Discourses and gender in doctoral physics:

A hard look inside a hard science

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Dedication

This dissertation is dedicated to the memory of my grandmother, Mimi, who knew a thing or two about gender and Discourse.

Mary (Dolly) Jardim (1912-2009).

"To err is human, but if you really want to mess things up, use a computer."

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Abstract

In Canada today, a gender disparity persists in the enrolment and persistence of doctoral students in physics. Scholarship on this disparity has, in the past, focused on issues of equity and difference in order to find ways to recruit and retain more women in physics. This approach offered a limited perspective on gender and relied on essentialist notions of being a man, woman or physicist. This study highlights the importance of a focus on gender as an aspect of identity construction, thus opening up possibilities for exploring how doctoral students navigate ideologies of gender at the same time that they learn how to become physicists.

Doctoral physics students have stories about what kinds of actions, behaviours and ways of doing physics allow individuals to be recognized as physicists. Viewing a physics department as a case study, and individual participants as embedded cases, this study uses a sociocultural approach to examine the ways doctoral students construct these stories about becoming physicists. Through observations, photo-elicitation, and life history interviews, eleven men and women shared stories about their experiences with physics, and the contexts that have enabled or constrained their trajectories into doctoral physics.

The results of this study revealed the salience of recognition in the constitution of physicist identities: individuals who saw themselves, or were seen by others, as physicists were more likely to pursue trajectories into academic physics. Further, various interchangeable forms of competence emerged as assets that can be used to achieve recognition in this physics community: technical, analytical, and academic competence were identified by participants as characteristics necessary to achieve recognition as a physicist. Additionally, achieving recognition as a competent physicist often involved a complex negotiation of gender roles and the practice of physics. The results demonstrated that a persistent tension exists between participants' conventional and gendered descriptions of doing physics and being physicists, and the actual business of doing physics and being physicists.

The study offers new perspectives on the interaction between gender and physics, and challenges current thinking about the reason for gender inequality in science and the best methods for rectifying that inequality. The dissertation ends with recommendations for further research and suggestions for the undergraduate and graduate physics curriculum.

Résumé

Au Canada, aujourd'hui, une disparité entre les sexes persiste concernant les inscriptions et la rétention des étudiants qui poursuivent leurs études doctorales en physique. Dans le passé, les recherches sur cette disparité ont portées sur les questions d'égalité et de la différence afin de trouver des moyens pour recruter et garder davantage de femmes en physique. Cette approche a offert une perspective limitée sur les sexes et s'est appuyé sur les notions d'essentialiste d'être un homme, une femme ou un physicien. Cette étude souligne l'importance de l'égalité des sexes comme un aspect de la construction de l'identité, ouvrant ainsi des possibilités pour explorer comment les étudiants doctorales naviguent les idéologies des sexes en même temps qu'ils apprennent à devenir physiciens.

Les étudiants poursuivant des études doctorales en physique ont des histoires des types d'actions, des comportements et des méthodes de la physique permettent aux individus d'être reconnus comme physiciens. En présentant un département de physique comme une étude de cas et des participants individuels comme des cas intégrés, cette étude utilise une approche socioculturelle pour examiner les manières que les étudiants poursuivant un doctorat construisent des histoires qui racontent comment ils deviennent physiciens. Grâce à des observations, extractions avec photos et entrevues d'histoire de la vie, onze hommes et femmes ont partagés des histoires au sujet de leurs expériences avec la physique et les contextes qui ont favorisé ou ont contraints leurs trajectoires menant au doctorat de physique.

Les résultats de cette étude ont révélés la reconnaissance saillante dans la constitution des identités des physiciens: des individus qui se sont vus ou qui ont été vus par d'autres comme physiciens étaient plus susceptibles de poursuivre leurs trajectoires menant au doctorat en physique. De plus, diverses formes interchangeables de compétence ont apparus en tant qu'atouts qui peuvent être utilisés pour atteindre la reconnaissance dans la communauté physique: les compétences techniques, analytiques et académiques ont été identifiées par les participants comme des caractéristiques nécessaires pour atteindre la reconnaissance en tant que physiciens.

De plus, gagner la reconnaissance en tant que physiciens compétents impliquait souvent une négociation complexe des rôles entre les sexes et la pratique de la physique. Les résultats ont démontré qu'une tension persistante existe entre les descriptions conventionnels et les descriptions sexospécifiques des participants qui pratiquent la physique et qui sont physiciens, et de la pratique actuel de la physique et d'être physiciens.

