that I established transparency, trust, and rapport with the faculty members. At all stages of interaction with the participants, from recruitment to interview to post-interview correspondence, I assured them that I would indeed protect all of their statements and reflections and keep all of their data strictly confidential. Finally, to assuage participants’ potential modification of statements to match my expectations, I clearly stated prior to each interview that there were no “right” or “wrong” answers to the interview questions; I told my interviewees that the purpose of my research was to learn about their own views and experiences.

Validity

As with any qualitative study, there are concerns with the validity of the data. I took several steps to address these concerns. First, the development of all conclusions and the
emerging theory was grounded in the data (Patton, 2002). Second, any ambiguous responses given by the faculty participants were followed up by questions during the interview or member-checking emails after the interview to ensure my understandings of their statements correctly reflected their beliefs. In addition, to ensure that the participants’ conceptualizations indeed related to scientific epistemology, I made certain that their views were consistent with the relevant characteristics of nature of science already established in the literature. Finally, the emerging themes from the data were based not on the perceptions of a single individual, but rather on the notions of the entire group of faculty members.

Limitations

As with any research study, there are limitations, though the methodological frameworks chosen to guide this study were carefully chosen. One limitation, for example, is this work’s reliance on faculty members’ recollections of prior experiences, recollections which can change over time. To counter this, I carefully reviewed each participant’s interview to certify that his or her responses were consistent throughout the entire interview. In addition, as previously mentioned, no full professors participated in this study due to the volunteer basis of recruitment. However, future research can perhaps reveal the views of this group of faculty, which can then be compared with the theory that emerged from this study, thus adding to the trustworthiness and accuracy of my conclusions.
CHAPTER IV

RESULTS

In this chapter, I present the faculty members’ interview responses that reflect their conceptions of scientific contributions, collaborations, and credit assignment. I will first introduce their understandings of scientific contributions, starting with their views prior to their faculty positions, which will be followed by their current views as faculty members. I will then present their explanations of why their views changed. The participants’ understandings of collaboration and credit assignment will be presented in a similar manner.

My findings are supported by verbatim quotes taken from the participant interviews, which have been unaltered with regard to grammar and/or syntax. However, any word or phrase that may compromise the confidentiality of a participant has been removed. In addition, square brackets have been included to provide annotations or a necessary context to a comment. When dialogue is shown, participants’ pseudonyms are given along with the interviewer’s words, indicated with an “I.”

Conceptions of Scientific Contributions

Early Notions of Contributions

Prior to or very early in their graduate studies, participants remembered having distinct views of what constituted a scientific contribution. In their recollections, most participants believed that they had a very limited, if any, understanding of what constitutes a scientific contribution. When asked to describe their early conceptions of this phenomena
some participants—like Angela, Phyllis, and Ryan—claimed that they were unconcerned with or unaware of the meaning or concept of scientific contributions.

Angela, 10th-year scientist: I was not necessarily concerned with this, okay? So, to me things were pretty straightforward, right? You work with someone, at the end of the day your name appears on a paper…

Phyllis, 6th-year scientist: Did I even think about it? [Laughs] You know, I don’t think I ever thought about it. It wasn’t until I got later into grad school where we started working on, you know, really new things that people hadn’t done before that you start thinking about that, or at least that I did.

Ryan, 5th-year engineer: Yeah, that’s a good question, I don’t know because I think it’s… probably not very, not very clear to be honest. I don’t know that I cared that much. That, it, it was just, uh, there were some things that people were finding out and, umm… I didn’t have any understanding that there was a method to go about finding that stuff out… People were just making discoveries, you know, serendipitously.

Phyllis’ and Ryan’s early definitions of scientific contributions—which involved “new things” and “making discoveries”—are seemingly general and vague. Helene and David also admitted that their notions were limited, claiming that their early definitions of scientific contributions involved some type of novel finding. Both of them attributed their limited understanding to a lack of exposure to research experience, particularly to navigating the literature of the discipline.

Helene, 18th-year engineer: I would have to say [my conceptions] were, somewhat limited… umm, I grew up in a household, my dad was, umm, a chemical engineer and he worked in a pilot plant and was always in research and development, so I had a sense of invention and the idea that you needed to nurture some ideas… And then I worked on independent study with a geochemist and that really, I think that independent study opened my eyes to how science worked, opened a pathway into the literature to see connections and that sort of thing.

David, 5th-year scientist: I didn’t have the ability to determine whether something was a contribution. So it was a more of a theoretical
understanding of, yes, you do something new. But if you had started [in graduate school] anything you do might be new because you haven’t looked in the literature enough.

In a similar vein, Oscar—a 5th-year engineer—expressed that in his early definition, scientific contributions were novel discoveries. This understanding also included the notion that these discoveries had altruistic and groundbreaking characteristics. He contrasted this definition with his current view of contributions, which included “everyday… incremental results.”

I guess [my earlier understandings were] more, umm, [long pause]… in line with, you know, what way people think of scientific contribution, that you know, something they find in the science section of the New York Times or some, you know, umm, a lot more, uh, groundbreaking, earth-shattering than, you know, everyday, you know, a little bit of incremental results, that you know, we find in a laboratory… so, yeah, anything to do with, uh, umm, helping people, you know, make their life a little better, or you know, make their car run more efficiently, or whatever.

In addition, Cecilia, a 4th-year engineer, expressed that as a graduate student she believed that spending time on a project was an indicator of making a contribution:

I hadn’t really thought about [contribution] as being original research. You know, I thought anything could be scientific contribution… The idea—before to me everything, of course you spend so much time on it so it must be a contribution, you know, as a student that’s what I thought.

Taken together, these results indicate that most participants’ early understandings of scientific contributions were often limited to discoveries on a grand-scale. They admitted that their understandings were quite vague since they either were unconcerned with or unaware of the notion of scientific contribution or since they had little exposure to the content knowledge and the research practices of their disciplines, such as working in laboratories or navigating the literature.
Current Notions of Contributions

When the faculty members were questioned about their current understandings of scientific contributions, it was clear that their understandings of scientific contributions had become more definitive. Though participants continued to define scientific contributions as “something new”, they added concrete examples of contributions. Their examples demonstrated their beliefs that contributions could range from solving problems in a novel way or adding more data to the established body of knowledge of their disciplines.

Cecilia, 4th-year engineer: I think to me it means, umm, not just taking something that somebody else has already come up with and then, applying it, but actually coming up with something new, maybe a new way to solve a problem.

Phyllis, 6th-year scientist: Uh, it may be a new idea. It may be a new theorem that can’t be applied yet, but maybe sometime in the future, umm, essentially anything new or different, a new way to apply something, a different way of looking at things… any of those are a contribution.

Ryan, 5th-year engineer: That, I think it’s filling in one of those holes that, that um… coming up with uh, an explanation of why something is happening or somebody had not been able to explain that before. Uh, or identifying, uh, a new need or, or a new problem that needs to be solved, or no one’s even looked at it before and answering the questions that go along with that.

These quotes demonstrate understandings similar to early notions, in that a contribution must be work that has never before been investigated with respect to what knowledge exists in participants’ proper disciplines. However, the participants identified specific ways of contributing, such as finding new approaches to solving a problem, applying ideas to a new context, or identifying new problems to investigate. Gabe, a 3rd-year scientist, also identified the creation of something new as a specific example of a contribution.
Gabe: I think there’s different levels of contributions. I see a lot of people that, uh, you know, put another brick in the wall type of contributions, like okay, we did this measurement, this measurement, we’ll do the next measurement. Which is really, good, I mean that’s, that, we need that. Umm, umm, but then I like the ideas of like, uh… like, I’m always, I’m always of the mind set, this is maybe my synthetic background is, “Let’s go make something new,” you know? Or, I measured something new, so it’s not been seen before. And so I think it’s the newness of it… So yeah scientific, I guess the novelty of creating something or discovering something new…

I: And when you say “new”, like how, how new is “new”?

Gabe: Something that’s never been reported before.

Gabe’s understandings of contributions reflect the interesting notion that there are “different levels of contributions.” He identified that there are seemingly simple “another brick in the wall” contributions, which he contrasted with new contributions that have “not been seen before.” The view that there are different types of contributions was also reflected by Oscar, a 5th-year engineer, when he was asked about his current conceptions of what constitutes a contribution.

Oscar: I guess… again, umm, advance knowledge or find out something that’s new that was not known before, I think that’s a contribution, you know, whether that be a student—a big business to make money or a cure for cancer, you know, that’s I guess a bigger picture thing. But you know… a new piece of data, or you know, uh initial, whatever, if that, uh, advances knowledge in a specific, you know, particular field, I think, yeah, that is a contribution.

I: So you’re saying, you said “something that’s new”, so how new is “new”?

Oscar: If it’s not done before, it hasn’t been done before.

Oscar also identified various degrees of contribution, describing an initial “new piece of data” possibly found by a student and contrasting it with “bigger picture” findings such as a cure for cancer. Additionally, like all the other participants, Oscar continued to highlight the notion that a contribution must be something that has never before been done.
In addition to the notion that contributions must be novel, some participants discussed the role of their communities of practice in their understandings of contributions. Karen, a 4th-year scientist, revealed her view that in order for a contribution to be made, it must be presented to and recognized by a community of peers.

For my understanding [a contribution] is that, it needs to be, umm, so first it needs to be something hasn’t been done before, uh, it needs to be interesting in the sense that it advances some area… that is recognized and appreciated as meaningful and even if it’s just an incremental step it leads towards answering some bigger, umm, more important questions.

Moreover, the following quote by Holly, a 3rd-year engineer, emphasizes the point that in addition to being presented to the greater scientific community, contributions should also have a positive effect on said community.

… As a definition, like having um, contributing something to the general knowledge base that everybody uses, umm, and I think that can happen through a lot of different things, umm—and it doesn’t have to be big. I mean, I’d say like in terms of like a, so more obviously like journal paper or a, umm, conference, umm, presentations are usually some, something of a scientific contribution to the field, at, you know, they’re, uh—but I think there’s some contributions that maybe don’t get published that are still contributions, like in, when you do something and the experiment doesn’t work and there’s a reason for it not working a lot of times people don’t actually publish that, however, umm, it does get, you know, I’ll have my students present it at some conference, or at even at a, you know, local meetings because it does actually end up, you know… people don’t have to repeat the same things over and over again.

In Holly’s perspective, presenting data from an unsuccessful experiment at a local conference constitutes a contribution because it will benefit peers who will “not have to repeat the same things over and over again.” This beneficial characteristic was also indicated in the previous quotes by Karen and Oscar, in their notions that contributions must
“advance” and move a field forward. Helene, an 18th-year engineer, also shared this understanding and elaborated on the nature of advancement.

Helene: It’s a contribution to the fundamental understanding or advancement of, umm, a particular scientific field, I guess, I would say. Some, some kind of tangible, in the sense that it can be used as another link in the chain or another building block, umm, that either, I or my research group or others beyond our research group can make use of to continue to inch our way up to advancement or, or have some kind of transformative effect on, umm, the way we do science.

I: So how, when you talk about an “advancement”, how much is an advancement?

Helene: [Pauses] I think that’s really difficult to quantify. Uh, I know I worked for awhile as a, umm, a program manager for the National Science Foundation and the mantra there is that it has to be transformative. Well, not everything that we do in our laboratories or in front of our computers is transformative in the sense that it makes a big splash and a gigantic leap. Umm, there, sometimes if there’s—a small insight can actually trigger, uh, a tremendous sea change, which might not at the time be recognized as transformative.

I: So that small insight can be a contribution?

Helene: Yes, yes. Yeah, as long, in my opinion, as long as it is communicated, okay?

These faculty members’ current definitions of a scientific contribution focused on research that has not been reported previously, emphasizing the importance of a contribution being acknowledged as meaningful, beneficial, or useful to the scientific community.