L'étude offre de nouvelles perspectives sur l'interaction entre les sexes et la physique, et met au défi les pensées actuelles sur la raison de l'inégalité entre les sexes dans les sciences et les meilleures méthodes pour rectifier cette inégalité. La thèse se termine par des recommandations pour des recherches plus approfondie et des suggestions pour le cursus des études du premier cycle ainsi que les études supérieures.

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Discourses and Gender in Doctoral Physics: A hard look inside a hard science

Introduction

> Peter and Saïd invited me to spend an afternoon with them while they prepared a number of tips they were testing on the STM (scanning tunnelling microscope). I was nervous because I knew that they were excited to have me along and I anticipated not being able to follow along with all of the procedures . . . I pretended to follow, and I pulled out some of my terminology that I remembered from a course on scanning electron and confocal microscopy during my master's degree, but truthfully, I was lost most of the time . . . In the end, there was a short circuit and the images could not be produced. Peter and Saïd seemed disappointed, but not discouraged. Apparently this kind of thing happens all of the time. We began to pack up our stuff when the lab technician, Tim, said to me "You know you're the first woman to be allowed back there [at the microscope]." I was a bit perplexed at this, as I knew the previous PhD student to use the STM had been a woman. "What about Marie?" I inquired. "Oh," he responded, "well, you're the first non-physicist woman to go back there. We'll have to perform a cleansing ceremony when you leave." Both Peter and Saïd looked at me apologetically, but I think I managed to appear unfazed. (Field notes, December 12, 2007).

This episode, adapted from my field notes, tells my story of being very out of place—a non-physicist woman in the physics lab, observing an experiment on a very large, very expensive instrument. As I reviewed the field notes that I took during four months of observation in the physics department, it struck me that this interaction encapsulated precisely what I hoped to explore in this study: the co-construction of gender and physics. During my visit to the lab that day, I encountered a great deal of scientific terminology, methodology, and principles that I had never heard of before and struggled to understand. While observing the experiment, I used as much scientific terminology as possible to relate the science I was observing with the science I myself had conducted in my undergraduate and master's degrees in molecular biology. In doing so, I positioned myself in relation to Saïd and Peter and others in the lab as someone who had a working knowledge of scientific concepts—my attempt to be recognized as an insider to science. The effect of this could have involved being recognized as a science-person. However, just before leaving, Tim cleared up any ambiguity about who I might be in the context of the lab. To him, first, I was a woman. As a woman and a non-physicist, I was regarded as an anomaly in the lab. Of course, the statement about the cleansing ceremony was said in jest, but the effects of what was said remain: I interpreted a message about how my efforts to be recognized as an acceptable presence in the laboratory were received. Tim forgot that there had been another woman in the lab before; in fact, she received a doctorate from the work she had completed on the STM. As a physicist, was she therefore not a woman?

This dissertation seeks to explore how doctoral students in physics construct ideas about their practices that draw on cultural discourses about who is able to be a physicist, what they should like, and how physicists should behave. To understand the interaction I just presented requires an exploration of the discourses or the folk theories that predominate in the physics community about who a physicist should be, and what characteristics are needed to be recognizable as a physicist. In what follows, I explore how participants construct these ideas, but also how they position themselves around these ideas in the constitution of their own identities as physicists. Ultimately, this dissertation will provide some insight into the cultural practices of a local physics department, and the range of *forms of physicists* these practices make it possible to be in this community.

Gender and Science Education

Evelyn Fox Keller, a theoretical physicist and feminist writer, has suggested that our current dualistic understanding of gender and science renders a situation where "any scientist who is not a man walks a path bounded on one side by inauthenticity and on the other by subversion" (Keller, 1985, p.174). According to Keller, this critical problem of identity stems from the unproblematic association of masculinity with science, and therefore the problematic association of femininity with science. My experience in the lab that day made me wonder if indeed it is possible to be both a woman and a physicist without a radical redefinition of those terms, and if not, how might those terms be redefined, or at least, how might they be subverted? Keller's work on the dualistic nature of masculinity/femininity and science/nature is still relevant today, as research into the issue of women in science often takes up these traditional and rigid views of gender and science (e.g., Fox, 2000; Herzig, 2004; Sonnert & Holton, 1995). Keller's work challenges us to start from a position where the terms *woman* and *scientist* are called into question, so that we may destabilize the current regimes of truth that are brought about from research into the so-called problem of women in science.