All of the participants’ understandings presented above indicate that there are two primary ways in which contributions could be made. In the first way, contributions can be additive, meaning that new knowledge is added to the discipline. These are the contributions that Gabe and Karen describe, respectively, as putting “another brick in the wall” or as “an incremental step towards answering bigger questions.” The participants included novel ways
of approaching a problem or making incremental measurements that fill in an existing gap of knowledge as examples of these types of contributions. In the second way, contributions can be transformative, where groundbreaking discoveries lead to new knowledge that actually changes the way people practice and think about a science or engineering discipline. These are the contributions that Oscar claimed are “earth-shattering,” the contributions that Helene described as being able to “trigger a tremendous sea change.”

In addition to these additive and transformative definitions of scientific contributions—often presented through the means of conference presentations or publications—another notion of contribution held by faculty members was the training and shaping of students. When asked how they believed they have made a contribution to science, participants replied in the following ways:

Helene, 18th-year engineer: I think through my publication record, umm, through my, umm, network, my professional network, umm, at, my attendance at meetings. Um, plus through my students and having thirty students out there, doing things… So, umm, a student that works in my laboratory who then later moves into industry or consulting or, the, umm, at universities can take that insight with them and then spread it to other students, other colleagues, other, other people in that industry. So, I, I think that’s a very a valid way of, of making a contribution.

Holly, 3rd-year engineer: I think I’ve been a mentor to a lot of people, so, uh, I hope, I feel like I’ve like contributed at least in the development of future scientists? Umm, even I think in grad school, I had undergrad, um, like research, uh students that would work with me.

Karen, 4th-year scientist: Even if I’m not going to change the world, maybe I’m making some incremental contributions, plus I work with students and maybe they’ll be even smarter and perhaps they, just an extent, umm, they will make, uh, something more significant or all of us collective, umm, our lives will be meaningful at the end.
Michael, 5th-year scientist: Um, so, I mean, I’ve—basically through the research that I’ve, that I’ve published I think, umm, and also, uh, I view it as very important to kind of, in my mentoring of other students, kind of teaching them the process by which research, in a successful research, takes part, umm, I think… I mean so part of the contribution is just the, the papers that I’ve published, that’s, that’s one thing. Um, but I think, uh, a lot of it is also teaching other people how to successfully do research, umm, as well.

Oscar, 5th-year engineer: What kind of contribution have I made? Umm, well for one thing, I guess, um, you know, I’ve had a bunch of papers that got published, and um, people reference those papers, so, you know, I think they learned something out of what I have done. I’ve trained, um, several masters students that went through my lab, but became all something else and then, I think that is also a contribution to science…

These understandings demonstrate that the participants believed contributions were not strictly limited to the addition of knowledge or transforming the way people think about a discipline through the publication of papers or presentation of results at a conference. Some participants believed that the direct training and transformation of their students into researchers also constituted a contribution.

Explanations for the Change in Notions of Contributions

The retrospective accounts of participants’ understandings of scientific contributions prior to or early in graduate school in comparison to their understandings as faculty members demonstrated a definite change in their conceptions. Though the idea that contributions must be novel persisted from their early understandings, the participants began to recognize the extent to which they could make contributions, with an emphasis on dissemination. The reason for this change was primarily through active research experience, as described by Oscar, a 5th-year engineer, in his following analogy:
Oscar: The reality of it, you know, what’s behind a curtain, yeah. So I mean, I’m, I’m a practitioner of science. Then, umm, you know… you understand the process and you understand what the contributions are, you know, if you go to, umm, if you go to a restaurant and you, you know, are served food, you know, a beautiful dish, you don’t know who made—how many people behind in the kitchen that put that together, okay? as a recipient. But if you are a cook, who works in the kitchen, then you understand that there are different people working in different parts of that dish and each one makes a small contribution, I don’t know, someone maybe just, peeling a potato, but that has to be done, also to put together your French fries, okay? So, from the recipient, may not understand, but once you’re practicing in the kitchen, you understand. That’s what I think is the, change that happen. No one really tells you, you know… I mean that’s how, that’s how people learn, you know, I mean you can read the same thing I said in a newspaper or in a book and maybe you can understand too, but, other people have to experience the one thing…

I: And when did you start identifying yourself as a practitioner of science?

Oscar: Uh… maybe after graduating…

I: Graduating from?

Oscar: From Ph.D.

I: Okay—

Oscar: And you know, going into conferences and presenting… well, I mean, as a graduate student, I presented work too, but, you know, I felt more like I was a student, you know, reporting part of my Ph.D. thesis, you know.

Oscar described that this “behind-a-curtain” research experience made his notions of scientific contributions more concrete. Interestingly, though he participated in research and presenting at research conferences as a graduate student, he did not identify himself as a practitioner of science even at that advanced point of his training.

Another reason for the change in understandings of scientific contributions was the exposure to work of other scientists and engineers through active participation within the science and engineering communities of practice. When participants realized that their
research connected and related to research being done by colleagues in other disciplines or institutions, they began to understand the relevance of their contributions.

Phyllis, 6th-year scientist: Well, when you start as a graduate student you start doing essentially proofs and when you start, you know, you work in this one little tiny area and you think, you know, contribution means something maybe new added to that area. But when you start to get further and further out of grad school you start seeing more and more connections to other kinds of mathematics, other kinds of biology, computer science, and you can start putting those things together so your definition of contribution gets broader based on the area that you work in.

Karen, 4th-year scientist: I thought I would be content with just working on a problem that nobody has worked on and coming up with results and let somebody else figure out if it, if that’s useful and it has certainly happened in the past. I have worked on some very big algebra problem and, years and years later it became important in physics… So I think in that sense my, umm, my definition, my understanding changed umm, the idea of usefulness has become stronger for me and I’m sure it will keep changing.

Jan, 20th-year scientist: I guess I’m realizing that my work has, umm, gone from being, sort of very specific, to institutionally specific, like looking at, okay our programs for example. What’s happening at [name of university] and all our students succeeding here… to, uhh, a much broader view, so looking at Research One universities and what’s happening at those, or looking at, you know, even beyond that, looking at comparisons between community college sector and four-year college, so I’m, I guess my work has really broadened, I’ve recognized that, umm, you know, you got to sort of take a big picture view to, to get information that’s going to be applicable and of interest to a broader group of people…

Relating to their beliefs that contributions should impact others in the scientific community, participants’ expressed that their notions of scientific contributions changed because of the acknowledgement of other scientists and engineers, particularly those outside of their disciplines. As described by Karen, David, Holly, and Cecilia, recognition and
validation by peers or more knowledgeable others—such as advisors—also helped form their definitions of contributions.

Karen, 4th-year scientist: I now know you need to make a leap of faith and other people believing that [your ideas] are interesting are, they’re promising, of course strengthens your own confidence and other people making progress helps you believe that, “Oh, I’m really on the right track, I’m not wasting my time.”

David, 5th-year scientist: You sort of build to more and more significant impact through time in your career and so a lot what I’ve been doing is basic stuff…they’ve been solid but not huge contributions, you know, just to be honest about it. But you know, there’s stuff that have gotten the readership, they’ve gotten cited, there are people interested in it, so, umm… that’s a good sign that you’re making some sort, some kind of important contribution to somebody at least.

Holly, 3rd-year engineer: Well, I think that’s when [prior to working in a research lab] I, I think, I still had this idea that, like you had to contribute a lot to really make a difference, and I think, umm, sometime in undergrad when I started working on these projects, I didn’t feel like I was making that big of a contributions but, you know, my advisor would acknowledge me in talks, and you know, I go, “Oh, okay,” you know… I think so, through those experiences I think I learned what, an understanding of what I would consider a major contribution and minor contribution, stuff like that…

Cecilia, 4th-year engineer: I think I get more and more stricter, just like, you know, it’s not just good enough for it to be new, you know, but is it interesting also? Before it was anything I do that takes a lot of time must be my contribution, right? ‘Cause I spent time on it. And then you realize, well, it has to be something new and now I think it just can’t be new, it has to be interesting ‘cause otherwise it’s not really contribution, it’s just, you know, fluff that’s out there. So I think with time, yeah, it does change. I: Okay. And why do you think it’s changed?

Cecilia: Maybe because you’re able to—as you gain more knowledge, umm, you’re able to do it and so you always want to challenge yourself and so maybe, you know it’s like, how do I contribute to, you know, I must—I do something different to challenge myself otherwise I’ve already done everything that I could do. So, I don’t know… I think it’s internal drive.
I: Based on all these, these experiences you’ve had and how you’ve defined scientific contribution, how do you think that you have made a scientific contribution?

Cecilia: Umm, well I guess the very, not the very first, but the major one would be your Ph.D. thesis, which by definition has to be a contribution or otherwise, you’d—we’re not allowed to graduate, you know? And the community at large validates that it’s a contribution, I think that’s probably something maybe I forgot to—that I hadn’t thought about before when you were asking that question, it’s also a scientific contribution when other people say it’s a contribution, so that the community helps to validate whether something is a contribution or not. And when you have a thesis, you know you have a committee, and they have to approve it and you have to present it and other people will think that that’s good, so then you think it’s good, too.

In addition to realizing the importance of recognition by the scientific community, the professional demands and requirements of an academic research position also influenced the change in participants’ understandings of contributions. When asked why their notions of scientific contributions changed, participants believed being a mentor in a position of authority and having the responsibility to come up with unique projects and questions as an independent researcher helped develop more concrete definitions of contributions.

Kelly, 4th-year scientist: I was idealistic when I was a grad student, you know? I was really idealistic and I wasn’t aware of like, politics or funding… but now, I mean, I think it matters in more practical terms I think of—before I just said, “I’m going to do this research, blah-blah-blah-blah-blah,” and I didn’t even think about, “Oh, that would be a paper, that would be a paper, that would be a paper.” Now I think, “I’m gonna do this pair of experiments and that’s going to be a paper, and then I’m going to do this pair of experiments and that’s going to be a paper,” because I need to get tenured here, you know, because, you know I need to go to a conference in six months, you know what I mean?

Helene, 18th-year engineer: I think the idea that, umm, that [contribution] can go beyond just a peer-reviewed publication has dawned on me as, as I’ve been a mentor, rather than just a mentee. And seeing what my students have
done, you know, I have, umm, my first Ph.D. student is now a department chair and so she’s gone up through the ranks and, and gotten tenure and so forth and so I, I can see how she’s influenced others.

Angela, 10th-year scientist: Well, you start as a plantation worker in, in [graduate school] you borrow from there to independent thinker and I take charge of what I write and I am the one now pushing new ideas and someone else works for me and, you know… thinking independently, that’s the idea, okay. If you are not connected to your previous advisors sooner or later you have to start thinking on your own… It’s a mental thing, so you, you sort of grow up and you start thinking, trying to, to use all the stuff you’ve learned from other people. It’s also, umm, a geographical problem I would say. Okay, if you are landing a job somewhere else, then you are not face to face every day with people who have been your advisors or who, eventually wanted to work with you on various things, then you are sort of forced to think on your own and, umm, then do your own stuff.

Ryan, 5th-year engineer: Hmm, doing it myself primarily… and now advising students. I feel like I’ve gotten much better at that by talking to a number of students, umm, and helping them with different research projects and identifying, uh, a research proposal… and then, and kind of just working through how to find the, how to find the fundamental research question.

These understandings demonstrate that the experience of having responsibilities associated with leading and owning a research group greatly influenced and formed participants’ understandings of scientific contributions.

Summary of Notions of Contributions

In their retrospective accounts, the faculty members explained that their early notions of scientific contributions were often confined to discoveries of grand proportions, due to limited research experiences and a lack of concern or awareness of the idea of contributions. These notions evolved as they entered their academic positions, as they also realized the numerous ways and various magnitudes that contributions could be made, ranging from making incremental measurements to creating new ways to solve a problem to
shaping students into future researchers. The participants attributed the change in their conceptions of contributions to a heightened awareness of their works’ connection to academic disciplines outside their own, the recognition and validation of their research from their colleagues, and the professional demands of being a research advisor.

Conceptions of Scientific Collaboration

Early Notions of Collaboration

Prior to or early in their graduate studies, the participants held limited understandings of what constituted a scientific collaboration. Like their notions of scientific contributions, participants did not often think about collaboration as graduate students, as demonstrated by the quotes by Ryan and Helene below. In addition, some participants’ early beliefs showed that collaboration meant simply working with other students or working on an advisor’s collaborative project, as shown by the thoughts shared by Helene and Kelly.