Over the past 30 years, researchers in the fields of gender and science education, along with those in feminist science studies have written about gender bias in the construction of scientific knowledge, the cultural norms and values of scientific communities, and curricular and pedagogical practices in science education (for extensive reviews of the literature, see Blickenstaff, 2005; Brotman & Moore, 2008; Whelan, 2003). Research and initiatives to address, in particular, the low percentage of women pursuing graduate degrees in the physical and engineering sciences have been met with limited success, despite a considerable investment of resources (Canadian Association of University Teachers, 2009; Ivie & Ray, 2005, Phipps, 2008).

A substantial literature has identified a high attrition rate for graduate women in the sciences (see Herzig, 2004). However, there is a lack of Canadian gender-disaggregated data on women who graduate with PhDs in science, and even less information is available about those who continue on in the workplace, either academic or industrial. The statistics that are available from Statistics Canada—our main resource for information about students transitioning from graduate studies to the workforce—are only moderately informative when examining the percentages of men and women completing doctoral degrees. In Canada, between 2003 and 2004, 43.5% of doctoral graduates in the biological sciences were women (Gluszynski & Peters, 2005). However, during the same period, only 22.9% of graduates with doctoral degrees in the physical sciences were women. Five years later, the enrolment of PhD students in biology went up to 48.7% women, whereas the enrolment of women in PhD programs in physics went down to 21% (CAUT, 2009). The exception to this is doctoral astrophysics, where the enrolment of women remains relatively constant at 33.3% (CAUT, 2009). The obduracy of this disparity, despite efforts to recruit women into physics (e.g., NSERC chair for women in science and engineering), should signal to researchers that the standard paradigm on research and interventions into gender issues in science are not sufficient to instigate change.

In Chapter 3, I will expand on the theoretical use of the term *gender*, but here I will foreshadow that I regard gender as a social construct that is manifested differentially in local contexts. It is important at the outset to make a distinction between gender and sex. Rennie (1998) discussed the problem of conflating the terms *sex* and *gender* in research on girls and women in science. She explained that, in educational literature, the term gender only gained currency in the late 70's when researchers began to make a distinction between sex, which is biologically determined, and gender, which is socially constructed. Research about the differential treatment of men and women students in science classes, however, refers to the gendered "differences based on socially or culturally determined behavior which are responsive to people's biological sex" (Rennie, 1998, p. 953). The importance of emphasizing the social construction of gender categories rests in the subsequent ability to see these categories as malleable and available to all individuals, not just those of a certain sex. Thus, masculinity and femininity are learned constructs, and becoming girls and boys or women and men entails constructing ideas about masculinity and femininity in the communal local social contexts in which people live (Paechter, 2007).

This theory of gender allows us to cast a new theoretical lens on research that has tended in the past to focus exclusively on women's experiences. For example, Butler (1999) called into question the very premise of research that seeks to redress gender imbalances by relying on a universal notion of female or woman. Butler argued that the terms man and woman are foundational to feminist studies and conform to and reinscribe the heterosexual matrix that constructs them. Therefore, research that produces that framework automatically reinscribes power. Butler (1999) further suggested that power is not just enacted in the framework of the subject/Other, but that it also operates in the production of that framing. So, our very question—what is the problem with women in science?—is troubled from the outset.

To address the problem of research that focuses on women as a category, Butler asked, "to what extent does the effort to create a common identity as the foundation for a feminist politics preclude a radical inquiry into the political construction and regulation of *identity* [emphasis added] itself?" (1990, p. xxix). The claims to a universal patriarchy that once dominated feminist thought no longer carries the same kind of foothold it once had; however, the universalized term woman that was similarly constructed in that framework has been more difficult to displace. Recently, research on the topic of gender and science has begun to challenge the assumptions upon which many of these research initiatives are based: that men and boys, and women and girls belong to homogeneous groups, and that masculinity and femininity can be unproblematically associated with these groups (Gilbert & Calvert, 2003; Henwood, 1998; Phipps, 2007).

Another underlying assumption, argued by Gilbert and Calvert, is that science is somehow gender-neutral. Based on this assumption, all that needs to be changed is the culture of science for it to be more female-friendly—presumably this could be done by generating a critical mass of women scientists in the most under-represented fields. This remedy was thought to be sufficient to change the representation of science as masculine, and thus permit the increased participation of women. However, this conception of the problem and its remedy may do more to reify the problem than change it.