Ryan, 5th-year engineer: I did not, not thought deeply about it at all. Especially, uh, um, multidisciplinary collaboration never really crossed my, there weren’t, I didn’t have a reason to cross my mind…

Helene, 18th-year engineer: I guess, you know, I really didn’t think about it [Laughs]. Umm, we had a, like I said, a large group of about ten to twelve Ph.D. students that worked together and so, we would help each other out if somebody had a field component to go out and help sample or, umm like I said, learn some very experiments in the lab and stuff, but, that was just seen as, part of working together. I don’t think we labeled it as collaboration.

Kelly, 4th-year scientist: You know, I’m trying to think... When I was a graduate student we didn’t really collaborate, well, at least on my projects. When I was a post-doc, we did some collaborations, that’s true, we did. And it was mostly like, the collaboration was, umm, okay, I worked on a project that was a collaboration between my boss and then somebody else. And then I went over to the other person’s lab and did all the work in the other
person’s lab and then that was the collaboration. You know what I mean? It was really, I worked in the other person’s lab for a few months, you know? That was like, the collaboration.

In their early notions of collaborations, some of the participants used their relationships with their advisors to describe their understandings. Karen, a 4th-year scientist, believed that her relationship with her advisor was not collaborative.

Well at first it was with my, uh, undergraduate advisor, but more strongly with my graduate advisor that at first he was the teacher, I was the apprentice, and you just, they tell you what to do and you do it, so that’s not collaboration in my opinion, it is not scientific collaboration, of course they also benefited from the things I was doing and I was learning from them.

Karen’s view implies that levels of skill or expertise were considered in her understanding of collaboration. For Karen, the authoritative position and higher skill level of her advisor made her believe that she did not collaborate with her advisor, particularly early on in her graduate studies. However, Karen also described the evolution of her definition of collaboration through her advisor-advisee relationships as both a graduate student and a faculty member. With more experience with research, Karen recognized the gap between her and her advisor decreased to a point where she was more knowledgeable than her advisor on a specific problem, a trend she also recognized with her own students. Once this level of knowledge and expertise was more equal, Karen believed that the advisor-advisee relationship was indeed a collaboration.

It was interesting how with the same person, as I was learning more and more, the balance became more equal, so we were able to talk as equals and in many cases… and that happens with everybody, my own graduate students as well, the student ends up knowing more than the professor on that specific problem, okay. So, the professor, uh, tries to keep the big picture in mind and you use the experience in, he or she has in many other problems they’ve solved before. Umm, and the student actually works on the
meats and grits of the problem, so, that, that kind of collaboration is, umm, advisor and student is, I would call it a collaboration although there still is feeling that one is the boss, okay?

The understanding of scientific collaboration described by Karen as she was starting her graduate studies was also expressed by Cecilia, a 4\textsuperscript{th}-year engineer. In her recollections of being a graduate student, she had difficulty believing that she collaborated with her advisor.

...What I also thought, like as a student, to me a collab—when I was a student I thought collaboration means I sit down here with you at the table and we’re working together, umm, so I had a much a narrower view of what collaboration meant and I think, I still feel like my students do sometimes because—and also it might be because out of respect they want to treat you like differently, and they don’t—they think that when you’re collaborating with someone they’re at the same level.

In her reflections above, Cecilia acknowledged that in her own experience as a student and as an advisor of students, graduate students have difficulty defining the advisor-advisee relationship as a collaboration, a difficulty she attributed to the authoritative position of the advisor. This dynamic between advisors and advisees was also elaborated by Michael, a 5\textsuperscript{th}-year scientist. Michael acknowledged that the authoritative position of his faculty mentor influenced his perception of collaboration with his advisor.

I: Did you feel like you were collaborating with your advisor when you were doing your Ph.D. work?

Michael: It was definitely different, umm… [long pause]. When, when you’re collaborating with your advisor, you know, your advisor is in a little more of a position of authority so, you’re a little bit less, umm, I’m, you’re a little more reluctant to kind of, uh, mention, kind of hare-brained ideas that may not work out ‘cause you want to impress your advisor and with your colleagues often times you can be a little bit more open and kind of, just brainstorm and, and, that’s, that’s really good for research. Uh, umm, of course the longer you know your advisor, the more you’re comfortable kind of, uh, trying different ideas and everything, but, umm, so there, there is kind of a little bit more, uh, freedom to kind of ex—you know, exchange all sorts
of different ideas with, with colleagues maybe more so than with advisors, that you’re trying to, uh, look, you know… trying to make sure that I’ve always looked good for my advisor and that I don’t say anything too stupid.

As a graduate student, Michael was reluctant to share his ideas with his advisor, though he did claim that the relationship with his advisor was a collaboration. Similar to Karen’s experience, Michael also realized that with time he became more comfortable sharing his ideas with advisor, which perhaps made it easier for him to view his relationship with his advisor as collaborative.

Together, these thoughts of the faculty members suggest that their early notions of collaboration were somewhat limited, which they attributed to their lack of consideration towards collaboration. Though some participants framed their early understandings of collaboration in the context of their relationships with their research mentors, some recognized the advisor-advisee relationship as collaborative, while others did not.

Current Notions of Collaboration

When the faculty participants were asked about their current conceptualizations of collaboration they expressed the belief that collaboration was the coming together of unique sets of skills and expertise to solve a greater problem or achieve a common goal. The participants’ reflections below highlight their beliefs about the importance of the symbiotic nature of collaborations. This is particularly demonstrated by Helene’s statement, and Karen’s claim that collaborations “should be really synergetic at the end.”

Kelly, 4th-year scientist: Umm, what constitutes a collaboration? I think, umm [pauses], working with someone else… uh, to achieve sort of a common goal or, umm, utilizing expertise from multiple laboratories or multiple sources to… umm, to, umm… come together on a project, you know, and not really, sometimes not even knowing what the goal is, you know. So, so, to maybe
like pursue a, an idea or investigate an idea, cause sometimes you really don’t
know what the goal is, but you just need to work together and go for it.

Helene, 18th-year engineer: I think collaborators, umm, bring particular
experiences and skill sets to make, umm, something greater than it could be.
Umm, rather than just a single investigator…

Karen, 4th-year scientist: It means, to me, one, uh, two or several individuals
with complementing skills, umm, working on a problem or a set of problems
and umm, not just making separate contributions on them, but, through
communicating and brainstorming and deeper thinking and more
communicating, umm, coming up with a solution which, uh, ideally…
shouldn’t… they shouldn’t be able to just draw a line, I did this, you did that,
it should be really a, synergetic at the end…

These participants’ notion that collaborations unite complementary sets of skills and
expertise to bring about a greater result was also demonstrated by Edward, a 14th-year
engineer. In his definition, Edward mentioned the role of graduate students:

I think to me the word “collaborate” implies more a, um, a bringing together
of skill sets and usually a graduate student doesn’t bring that to the table.
[But] a genuine, multi-lab collaboration, umm… where everybody made an
important contribution, um, it ended in a, you know, uh, a joint publication
and it was the bringing together of skill sets that no single lab had.

Here, Edward expressed his perspective that graduate students do not often bring enough
skills or expertise needed to a project to be considered collaboration. This again highlights
how one’s beliefs about the power dynamic and level of skills between advisors and students
can greatly influence one’s understanding of collaboration. Interestingly, Edward’s
understanding can be contrasted with Karen’s views, stated in the previous section, when
she stated her belief that “advisor and student is… a collaboration although there still is
feeling that one is the boss.”
The notion that the advisor-advisee relationship is collaborative was also expressed by Cecilia, a 4th-year engineer. Cecilia’s understanding of collaboration actually changed from her early notions, presented in previous section. In comparison to her views as graduate student where she believed that collaboration involved working with those “at the same level,” her understandings as a faculty member demonstrated her firm belief that she does indeed collaborate with her own graduate students.

In all different levels, I mean, clearly if you’re both working on the same problem and um, you know, equally sharing the work then that’s collaborative. But there could be times where, if you’re the advisor, you’re clearly collaborating with your students. You’re not doing most of the work, but you’re filtering ideas or suggesting directions which have a big impact on where the research goes in the end. So that’s collaboration, even though the students probably don’t feel like you’re collaborating with them, they think you’re just telling them what to do, but, you know, that’s collaboration… You don’t have to collaborate at the same level, so, umm, anything that kind of helps make that product in, in the end is a collaboration, whether we did it together or, you know, in a hierarchy or whichever way we did it, it’s a collaboration.

In her reflections, Cecilia acknowledged that in her experience as both a student and an advisor, graduate students have difficulty defining the advisor-advisee relationship as collaborative. As a faculty member, however, her understanding shifted, as demonstrated by her belief that “you don’t have to collaborate at the same level.” Cecilia’s newer understanding of collaboration focused more on the degree of contribution to a project, when she claimed, “Anything that kind of helps make that product in, in the end is a collaboration.”

Like Cecilia, Michael’s view of collaboration as a faculty member also shifted from his view as a graduate student, which was presented above. Michael, a 5th-year scientist,
believed that his relationship with his graduate advisor was a collaboration, which can be contrasted with his current view as a faculty member.

I: From where you’re at, your, your position now, as an advisor, do you think that you collaborate with your students?

Michael: Umm… interesting. I think, uh, probably a lot of—I see probably the same phenomenon [referring to his reluctance to share ideas with his graduate advisor] with my own students. Uh, so I try and encourage them to, you know, just brainstorm any ideas they might have. Umm, and, uh, but I can definitely see, uh, a little bit of reluctance to try and be as completely forthcoming as possible because, you know, they’re, they’re worried about, I never think of myself as an intimidating person, but I can see my students are a little bit intimidated sometimes in our research conversations, so they’re kind of reluctant to, you know… I keep going, “Why don’t you go to the board and work through all this?” And they’re kind of like, “Really? I have to go, you know, work it out in front of you and everything?” So it’s, umm, whereas if they’re just talking amongst themselves, then they’re much less, uh, worried about, you know, making mistakes, they’ll try and explain something at the board, uh, a lot more casually, and a lot less worry free than if I’m sitting there watching them, kind of, you know, so that’s one of the main differences I think. Umm, collaboration works well between people, I think of the same rank in some sense. If one is a, kind of the boss of the other person, then, umm… you kind of got that entering into the picture as well.

In his earlier reflections, Michael was reluctant to share his ideas with his graduate advisor, though he did claim that the relationship with his advisor was a collaboration. Interestingly, in his view as a faculty member, Michael seemed hesitant to state his belief of whether or not he collaborates with his students. He believed that the authoritative position of an advisor made it difficult for students to recognize the advisor-advisee relationship as a collaboration. Michael’s view that collaborations work more effectively with individuals of similar or equal standing was shared by Edward, whose notions were discussed above.
In sum, for most of the participants, collaboration was defined as two unique sets of expertise—often of individuals with equal professional standing and level of expertise—working together to accomplish a common goal. Some of the participants believed that they collaborate with their own students, though they recognized that their students may not view the advisor-advisee relationship as collaboration due to the perceived power differential that exists between the faculty mentor and the student.

*Explanations for the Change in Notions of Collaboration*

In their retrospective accounts, all of the participants expressed that their notions of scientific collaboration changed from their understandings as graduate students to their understandings as academic researchers. They expressed that the primary reason for this change was the ownership of their research, often out of necessity to achieve their research goals: they dictated the collaborations, they decided who they needed on their research teams, and they reached out to individuals with the expertise that they themselves did not possess. Because of this control, the participants believed that they gained a full understanding and definition of scientific collaboration.

Kelly, 4th-year scientist: I think about how it’s more equal, you know, more of a contribution, umm, more equal partnership, umm, at my end at least. I don’t know although, if you ask one of my students about, I feel like, that’s a good question, I’m not sure if their idea of a collaboration is very different than my idea was when I was a post-doc, you know what I mean? I’m not sure. I see, I mean, you know at my level, you know, I’m going to be like the boss, and we have these, you know, exchanges and motivations that a lot of times the graduate students aren’t there, you know? I’m running a collaboration [Laughs]. Umm, and [pauses] I think that’s the main reason, like, I’m the one who dictates what a collaboration is. You know, whereas before I wasn’t in control of it. You know, so, I’m deciding what it is. Before it was like, I just a piece of it. You know?
Cecilia, 4th-year engineer: Well, because now I decide what I do. [Laughs]. So if I decide what my project is, I realize, I don’t have all the experience to do it by myself, so I’m just going to bring in everybody who I need to help me figure it out… So I think maybe the ownership of, of umm, when you own an idea, then, you have to reach out a lot more. And also, at the same time there’s other people. Before I didn’t have the freedom to get involved in ten different projects, right, I had to be doing my thesis. Now I might be involved, just like, not as a main person, but as, as this little auxiliary person in some other project because I have the freedom to choose to do that.

Holly, 3rd-year engineer: Umm, so, from a PI now, so as a person directing the lab, I think you go out and seek collaboration when you’re doing some project and you think it will be important, but there’s, there’s an area that, you know, I’m not an expert in… so I work with someone in the chemical engineering department who is an expert in, in nano-particle synthesis and characterization.

Jan, 11th-year scientist: On the fly, it was literally on the fly [referring to how she learned how to collaborate]. In fact, uh, most of my work has been kind of on the fly because there, it’s new, you know I mean, and in some ways that was kind of neat, it was scary at the time… So I had to sort of out of necessity if I was going to make it, if I was going to do this kind of work, I had to sort of just get out there and meet people and do it, I didn’t know what the hell I was doing.

Gabe, 3rd-year scientist: Desperation… [Laughs] No, no, no, I’m being, I’m being very honest. Like, umm, you know, I, I have a collaboration with some folks in biology that do bio-piling research. I don’t know anything about biology, I don’t, I mean could maybe find a cell in a microscope and that’s about it. Umm, but again, I, I—I feel like we’ve got a pretty good understanding of surface chemistry. So, can we work together and help each other out?

Similar to the experiences that helped form their notions of scientific contributions, participants also expressed the importance of peer recognition—to help build their reputation—in establishing their understandings of collaborations. One of the essential components of collaborating was having others recognize their own ideas as interesting—as
described below by Toby—and having the confidence in their own work and reputation—as described by Edward.

I: How did you learn to do collaborations?

Toby, 3rd-year scientist: I guess just, just by doing it, I mean, you know, you go to conferences and you talk to people and you, there is definitely an intimidation factor that exists and sometimes, you talk to someone who’s really, really bright and you share them your ideas and they really like it… Umm, but yeah just, just from talking to people, and showing them your ideas.

Edward, 14th-year engineer: I think [my conception of collaborations has] evolved. I mean, you know, in terms of how to make it happen and who to reach out to. I think in… a component in sciences that you have to build a reputation to a degree where, uh, you feel comfortable enough in approaching somebody about a collaboration, that you’re not going to be turned down just because you’re the new kid on the block. Yeah, so, umm… so for me I, I think the, um, the ease of collaboration has improved over time… I don’t—I don’t think it’s, in my case it was never something that I took a class on collaboration or, uh… I think it’s uh, uh, being observant of how things work and umm, that I think that there were some personality factors that matter. You need to be somebody who can, who can seek out a collaboration, uh, approach people and, ask them [for] help.

All of these reflections demonstrate that the ownership and control of research projects and the need to build a reputation in the community of practice greatly influenced the participants’ understandings of scientific collaborations.

Summary of Notions of Collaboration

From their recollections, the faculty members explained that their early notions of collaboration were not well-developed, due to a lack of consideration of the term. For those who mentioned the relationships with their Ph.D. mentors in their early notions, some described the relationship as a collaboration, while others did not. Their conceptualizations of collaborations evolved as they entered their academic positions, acknowledging the
synergistic nature of collaborative efforts. Much like their early notions of collaborations, some believed the advisor-advisee relationship was collaborative, while others did not. The participants identified ownership of their research programs and peer recognition in their desire to establish their reputation as the primary factors that changed their perceptions of scientific collaboration.

Conceptions of Credit Assignment

Notions of Credit Assignment

As seen from the interview protocol used in this research, the participants were asked only about their present notions of credit assignment. This was due to the assumption that prior to their faculty positions, they would not have sufficient opportunities or power to assign credit, based on a theme that emerged from the pilot study. However, as will be revealed, the participants discussed their graduate student experience to a great extent when reflecting on how their notions of credit assignment formed.

Participants were questioned about their understanding of how credit is assigned for contributions and collaborations. Their responses differed according to the discipline of the participant. Those in the disciplines of mathematics and computer science understood that credit should be assigned to all individuals that made a contribution to the project, with contributors presented in alphabetical order on the author list.

Phyllis, 6th-year scientist: You get your people together, you work on the project, assuming everybody did a fair share, it’s alphabetical on a paper.

Toby, 3rd-year scientist: From what field you’re in. If you’re a, if, if, if you’re in a, if you’re in [my discipline] and then write up one paper with someone then, it’s just when everyone contributes, so you just do the logical thing
which is write the authors in alphabetical order. But in [other] science it’s a lot more superficial and they get, they care about the specific author and all this bullshit, um, so it just depends on the field, like, author order is only one thing and there’s such a, I mean, there’s, it’s a lot more pub—it’s a lot more political in the [other] sciences than in [my discipline] because you’ve got the grad student who does all the work in the lab and some advisors like to put their students as first authors, some of them don’t like to give them credit at all because they want them to be the only author so… it’s just, it just depends on what, on what field you’re in.

I: Okay. Umm, for, I mean you’re saying that the person that contributes, how do you determine a person has made, has, has done enough contributing, contribution to go on a paper?

Toby: Umm, well, I don’t know, a lot of this is just time, like, you know, if I work with someone and they got, you know, they put in a lot of time into it, I mean I’m not going to invite them to work on something if they can’t contribute…

Interestingly, when asked earlier in his interview to define his notion of contribution, Toby framed his understanding in the context of publications. When asked about his understanding of what constitutes a contribution, he responded:

Umm, to do something that other people… umm, are interested in. I mean there’s a hundred and thousand some papers in [my discipline] every year and most of them are, um, are not right…spread, I mean, most, most of these papers and publications are not—most people don’t really care and they’re not going to make or break anything in the future, but there’s a small group of people that care, so I guess it’s doing something that is non-trivial and someone else is, might be interested in it.

Here, Toby’s perception of contributions was not as concrete as the other participants who gave specific examples of ways one could make a contribution. Perhaps due to this lack of specificity, Toby had a difficult time articulating what he deemed sufficient as a contribution on a paper, as he claimed, “Well, I don’t know, a lot of this is just time.”
Michael, a 4th-year scientist in a discipline which also assigns authorship alphabetically, went into great detail about his understanding of credit assignment, discussing his own struggles with determining what warrants credit.

So, I mean that, I guess the main form of credit would be authorship on publications. Umm, and... there’s basically there’s the question of what warrants or doesn’t warrant authorship and then there’s, if you are an author on a paper there are questions about ordering the names and things like that. One nice aspect of [my discipline] for the most part is the ordering of the names is almost always done alphabetically, uh, so that is less of a contentious issue. Umm, it’s actually kind of interesting if I collaborate with people in other disciplines, uh, I’m a little bit out of my league when it comes to ordering the names on the papers. More or less I tell them, “Do whatever makes sense for your discipline,” because the people in my discipline don’t really know what the intricacies of name ordering really means, they’re used to just seeing alphabetical, uh, names on the paper. So, in most of our publications, uh, no author is treated as being uh, better than any other author, so all authors are kind of, are equal, uh more or less and it’s just alphabetical. Umm, so that actually is, I really like that, uh, because it, it removes that kind of layer of contention or stress about, you know, “Am I going to be first or second author?” or what not. Umm, so the main question in my discipline is basically what warrants authorship and what doesn’t warrant authorship. And that’s sometimes a tricky issue. Umm, basically anyone who’s directly contributed to the, uh, to the research in terms of, you know, contributed ideas that have, have, uh, substantially helped solve the problem at hand, they definitely deserve to be authors. Umm, trickier cases would be people who are, you know, on the team, but really haven’t, really contributed too much. I tend to, uh, view those folks as deserving authorship, unless you got, you know, a team of twenty people or something, it, it just kind of untenable to have an author list that long. Umm, uh, also you have people that kind of aren’t really part of the team, so to speak but, they’re people, they’re people who you’ve consulted with, with questions who have actually given substantial guidance that really has kind of cracked the problem wide open. Uh, you might want to offer authorship to those folks if the contribution was kind of worthy enough and that’s just a judgment call you’ve got to make. Um, one difficulty is, umm, sometimes authorship is used in kind of a political way, uh, where you have, maybe somebody who has loosely worked with the project but is in a position of
authority and so you want to kind of extend them an offer of authorship to
kind of, you know, make them happy with you because they, uh, well if
they’re in a position of authority they have some say over your promotion
and things like that. Umm, so that sort of situation, I haven’t really witnessed
that, uh, personally myself too much. Umm, I can imagine a lot of scientific
disciplines where there’s a lot, uh, I mean, I’ve certainly, uh, heard of that
happening a lot in academia, you know, people that have high rank, kind of
making their way onto more author lists than they should be on. Umm, just
because, of their, you know, position kind of, overseeing everything. Umm, I
think that the person, if you have uh, a group effort, a bunch of students
doing research and the research is being overseen by a faculty member,
generally the faculty member deserves to be on the author list. Umm, uh, if
the faculty member is kind of playing a mentorship role over the students,
umm, especially if the faculty member is, uh, funding the students. Although,
funding research doesn’t necessarily just entitle you to authorship, that’s kind
of, in some disciplines that might be the viewpoint. I would say you actually
have to be actively involved in the research itself to be entitled to authorship,
not just, you know, paying for the authorship. Umm, but uh, in the situation
where a professor has more or less just kind of a team of students working
for that professor and the students, more or less do all the work, and the
professor just, you know, pays the bills… it’s still kind of a judgment call.
Usually I would say that the professor probably deserves to be an author if
the professor has been at least minimally involved in the research process,
umm, uh, just because the research really wouldn’t have taken place without
the professor’s guidance and what not.

Michael’s understandings of assigning credit was similar to that of Toby, as they both
demonstrated the belief that the disciplines of computer science or mathematics practice
more “logical” and less “contentious” methods of assigning credit in terms of the ordering
of authors. They believed that in the disciplines outside of their own, social and political
issues associated with credit assignment were more prevalent. However, Michael seemed to
struggle with contention in his own experience and understandings of what occurs in his and
other science disciplines. Michael mentioned his own experiences with the “trickier cases” of
giving authorship credit to team members who did not necessarily participate on a project
and also his awareness of the practice of gift authorship (Smith, 1994), where credit is given to individuals “in a position of authority” who often simply funded the research. Michael’s views of credit assignment were consistent with his views of contributions given earlier in his interview:

Umm, if I have a student who joins a research project, one week before the publication goes out, you know, is that student, even though they’re part of the team for some amount of time that you know, we’re doing research, uh, would I call that kind of a research contribution? It’s, it’s really, it’s a tough… that’s a very difficult question to give kind of a definitive answer to. Umm, probably I would say uh, a research contribution definitely has to be, a student or a colleague who has, uh, I would say kind of been on the team in some sense? So typically you kind of have a well-defined team of people that are kind of working on the project, umm, and anyone on that team, even if they haven’t, umm, you know, directly solved an aspect of the problem, if they’ve been kind of actively working with the whole team on the project the entire time I would say that’s a, that’s a contribution worthy of authorship and everything.

Interestingly, Michael’s collective reflections suggest that one does not necessarily have to “directly solve an aspect of the problem,” to be assigned credit.

Participants in the remainder of the science and engineering disciplines also recognized the politics of credit assignment and acknowledged the nebulous situations that could make credit assignment difficult. They placed these difficulties in the context of issues relating to promotion and tenure or the influence of power relations within their communities.

Holly, 3rd-year engineer: You know, there’s some big labs where the big name person is always last author, even though he did—or even first author—even though they didn’t do anything, which is kind of weird…

Cecilia, 4th-year engineer: With the proposals, it was more because, as it—if you’re trying to play a game or you want to repeat this game, you don’t want to burn anybody, you don’t want to say… assign little credit and
[collaborators] might feel like they don’t want to work with you anymore. Umm, and sometimes—and I will always ask them, I will say you know, “I’m giving you this, this percentage,” and sometimes they’re like, “No, no, give yourself more.” And then that’s fine, but I’d rather it that way, umm, than another way, even though that’s only for internal purposes, you know, that doesn’t get published anywhere or anything like that, the department’s going to see that you were assigned this percentage for it because when you go to have your annual review they’re going to look at that. So you… ‘cause, umm, it gets more weight when you were the person in charge or the PI so they want to see that you have more credit because it means that you were the one in charge. Umm, [pauses]… and like I said, I, I had heard some stories about some people getting burned on that.

Angela, 10th-year scientist: Personally when I see someone’s very famous name showing up on a paper that doesn’t discuss what traditionally that guy is doing, I strongly suspect that the name was added on just as a booster for the overall, umm, how should I say, rating of the paper, as a sort of, well, if so-and-so’s name appears on it, it means that it’s good type, or the, as a sort of vali—booster for the refereeing process… We are talking influence… and again this is quite common, you want to be friends with influential people and how do you become friends? You give them ownership of something that is really not, umm, you know, you increase their publication numbers and this is what they, it’s a subservient type of attitude but it works.

In the disciplines where authorship and credit is not given alphabetically, participants explained their beliefs and practices on the criteria of authorship ordering. Some participants—like Kelly and David—believed that first authorship was warranted to the individuals who conducted the majority of the work, which they qualified as those who performed the experiments or wrote the manuscript of a paper. In addition, Holly—stating that she actually wrote the manuscripts—claimed that time spent on a project also qualified as deserving of primary authorship.

Kelly, 4th-year scientist: The way we’ve always done it is like, the person who carries out the experiment, the biggest body of it, the work, and writes the paper, that’s the person who’s usually, like the first author. And it’s different
in every field, but like in our field usually the first author is the person who does most of the work. Yeah. And so like, that’s mainly how we do it.

David, 5th-year scientist: Oh, generally, umm… First person did all the work. Last person is the PI. And then… it’s descending order from that first one, how much you contribute, so it’s down, down, down, down, down, you know, so usually, you know, like the last person might be the, the, the, umm, corresponding author. It’s their lab, they’re the central person, the first person on there is the student, post-doc, whatever who did most of the work, really was in the trenches doing it. The other people did some other part of the work, or had some really critical contribution that the whole paper depends upon, the contribution depends upon, you know… Umm, but basically, yeah, first person is the most important, declining, last person is the, the head honcho in the lab, so…

Holly, 3rd-year engineer: It’s kind of a hard question. Umm, I mean, personally, like if I’m writing a paper or something, umm, I think, uh, I sit there and write out like basically who’s contributed at all, uhh, and, there’s a, a couple times where I’ll put someone in, in as like an acknowledgement as opposed to as an author, if it’s just like they initially helped train one of my students or they showed some technique, umm, like the one or just a couple times, things which were really helpful but it wasn’t like that in and of itself umm, made a significant impact on it, umm, but then the rest of the people usually I give credit somehow. Umm [pauses, hesitates] there’s always like the student whose project it is that I’d say was the major contribution, and then, umm… usually kind of almost assign it by how much time that got put into it, I guess?

In addition to assigning primary credit to those who performed “most of the work” on a project, participants such as Helene and Oscar, 18th-year and 5th-year engineers, respectively, mentioned that providing an intellectual contribution to the research was also a major criteria for deserving credit.

I: So what is your understanding of how credit is given, umm, for a scientific contribution?

Helene: Umm, I think—through co-authorship, is I think the primary way that, umm, credit is, is viewed, umm… so depending on, umm, who’s first
author or second author, that type of thing, I think that, umm, helps define umm, the amount of contribution.

I: And how is it decided who gets first author and who gets second author?

Helene: Sometimes it’s a very deliberate conversation, umm, it… it’s umm… and… who, umm, puts in the, the bulk of the work as far as putting together the manuscript, umm, often is, is the one who has, uh first authorship. Umm, and then, umm, looking at the contribution to the intellectual and, uh, the heavy lifting also in combination and, and then the authorship is, um, divvied out from there.

Oscar: You know, if anyone had any part, intellectual contribution to it you, they should be listed as co-authors…

I: So, can you define for you, for me, what is an intellectual contribution, in your mind?

Oscar: Umm… you know, everything that goes into produce the results, you know, and then, uh, a publication, so, umm… well, you know, helping with the data collection or analysis, you know, that’s a contribution, okay, even if he or she didn’t dream up with a particular method.

In contrast to these thoughts of Helene and Oscar, Angela, a 10th-year scientist, gave her reflections about giving graduate students primary credit and authorship, stating her belief that students do not actually provide significant intellectual contributions:

Angela: Actually in [my discipline], I don’t know how it works in other domains, but again, if you have a graduate student working for a major professor, most of the time, in, like in 99% of the cases, no matter what the student contribution is, he will get first author rights. No matter what. In [my discipline] the rule of thumb is juniors get ahead.

I: And why do you think it, why do you think it works that way? Why do you think we put the, you say the juniors first in that?

Angela: It’s an unspoken rule. I mean everybody in the business looking at that paper knows that so-and-so, the last one on the list is the one behind, the brains behind the thing…As a rule of thumb it seems to me that works without fail is grad student gets the first name on the paper no matter what. And the advisor is second no matter what. Junior person gets first position, no matter what, and uh, the advisors will be happy to be listed at the end, okay? Even though, again, intellectually speaking it’s always the advisor’s
idea, and the draft work comes from the student, but this is a growing process. And you’re essentially to see that at the end of the day the grad student appreciates not just the, you know, work done to get to that result but he gets write the first draft of the paper, even though usually the advisor’s editing that changes that paper about 80%, at the end of the day that’s, you know, how the balance will come out. So, I guess everybody’s doing it…

In her statement that “juniors get ahead”, Angela was perhaps implying that assigning primary credit to a student is a means used introduce a student to the community of practice. In fact, when discussing how they decide to assign credit for their students, many of the participants mentioned that they assigned authorship credit to benefit their students. Like Angela, the following quote by Jan, an 11th-year scientist, states that although the idea behind the project comes from the advisor, she believed giving students first authorship allows students to “shine”.

Umm, luckily, I’ve always worked with really good people and actually in my younger years… you know, people I was working with who were further along were, were just always generous, they would just always give me the first authorship because they knew I, I needed that, you know, in my career advancement, they knew I needed it and they didn’t need it, you know, it wasn’t so important to them anymore. So that’s how it happened in my younger days a lot of times, umm, actually, which was—and that’s not to say that I didn’t do a lot of work, and didn’t deserve to be there, but, you know, they all just sort of said, “Oh yeah, you can be the first author.” Umm, now, you know, umm, I guess yeah, I guess the tide is sort of turning a little bit because, um, so now… Umm, most of the time I let the student be first author because most of the time they’re doing, I mean, even if the idea came from me, they’re doing most of the work… and that provides more opportunities for people to sort of shine.

Additionally, the following statements from Cecilia, Gabe, Michael, and Edward also represent the notion that assigning credit to students is beneficial for student recognition, success, and career advancement:
Cecilia, 4th-year engineer: So I just have the policy that my students always have their first name, they’re always first authors, unless they really screwed it up and I had to go in and do most of the work to write the paper. Umm, then in that case it won’t be. But usually I will always let my students be first author.

I: Okay…

Cecilia: Umm, some people told me that was dumb, but, whatever.

I: Who told you it was dumb?

Cecilia: Umm, a more senior professor at [name of collaborator’s university]. ‘Cause she, I’m also, like, working with her on a smoking thing and we were discussing about, when we were submitting the paper she’s like, “What are you going to—the author list?” And I was like, “Well, the student who’s working on it, then me, then you.” And she said, “No, you’re a junior professor, put your name first.” And I’m like, “Well, I have this policy,” and she’s like, “Well, that’s dumb.” Well, not dumb, but you know, she—not, not in that words, but…

I: Where did you, where did you learn about, about these, the way that credit, that credit is assigned? How did you come to these understandings or—

Cecilia: Well, my advisor always put my name first.

I: Okay.

Cecilia: And umm, even though, no matter, I mean it’s—I guess it’s true that I spent the most time on it but he, he could have decided to put his name first, he could… you know, I would have deferred to whatever he told me. And he always let me do that, so I, I thought that was nice and it helps you when you go look for jobs. So I want to help my students be successful when they graduate, so that’s where I came to that conclusion…

Gabe, 3rd-year scientist: I’ve seen this happen and I’ve been guilty of it. I, I don’t know, that, like to me, uh, the first author is… the first author is typically the grad student who did the work and came up with the idea, umm, the names in between are those who actually did work to contribute to it, umm, so a good examples, you know, they actually ran the instrumentation, did the data analysis, for, for that particular data set, so yes, they are absolutely deserving of credit… And then, um, typically I would like the advisor to be last authorship. Or if there’s any other faculty or whatever, have them be at the end. So I always, I always like the students up front. Because, let’s be honest, they’re the ones writing it, they’re the ones actually doing the work. And I always try and do that, too, when, like I gave a talk
this morning and for each section I actually made sure I highlighted the student who was responsible behind that work. Because you know, I don’t know, it’s, they’re, I think they should be rewarded for what they’re doing and people, and, and it’s, well it’s more transparent about who is doing what.

Michael, 5th-year scientist: Uh, sometimes, umm, you feel like, well there’s, there’s this student that’s maybe joined a project kind of halfway through, or hasn’t really contributed that much but, uh, this might be important for their research career, to um, you know, have more publications under their name, so you might be tempted to kind of, you know, put them on the author list—err on the side of putting them on the author list than off the author list, even if technically probably the right thing is, is that they’re not really supposed to be on the author list, you probably want to be… you know, it, it, if it’s your student you want their stu—you want your student to succeed so you want to give them as many publications as possible, so those are, those are some types of situations, uh, that probably I’ve been more directly involved with, uh, involving authorship where things have been a little complicated.

Edward, 14th-year engineer: If the student, uh, is completely aware of what the goal of the research is, uh, is engaged in the work, not just behaving as a technician than I, that, that’s the minimum requirement to get listed on a paper. Having said that, I will always err on the side of putting a student on because I think it’s, um, important for their careers.

Together, all of these reflections of the faculty participants have interesting implications towards the relationship, if any, between credit assignment and scientific contributions. Though all the participants believed that they assigned credit to all those who “contribute” to a research project, they recognized that socio-political factors—such as power relations with funding researchers or strengthening the careers of students—influence how credit assignment is practiced within their research communities.

Experiences That Led to Notions of Credit Assignment

Unlike their understandings of scientific contributions and collaborations, participants were not questioned about their early notions of credit assignment due to the
assumption that prior to their faculty positions they would not have sufficient power or opportunities to assign credit. However, their current notions came from what they observed from reading the literature and writing manuscript drafts during experiences prior to their faculty positions. They often “figured out” and were never explicitly told how credit through authorship was assigned on papers. As students, if their advisors gave them the responsibility to write a manuscript, they knew that their name belonged somewhere on the author list.

While deciding this listing, participants reflected that they copied or reproduced what they observed in the community of their discipline and they did not question otherwise.

Kelly, 4th-year scientist: I don’t know [how I learned to assign credit]. It was like… you know, I have no idea. It was kind of like, umm… I think it was like, okay, I mean, I remember going to group meetings where we’d talk about papers and my boss would say, “Oh, that’s a good paper, who’s the last author on that?” And then we’d say, “Oh, ummm… whoever.” And she’s like, “Oh, okay.” And then, you know, so we caught on that, you know, the last author must be, you know, the person whose lab it’s from, you know. And then, umm, I remember, uh, having to figure out a lot of stuff for myself of course, and I remember, thinking, umm, a lot of times I had to find out methods for myself, you know… you see a pattern over and over and you sort of think, this is how I must do it, you know… Yeah, nobody ever said this is the way it is, but, like pattern recognition, I guess…

Cecilia. 4th-year engineer: Well, my advisor always put my name first… Umm, even though, no matter, I mean it’s—I guess it’s true that I spent the most time on it but he, he could have decided to put his name first [on a paper], he could… you know, I would have deferred to whatever he told me. And he always let me do that [put her name as first author]… so that’s where I came to that conclusion.

Helene, 18th-year engineer: I think I learned through osmosis! [Laughs]. I don’t remember, uh, my, any particular conversation with my mentor about, “This is what you need to do,” or “This is how it needs to be done.” Umm, so, I think I just kind of soaked it up, I don’t remember particular episodes that, that that was discussed explicitly.
Toby, 3rd-year scientist: Just being in the field and observing…. it was just talking to people, I mean it’s… if someone contributes then they, they get put on as an author, and it’s typically done in alphabetical order because, I think, personally I think that opening it up, yourself to, who contributed the most is a huge can of worms and it can get very political…

I: Uh, where did you learn about these things, where did you learn about, you know, the whole ordering of authors on a paper and give students credit?

Edward, 14th-year engineer: Osmosis. [Laughs]… it’s being, you know, uh, umm, I know that in today’s environment, more and more there are classes and seminars and what not you can take, uh, to help prepare you to be a professor. Umm, when I came of age, that there were no such things and you just learned the ropes by climbing them. And, um, observing what other, other, how other people ran their labs and, um, being aware of, you know, when a colleague published a paper I would look and see who they published, who, who was on the author list and, you know, uh, scratching my head about, why somebody was on it or why they were on the list, the way it worked. But it’s more learned by doing, learn by observing…

Participants’ conceptions of assigning credit as faculty members came from their definitions established as graduate students. Unlike their understandings of contributions and collaborations, these understandings of credit assignment did not appear to evolve significantly over time. The participants stated that their conceived notions of credit assignment were simply applied to new practices in their faculty positions, particularly while writing grants and proposals, in which they experienced the negotiation of funding and lead investigator positions.

Summary of Notions of Credit Assignment

From their personal accounts, the faculty members explained their current notions of credit assignment, which were learned from their experiences of observing credit assignment through authorship in their communities of practice. The participants claimed that they simply “figured out” how credit through authorship was assigned on papers, being never
explicitly trained in authorship assignment. Furthermore, the reflections of the faculty members showed a limited connection between their understandings of scientific contributions and their understandings of credit assignment; contribution was important but not the sole factor considered when deciding what warranted credit. This may be due to the possibility that credit—at least in the form of authorship—is more of a sociological currency than a scientific one.

Summary

Elucidating academic researchers’ past and present conceptualizations of scientific contributions, collaboration, and credit assignment has demonstrated a definite evolution in their understandings. In their retrospective accounts, the faculty members explained that their early notions of scientific contributions and collaboration were often under-developed, which they often attributed to a lack of concern or awareness of these phenomena. As they entered their academic positions, the faculty members’ understandings of contributions and collaboration became more definite, due to the experiences of being exposed to academic disciplines outside their own, having their research recognized and validated by their communities of practice, and owning the professional demands affiliated with being a research advisor. Moreover, their notions of credit assignment did not completely overlap with their notions of contributions, perhaps due to the socio-political factors associated with credit and authorship. Using these understandings, in the following chapter I will discuss how the evolution of the faculty members’ perceptions of all these phenomena relate to the ultimate goal of this research, investigating the development of academic researchers’ scientific epistemologies.
CHAPTER V
DISCUSSION

In this chapter I will address my main research question pertaining to the scientific epistemological development of academic science and engineering researchers. First, I will discuss the evolution of the faculty participants’ understandings of scientific contributions, collaborations, and credit assignment. Through examining the changes in their conceptions and identifying and highlighting the experiences that influenced the changes in their understandings, a few themes arose from the overall data. From these themes an overall theory emerged—a theory describing the development of the participants’ personal epistemologies of science—which has potential implications for the development of professional identity.

Responses to Guiding Research Questions

To elicit experiences through which the faculty could reveal the development of their personal epistemologies of science, my research was guided by the following questions:

- What are engineering and science faculty members’ current understandings of contributions, collaborations, and credit assignment in scientific research?
- Have those understandings changed over time? If so, how and why?
- What specific experiences have led to those particular understandings?

As seen in the previous chapter, each of these questions was answered in the faculty members’ reflections.

In their academic positions, the faculty members’ understandings of contributions focused on novel discoveries, which could take form in numerous ways and various
magnitudes, ranging from making incremental measurements to creating new ways to solve a problem to shaping students into future researchers. The faculty members explained that their notions of scientific contributions had changed over time, realizing that their earlier understandings were often limited to discoveries made on a grand scale. The participants attributed the change in their notions of contributions to experiences such as being exposed to a wider range of science and engineering disciplines, having their research acknowledged and valued by their communities of practice, and owning the responsibilities affiliated with being a research advisor.

As faculty members, the participants held the understanding that collaborations had a symbiotic nature, defining collaboration as a union of complementary sets of skills or expertise to achieve a goal. Like their notions of contributions, they acknowledged that their notions of collaboration had changed over time, noting that their earlier conceptions were often limited or non-existent. Furthermore, some of the participants included the relationship with their Ph.D. mentors in their definitions of collaboration, with some recognizing the advisor-advisee relationship as collaborative, and others not. The faculty members credited ownership of their research programs and desire to build a reputation within their communities of practice as the primary experiences that led to their perceptions of scientific collaboration.

The faculty participants finally demonstrated their understandings of credit assignment which, unlike their notions of contributions and collaboration, were more difficult for them to articulate. Though all the participants believed that credit should be assigned to those who “contribute” to a research project, they also recognized that socio-
political factors—such as power relations with funding or authoritative researchers or strengthening the careers of students—influenced their practice of credit assignment. Because of these factors, the participants acknowledged that contribution was not the sole factor in determining what warranted credit through authorship. The participants also noted no concrete experiences that led to their understandings of credit assignment, stating that they simply “figured out” how authorship and credit was assigned on papers during their graduate school training, having never been explicitly trained in authorship assignment. Interestingly, these “experiences” are consistent with Ph.D. chemists (House & Seeman, 2010) and science post-doctoral fellows (Eastwood, Derish, Leash, & Ordway, 1996; Tarnow, 1999).

Taken together, the participants formed their notions of scientific contributions, collaborations, and credit assignment from the accumulation of their research experiences, starting primarily in their graduate studies to their current positions as faculty members in academia. These understandings were found to evolve over time, as the quality and type of daily practices changed from graduate student to academic researcher.

A Model of the Development of Scientific Epistemologies

The guiding research questions of this study aimed to help answer the overall question of this research, which was:

*To what extent do scientific epistemologies develop for academic scientists and engineers through their engagement in professional practice?*

In answering this question, the collective reflections of the faculty members largely focused on their views pertaining to the development and progress of scientific knowledge. By mainly examining their conceptions of scientific contributions and collaborations, an overall
Figure 5.1 A model of scientific epistemological development through professional practice theory emerged from the data, which demonstrated the particular experiences that helped the participants reach more enlightened scientific epistemologies (Figure 5.1).

In their retrospective accounts describing the change of their notions of scientific contributions, the faculty members demonstrated that their scientific epistemologies indeed matured with respect to their understandings of how scientific knowledge is developed. With greater exposure to the science and engineering communities, receiving recognition from these communities, and acquiring faculty member responsibilities, the participants realized the various degrees and wide range of ways that contributions can be made. Interestingly, the two primary ways in which participants described scientific contributions—being additive or transformative—bring to mind the views of scientific philosopher Thomas Kuhn and his
descriptions of the nature of science in *The Structure of Scientific Revolutions* (1962). The participants’ additive definition was consistent with what Kuhn calls “normal science,” science which is practiced under a universally accepted paradigm. This paradigm is a scientific outlook—a set of assumptions, beliefs, and values shared by a scientific community—about how science is conducted, how science should proceed, and what research questions are important to tackle. Additionally, their transformative definition was consistent with what Kuhn calls “revolutionary science.” In revolutionary science, there is a complete shift in paradigms, a shift that drastically changes the way a community practices and understands science. All of the participants’ understandings as faculty members demonstrated the additive definition and the belief that they practice normal science; as Helene claimed, “Not everything that we do in our laboratories or in front of our computers is transformative in the sense that it makes a big splash and a gigantic leap.” David, a 5th-year scientist, also insightfully articulated his awareness of the difference between additive and transformative contributions, adding that most of the contributions made daily are of the additive type:

So it’s kind of science “Small S” versus science “Big S.” Uhh, and, and science “Big S” is really, you know, did you find something that nobody knew before? And that’s something you’re contributing because science “Small S” is just, I don’t—it’s just a definition I’ve made up for myself is this idea of—if there are people who use the scientific method to answer specific practical questions, I kind of call that, you know, science “Small S” versus science “Big S” which is like, you know, *Science* and *Nature* articles where it’s like nobody knew this before or this completely changes our idea about something and then… the big ones are the ones that really kind of change people’s ideas. There are a lot of small contributions to “Big S” science along the way, which is what most of us are doing actually. Very few of us make that big, huge critical leap. You know, it’s filling in the story that somebody
has sketched out with that initial big discovery... I guess it’s, you know, finding a new continent versus mapping all the rivers.

Though none of the other participants articulated these understandings to the extent which David did, all of participants recognized the difference between additive and transformative contributions. Interestingly, David continued to reflect on his understanding of contributions:

I think I just have more of an appreciation for... how little most of us can actually contribute, just because of the limitations of time and money and— you think you’re gonna be in *Science* every year when you’re starting out and you then you realize, “Oh, you know what? Not gonna happen” [Chuckles]. You know, ‘cause, so it’s... you know, at a certain point you have to confront that you’re just not gonna be like changing the world every year and you might not get any chance to do it during your... [long pause]... blah, I guess I’m talking about something else actually, but it’s, it’s, it’s an evolution of, of—your understanding of, of what it takes to make a contribution, you’re, you know, developing some humility about how much contribution you can make and then, you know, trying to... So, uhh... because I think, you know, I... can’t say that my understanding has changed that much of what a contribution really is, but it’s just a much more, realistic view of how that contribution comes about.

This quote captures an understanding that the participants shared, the confines to which their own research influences scientific progress. The recognition of the limited extent to which they actually make scientific contributions demonstrated their more mature scientific epistemologies.

In a similar manner, the faculty members realized that their notions of collaborations also evolved. They attributed their change in understandings of collaborations to the receiving of recognition from their peers in the scientific community and—most notably—to the ownership of their research programs, often out of the necessity to achieve their
research goals and professional demands. As Kelly stated, “I think that’s the main reason [my views of collaboration changed], like, I’m the one who dictates what a collaboration is. You know, whereas before I wasn’t in control of it. You know, so, I’m deciding what it is.” Through dictating the collaborations, the faculty members decided who they needed on their research teams, often reaching out to individuals with the expertise that they did not possess. Because of this control over collaborative projects, the participants believed that they gained a fuller understanding and definition of scientific collaboration.

The interaction with collaborators in their proper communities of practice may have also developed their scientific epistemologies, with respect to the socially and culturally embedded nature of science. For example, Karen, a 4th-year scientist, stated that contributions are difficult to make without collaboration:

Maybe that’s the biggest change [referring to her understanding of collaboration from graduate school]. I mean, yeah it sounds good, “collaboration”, people helping each other, but I, I thought that there is so much you can do on your own and maybe just with a little help of somebody, but reading on your own, studying on your own, I thought that, in my mind that was going to be sufficient and now I understand that umm, you do very little scientific contribution if you don’t try to collaborate.

Though it was not explicitly stated by all the faculty members, their characterizations of the synergistic nature of collaborations may imply their understanding that greater progress of scientific knowledge is achieved through collaborative efforts.

Interestingly, the participants’ notions of credit assignment as faculty members were largely derived from their experiences in graduate school, unlike their notions of scientific contributions and collaborations which were primarily developed in their positions in academia. They claimed that their understandings of credit as faculty members came from
their practices as graduate students, only these understandings were applied to new situations such as writing grant proposals with co-investigators. It is possible that as graduate students, definitions of credit assignment were most concrete—relative to their understandings of contributions and collaborations—because credit assignment through authorship was a relevant practice, recognized as a meaningful activity at that point in their research career development.

In the transition from graduate student to academic researcher, there was a change in the participants’ daily research practices and activities. As academic researchers, the faculty members found themselves in a position of authority and control that required leading and managing a research program, developing and organizing teaching courses, training and mentoring students, collaborating with peers, contributing and producing quality publications, and obtaining and budgeting research grants and funding. While in their faculty positions, the participants’ own decisions and actions enabled them to define what each of these activities entail. Through defining these activities, the participants also struggled with distinguishing themselves from their graduate and post-doc advisors in establishing their own unique research programs. As stated by Angela, a 10th-year scientist,

A big issue today is getting independent, not working in the same area as your advisor. Trying to, trying your own path…and this is not easy, really, it’s very difficult, but at the same time, uh, you, you have to find a way of, uh, getting the, some… let’s say distinguishable results from what your advisor had done.

The faculty members acknowledged that ownership was a key component in gaining this independence. In their reflections, the participants believed that they developed this ownership primarily with the responsibility to conduct and control the research as faculty
members, in contrast to their positions as graduate students or even post-doctoral fellows. Also, in their attempts of “getting distinguishable results” from previous advisors or mentors, there was a sense that the participants desired to create their very own niche in their proper community of practice. This was also implied when Edward discussed his understandings of collaboration, stating, “I think a component in sciences [is] that you have to build a reputation to a degree where you feel comfortable enough in approaching somebody about a collaboration, that you’re not going to be turned down just because you’re the new kid on the block.” These faculty members’ reflections demonstrated that they wanted to find their own unique place in their professional communities.

In turn, the ownership of their research programs allowed the participants to better understand how they make contributions and how they participate in collaborations within the scientific community. This was made explicit in the reflections of David, a 5th-year scientist:

Okay, I’ve got at least a few things that are mine, no one can argue with me about it’s theirs or yours, great. So at a certain state you have to establish an independent track record early on before you can feel, really liberated enough to collaborate… Umm, and you’re just always going to have to maintain, you know, some subset of work that is really your work, that you are lead—you know, you’re the organizer and other people are collaborating with you as opposed to you collaborating with them… have them know that you are an independent operator who is not just basically a service provider for somebody else… You have independent, creative, original ideas, uh, that you’re going to execute, uh, through, you know, through your own efforts and bringing in expertise when you need to and so I think, the worst time for collaboration is early on when you’re going through that phase of…not having a lot to your name yet and trying to establish yourself… But you have to establish your own small side stuff as well, so that you can have some independent work going on… like okay, I’ve proven I can do my thing.
Through this ownership described by David, through their peers’ willingness to collaborate in projects, and the scientific community’s acceptance and acknowledgement of their contributions—primarily in the form of publications and graduating students—the participants were possibly gaining a strong sense of validation and self worth. With the help of recognition from their communities of practice, the participants perhaps began to recognize themselves as the experts of particular topics within their disciplines.

Recognition, Ownership, and Allusions to Professional Identity

Considering all of their experiences, the participants indeed matured in their understandings of scientific contributions and collaborations in their positions as faculty members, indicating a development of their personal scientific epistemologies. The professional practices that primarily influenced this development were the ownership of their research programs and the receiving of recognition from their communities of practice. Interestingly, these two factors—recognition and ownership—have also been found to be factors that contribute to another phenomenon: professional identity. Though there is a plethora of literature focusing on professional identity and how it develops, there is no consensus on a definition of the term, which can be attributed to the fact that professional identity has been investigated in a wide range of theoretical disciplines such as philosophy, psychology, and sociology. However, the previous research gives significant reference to the conceptualizations of Schein (1978) and Ibarra (1999), who define professional identity as the relatively stable sense of one’s own self based on the attributes, beliefs, values, motives, and experiences within a professional context.

Rooted in social formation (Bruner, 1960; Vygotsky, 1978) and situated cognition theories (Lave & Wenger, 1991; Wenger, 1998; Brown et al., 1989), it is believed that
professional identity essentially arises from the interaction of the self with the community of practice of a profession. In other words, professional identity is a product of negotiating the social expectations of a profession with an individual’s own presentation of his or her self within a certain profession (Nyström, 2009). Because of the complexities of this negotiation—complexities rooted in the fact that an individual can simultaneously hold various identities within various communities—there is a limited understanding of how professional identity exactly develops and what pedagogical or experiential strategies best foster its development. Nonetheless researchers in all disciplines agree that gaining an understanding of professional identity development is vital, as it can inform essential strategies to help in an individual’s socialization into a profession (Baxter Magolda, 1999; Colbeck, 2008; Sweitzer, 2008; Thiry, Laursen, & Hunter, 2011).

Despite these limited understandings of professional identity, previous research has suggested that recognition and ownership are two important factors that influence its development. Receiving recognition from others has been found to influence the professional identities of all individuals (Gee, 2001), male and female undergraduate engineering students (Tonso, 2006), and women of color in science disciplines (Carlone & Johnson, 2007). Moreover, while recognition was acknowledged as a primary factor that influenced the participants’ changing notions of scientific contributions during their faculty positions, many of them also stated that encouragement from their undergraduate advisors or professors was one of the major factors that influenced their decision to attend graduate school. When asked the background question of why they chose to pursue Ph.D. degrees, the participants responded in the following ways:
Kelly, 4\textsuperscript{th}-year scientist: For so many reasons… Umm, I loved learning… and the idea of continuously learning new things is exciting and because I could—loved the challenge of going after something difficult to attain. And then the encouragement from mentors, teachers, and peers…

Holly, 3\textsuperscript{rd}-year engineer: I was working in a lab [during undergrad] and I was really getting along with the professors, he was really nice, and, uh, so what happened was, I was just going to do the masters, you know, uh, and then, uh, senior year he was like, “Oh you, you should apply to the Ph.D. program.” And I was like, “Well, you know… I’m going to wait ‘til my, you know, doing my masters to think about it.” He’s like, “No, no, you should, you should apply to [name of university] now, you can think about the other ones later.” [Laughs] So I just really quickly—so I like filled out the application… I didn’t really apply anywhere else at that point and, umm, yeah so, it was kind of like, I guess, a little bit of inertia.

Toby, 3\textsuperscript{rd}-year scientist: …You apply to grad school because you get paid, I mean, it’s, umm, you don’t have to pay full—you actually get paid in addition, so you might as well go there… And I was encouraged by professors to go to grad school and so I did.

Edward, 14\textsuperscript{th}-year engineer: Well, I worked for the EPA at their facility and so I got exposure to, uh, to maybe more conventional scientific, uh, um, experimental work, and, uh I liked it. I liked the experience of asking questions, designing experiments, collecting the data and, uh, umm, reporting of the work and, um, one person in particular who worked at the EPA was very encouraging to me about going on, uh, for doctoral work, because he felt that I had uh, the right tools to do that, and I liked the idea.

David, 5\textsuperscript{th}-year scientist: Uhh, I’m still not sure [Laughs]… I guess I was encouraged quite heavily by my undergraduate advisor, uh, but I also… uh, I didn’t really have any strongly formed ideas about what I exactly was gonna do after undergraduate?

Though this encouragement—\textit{i.e.}, recognition—from professors, advisors, and peers during their undergraduate studies did not appear to be related to this dissertation’s focus on scientific epistemologies, the recognition the participants discussed in this context may allude to the participants’ development of professional identities.
Likewise, ownership has been highlighted as a key factor in establishing professional identities. Research with graduate medical students (Hamstra, 2007; Kenyon & Brown, 2007), nursing practitioners (Glen, 1998; Halford & Leonard, 2003), social science researchers (Berardi, 2002), secondary school teachers (ten Dam & Blom, 2006), and undergraduate students participating in science and engineering research programs (Seymour, Hunter, Laursen, & DeAntoni, 2004; Hunter, Laursen, & Seymour, 2007; Thiry et al., 2011) have all indicated that ownership is a key element in professional identity formation. As stated in the psychology literature, “Ownership helps people define themselves, express their self-identity to others, and maintain the continuity of the self across time” (Pierce, Kostova, & Dirks, 2003, p. 89). In addition, factors that contribute to ownership include effectance, the ability to affect and control one’s environment (Furby, 1978), and belonging, the sense of having a place (Porteous, 1976). Both of these ownership constructs were demonstrated by the faculty members’ experiences. In their beliefs of having complete control and authority over their research to help them define their notions of collaborations, the faculty members established their effectance over their work. Also, in their struggle to create their very own niche in their communities of practice—as demonstrated by their desire to build a reputation for themselves to help forge collaborative efforts—the faculty participants were expressing their efforts to find belonging. Though the results of this research primarily highlighted how ownership was a major factor in developing the participants’ personal epistemologies of science, these understandings of ownership may also suggest connections to professional identity development.

With the literature acknowledging recognition and ownership as key factors in professional identity development, it is most interesting that these factors were also found to
contribute strongly to the development of the faculty members’ scientific epistemologies. Moreover, the research with chemistry graduate students previously discussed in the pilot study of this dissertation also indicated that students’ limited understandings of scientific research ethics and normative values arose from their under-developed epistemologies of science, which we believed stemmed from a limited sense of professional identity (Verdan et al., 2010). In turn, the body of work presented in this dissertation introduces a new hypothesis, a possible relationship that has not been previously reported in the literature: the relationship between the development of scientific epistemologies and the development of professional identity for practitioners of science and engineering.

Summary

In addressing my overall research question, I discovered that the scientific epistemologies of academic scientists and engineers matured primarily in their positions as faculty researchers. This maturation was attributed to two major factors: the ownership of their research programs as faculty members and the recognition of their research programs by their communities of practice. Furthermore, since ownership and recognition have been found previously to be important components of professional identity, this research indicates a possible relationship between the development of personal epistemologies of science and the development of professional identities. The implications of this potential relationship has the promise to guide further research and inform the training and mentoring of future scientists and engineers, which I will discuss in the following, concluding chapter.
CHAPTER VI
CONCLUSIONS

As stated in the introduction of this dissertation, the overall goal of this research was to reveal the formative experiences that contribute to academic professionals’ understandings of scientific knowledge development and research practice in the science and engineering disciplines. This research revealed that through engagement in professional practice, science and engineering researchers in academia developed their personal epistemologies of science particularly with respect to their understandings of how scientific knowledge progresses and how society and culture influence the growth of scientific knowledge. This was made evident by the fact that concrete understandings of contributions, collaborations, and credit assignment were primarily formed through the experiences of owning a research program and having that research program recognized by the professional community of practice.

The model of scientific epistemological development that I have posed in this research—with its emphasis on the role of recognition and ownership and the possible relationship with professional identity development—can perhaps be used to recommend both further avenues of research and changes in training and mentorship practices for those on the trajectory of science and engineering careers. With the recent call to have one million more college students graduate in science and engineering disciplines within the next ten years (President’s Council of Advisors on Science and Technology, 2012) and the call for reform in science and engineering doctoral education (Golde & Dore, 2004), this model could serve as a timely part of that discussion.
Implications for Further Research

For the faculty members, the maturation of scientific epistemologies occurred through active engagement in their science and engineering communities. As mentioned in the preceding chapter, recognition and ownership—which were found to be critical factors in the development of the participants’ epistemologies—have also previously been established as key components of professional identity development. Thus, this research posed a new hypothesis of a possible relationship between scientific epistemological development and professional identity development. Since this relationship has not been alluded to either in the scientific epistemology or professional identity literature, further research can elucidate the nature, if any, of this relationship.

The possible connection between the phenomena of scientific epistemology and professional identity—through the attributes of recognition and ownership—can be investigated through various avenues. While the participants attributed their changing notions of scientific contributions to recognition from their science and engineering communities during their faculty positions, many of them also stated that encouragement from their undergraduate advisors or professors was one of the major factors that influenced their decision to pursue a Ph.D. degree. Though this encouragement—i.e., recognition—during their undergraduate studies did not explicitly relate to the participants’ personal epistemologies of science, it is possible that recognition in this context was associated with the faculty members’ professional identities, as this recognition was a factor that helped the participants choose to continue on the trajectory of science and engineering careers. Moreover, the influence of recognition from the community of practice on one’s identity formation is already well-established (Wenger, 1998). It is possible that as the participants
made and received recognition for their own contributions to the science and engineering communities—primarily in the form of publications and conference presentations, but also including the training of graduating students—they believed their work was validated, perhaps reaffirming or strengthening their professional identities. Receiving recognition from faculty mentors or more advanced members of their communities may have helped to reinforce their professional trajectories and perhaps strengthened the professional identities they held at the various stages of training. Further studies with science and engineering practitioners from undergraduates to academians, focusing on the influence and effects of all degrees of recognition—both positive and negative—during engagement in scientific research practice, may elucidate any possible connections between the development of scientific epistemologies and professional identities.

The ownership of their research programs was a primary factor in forming the faculty members’ notions of collaborations, in turn influencing their personal epistemologies of science. However, the role of ownership may also suggest connections to professional identity development. Although the participants discussed ownership only in the context of their faculty positions, previous studies have suggested that the ownership felt by undergraduate science and engineering students over their research projects helped contribute to the students’ professional identities as scientists (Seymour et al., 2004; Hunter et al., 2007; Thiry et al., 2011). One can speculate that faculty members find themselves in positions with major responsibilities. Unlike any other point of professional education or training, academic research positions come with the responsibilities of advising and mentoring both undergraduate and graduate students, developing and teaching courses, writing grant proposals and scholarly articles, obtaining and budgeting research funds,
participating in various committees and conferences, and collaborating with professionals in other disciplines, all in addition to starting their own research programs (LaPidus, 1998; Austin et al., 2009), all of which are meaningful, authentic activities as defined by their communities of practice (Brown et al., 1989; Lave & Wenger, 1991). Perhaps if faculty members have a personal sense of ownership over these various activities, they may recognize the relevance and importance of these activities for their own professional identity development. As stated by Bhattacharyya (2008), “Identity formation helps the individual define which activities are meaningful” (p. 91). This may motivate faculty members to learn these activities meaningfully for themselves for their own personal benefit, by attaching a personal meaning to these activities with communal meaning. Therefore, further research studies can reveal these understandings of ownership, investigating if various degrees of ownership exist at various stages of professional training and probing how those understandings of ownership may affect a student’s or practitioner’s perceptions of professional identity and the nature of science.

Educational Implications

Given this dissertation’s focus on post baccalaureate experiences, the following recommendations will center on improvements in graduate training and mentorship in the science and engineering disciplines, which may enhance their understandings of the nature of science. The results from the chemistry graduate students and the retrospective accounts of the faculty members indicated that their personal epistemologies of science appeared to be quite limited while pursuing their Ph.D. degrees. Moreover, numerous studies have demonstrated that individuals do not learn about scientific epistemology in an implicit manner, i.e., “by osmosis” (Workman & Bodner, 1997; Abd-El Khalick & Lederman, 2000a;
Samarapungavan et al., 2006). It has been suggested that one of the primary reasons that students do not learn about the nature of science through implicit methods is that typical science teaching involves a logical presentation of the “finished, well-formulated product of scientific research, not ‘science-in-the-making’” (Elkana, 2000, p. 472). Therefore, graduate students need specific and explicit assistance in this area to develop more sophisticated personal epistemologies of science (Verdan et al., 2010). In addition to pedagogical strategies, which have widely been discussed in the literature, authentic research activities may serve as another venue in which to explicitly develop students’ epistemologies. Since the results of this work indicated that faculty members’ scientific epistemologies primarily solidified with ownership and recognition experiences in academic positions, better developing the NOS understandings of graduate students through professional practice should require mentors to give recognition to students’ research efforts and to create opportunities for students to take ownership over research projects.

Of these two ways to enhance mentorship, giving recognition is more easily achieved than establishing ownership. Research advisors and other well-established members of the community of practice can give recognition through acknowledging students in conference presentations, designating students as mentors for new research group members, and—most notably—assigning credit and authorship to students on research publications. All of the participants expressed that these were formative recognition experiences during their graduate training. Ownership, however, is more difficult to institute since it requires effort from the mentor and—most importantly—the students themselves. Because ownership stems from within an individual, it is ultimately the responsibility of a graduate student to
accept and establish ownership. As one faculty participant mentioned about training his graduate students to understand research,

It’s just opening the door, that they have to walk through the door, you know, you can’t, you can’t lead them all the way down the path.

Therefore, faculty mentors must create opportunities for students to develop ownership, while students must embrace these opportunities and integrate them into their understandings of professional research practice.

To construct these opportunities for ownership, I suggest that academic research advisors and their graduate students explicitly establish and comprehend the learning expectations of Ph.D. training and research projects. When these learning goals are not made clear, the advisor’s meaning of a particular activity may be quite different from the graduate student’s meaning of said activity, causing a disparity between the advisor’s and the student’s learning outcomes. However, by explicitly establishing and mutually creating learning goals, students will have a vested stake in their research projects. By being involved in the formation of their own learning outcomes—whether they be developing technical or conceptual expertise, strengthening communication and oral skills, or enhancing teaching or leadership abilities—students may be able to develop a sense of ownership for their research project and Ph.D. education. Moreover, by creating these learning outcomes together, advisors can also explicitly demonstrate to students how various daily research activities are congruent with the practices of science and engineering researchers. As students recognize that these activities are authentic activities of the community of practice, they can also enhance and develop their personal epistemologies of science and perhaps even their
professional identities. Therefore, the mutual creation of learning goals will allow students to be engaged in meaningful activities while developing a sense of ownership for their research.

Conclusion

In sum, this body of research has revealed the development of academic science and engineering researchers’ personal epistemologies of science. Through engagement in research practice, they realized that scientific knowledge could develop in ways similar to “finding a new continent” to “mapping all the rivers.” The development of their epistemologies was heavily influenced by the recognition of their research programs by their communities of practice and the ownership of their research programs as faculty members. In order to have the best prepared workforce of future scientists and engineers, students and educators alike should consider recognition and ownership, and together establish the most effective ways to foster the development of these two phenomena.
Appendix A: Pilot Study Interview Protocol

Project Title: Normative and ethical conceptions of chemistry graduate students

INTERVIEW PROTOCOL

Background
1. In what year of graduate school are you in currently?
2. Prior to coming here, what types of experiences did you have with scientific research? How long did those last?
3. Before coming to this university, did you work in a scientific field? If so, can you please explain what you did and for how long?

Scientific Norms
1. Can you please tell me your understanding of what constitutes scientific misconduct? How about good scientific conduct?
2. Are any of these standards specific to your field or do you think that they are independent of a field?
3. What experiences led you to develop your current understanding of scientific misconduct in your field?
4. Have your ideas about what constitutes acceptable versus unacceptable behavior in your field changed over time? If so, how have they changed? Why do you think they changed?

Ethical Conduct
1. When you do an experiment, how and when do you know that the conclusions are valid?
2. During an experiment if there is a small error, such as spilling a small amount of a measured substance, what do you do? On what bases do you make your decision(s)?
3. Do you collaborate with anyone in your research? If so, have you been in a situation where your results of an experiment did not agree with those of your collaborator? How did you resolve that?
4. How do you determine whether data may be excluded from your research? How do you deal with error, in general?
5. Have you ever shared data with another scientist? What are the potential problems with that?
6. How is authorship decided in your group? How do you feel about that arrangement? What is the ideal way of determining authorship, in your mind?

Do you have any conflicts with your personal standards of conduct and those observed in the course of your research? If so, what are the differences? How do you reconcile these differences?
Appendix B: IRB Informed Consent Form

Consent Form for Participation in a Research Study
Clemson University

Gautam Bhattacharyya & Andrea Verdan – Department of Chemistry

Conceptions of Contributions, Collaborations, and Credit in Scientific Research

Purpose of Research
The purpose of this research is to explore how engineering and science researchers in academic positions understand and practice the concepts of making contributions, participating in collaborations, and assigning credit in scientific research.

Specific Procedures to be Used
You are asked to participate in a single interview lasting 45 to 60 minutes. The questions in the interview will focus on your beliefs and perceptions of the concepts of contribution, collaboration, and credit assignment in scientific research. The interviews will take place in your office or in a room of your choice 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. After completion of data analysis, all tapes and written artifacts will be destroyed. Federal regulations require all consent forms to be maintained for at least 3 years after the completion of the study. After this time, the consent forms will be destroyed. You will be 1 of approximately 20 participants of this study.

Duration of Participation
You are asked to participate in a single interview lasting 45 to 60 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 your department, in the College of Engineering and Science, 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 interviewing researcher will know the identity of the 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. The interviewer will complete the transcriptions.

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 your department, in the College of Engineering and Science, 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 PI, 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 C: Excerpts of Subjectivities and Personal Reflections

Questions pondered prior to dissertation research:

Identity and empowerment: these are two things that really interest me. This perhaps ties in with my own lofty altruistic ideas, but I think that I have always wanted to make a difference in the world. Ever since I was a little girl, I wanted to be a doctor, someone who helps people feel better. I later discovered that I could not handle the stress of being a doctor, but I found that I really liked helping people learn. I love seeing those moments when the light bulb goes off in a student’s head... How can I help people have that moment, not just in the learning a chemistry concept, but in the learning of themselves as people? I am always trying to understand myself and how I “fit” into the vast world that surrounds me and I am always humbled by seeing the various ways people live their lives. I think that a research project based on these ideas—helping people learn about themselves—is very worthwhile.

Reflections on recognition:

Did participants recognize themselves as merely graduate students? Perhaps there was self-doubt in recognizing that they had the content knowledge and competence, which made chemistry graduate students resistant and hesitant to acknowledging themselves as researchers? I believe the tendency to communicate with their advisors and get approval of their results from their advisors or confirmation of the work by the literature demonstrated their lack of confidence in their work, or lack of recognition of their own competence and knowledge of science content (but I need to look at the data again to see if it exists here)... Now as academic research advisors, it seems the participants recognize that giving students authorship helps in the recognition by others, so that the students’ careers as researchers will be moved forward. Maybe as graduate students, the recognition of SELF as an expert in the discipline is minimal mostly may be due to their belief of the lack of content/knowledge competence (even though they may have it) and lack of ownership of the work (does not come up with the research questions/ideas)?

Reflections on my notion of contributions:

Based on my brief reading through of all of these interviews, I’m feeling quite discouraged. What is it that is new about my work? How is this work a contribution? How is it significant and valuable to a greater community of people, of scientists, of chemists? Is this going to change anything? After reading through all these interviews and finding these broader themes, I feel as if all the responses were quite obvious, in the sense that these interviews didn’t really need to be conducted to find what the data reveals. It’s all self-evident. So what do I do with that? It’s quite frustrating and I don’t know where to go from here. And this feeling of frustration will definitely make me look at the data through a different lens...???

Reflections on my ownership of my research:

Is authorship the advisors’ implicit way of giving students recognition (key component of identity)? But what would the students think about this? Does this build their confidence in the work that they are doing? Can they take ownership of the work if the research idea was not their own? Thinking about my own research, yes, it’s nice to have my papers out there, but what does that mean to me? I feel like I “own” my chemical education work to some extent, but my bench chemistry research does not feel like my own. I basically tested three compounds that are very similar to others that have been studied and I conducted experiments on them that have already been previously outlined. Where’s the new and novel in that?
REFERENCES


LaPidus, J. B. (1998). If we want things to stay as they are, things will have to change. *New Directions for Higher Education, 1998*(101), 95-102.