To address these concerns, science-education research, particularly at the level of school science, has turned to sociocultural theories of identity and learning (Brotman & Moore, 2008). Research now pays greater attention to the ways that schooling, and in particular science education, has acted to reproduce a view of science as objective and dispassionate and has concomitantly privileged certain groups of people and marginalized others (Carlone, 2004). In doing so, this kind of research examines the ways that students who are marginalized from science can experience difficulty engaging with science and seeing themselves as scientists (Barton, 1998a; Carlone & Johnson, 2007; Wood, 2004).

Research questions

The overarching goal of this dissertation is to take up this recent approach to understanding issues of gender equity in physics-education research, but at the tertiary level where sociocultural frameworks have only recently been employed (e.g. Danielsson, 2009; Tsai, 2004). To that end, I will explore the usefulness of a theoretical approach to studying issues of gender and science that looks beyond categories of woman, man, and physics and attempts to explore how discourses of gender and physics are co-constructed in local contexts. Sociocultural theories of identity allow us to explore the constitution of physics communities as constructed by discourses of what it means to do physics and to be a physicist (Gee, 2005; Holland, Lachiottee, Skinner & Cain, 1998). Post-structuralist theorizing of gender presents us with possibilities for creating a more complicated picture of gender relations in physics (Butler, 1990; Davies, 1989, 1993; Paechter, 2003a, 2003b, 2007; West & Zimmerman, 1990). Drawing from both sociocultural theories of identity and post-structuralist gender theory, I explore the construction of a physics community through discourses about what it means to do physics and what kind of physicist it is possible to be in this local setting. Using qualitative data, I construct stories that detail the resources that participants bring to their practice as physicists and explore how these resources contribute to participants' ideas about doing physics. I then examine how the women participants in this study construct identities as physicists through their various forms of participation in the discourses of physics. To achieve these goals, I ask the following research questions:

1. What experiences and contexts have contributed to participants' trajectories into and through academic physics?
2. How do physics doctoral students describe the practice of physics in their local contexts of research teams in a particular physics department?
3. How do physics doctoral students describe what forms of physicist it is possible to be in their local contexts of research teams in a particular physics department?

4. How do women doctoral physics students use their schema and resources and the available forms of physicist to participate in their research groups and physics department, and to construct their identities as physicists?

Empirically, the research presented in this dissertation was conducted through observations, interviews, and a novel methodological approach called photo-elicitation to generate stories that construct the field of physics. Using an analytical approach that regards identity as stories of recognition, I describe how doctoral students accept, refuse, or negotiate the cultural discourses of physics. Theoretically, this dissertation challenges researchers to rethink the approaches to studying gender and science, and in particular, to move towards a more nuanced understanding of the ways that gender and physics are co-constructed.

Physics as a Research Site

The physics department where I conducted this study is well-renowned and provides programs in theoretical, observational and experimental astrophysics, biological physics, condensed matter, theoretical and experimental high energy physics, theoretical and experimental nuclear physics as well as non-linear, applied, and medical physics. My contacts with the physics department stemmed from my friendship with a finishing doctoral student in theoretical high-energy physics. I used this relationship coupled with a master's degree in science to construct a pseudo-insider status for myself in the department. My insider status did not come from an epistemological familiarity with physics, but rather from a superficial familiarity with the social structure of the department. Circles of friends, teams, student councils, and their various epistemological alignments with disciplinary subfields became apparent to me through my social connections in the department. This contact also enabled me to recruit participants. By positioning myself as an insider to the social network of some of the groups within the department, I was able to identify a few participants for the study, who subsequently referred me to acquaintances that they believed would also be interested in participating. Ultimately, I chose to invite participants to the study from three epistemologically distinct fields of physics, thus three distinct research labs or groups including theoretical, observational, and experimental approaches to research. Each represented different subfields: theoretical high-energy physics, observational astrophysics, and experimental condensed-matter physics.

Physics, as a designated hard science, is often positioned in popular discourse as incompatible with femininity (Schiebinger, 1999). The strong associations between femininity and women thus render women as incompatible with physics in public understandings of who is able to participate in the discipline. This was made evident in 2005 when Larry Summers, then president of Harvard University, described women as less capable than men in math and physics. His speech sparked outrage when he argued that women may lack innate ability for spatial reasoning or abstract thought, which has led to their under-representation in the harder sciences, such as physics. He suggested that the under-representation of women in science can be explained by:

> the general clash between people's legitimate family desires and employers' current desire for high power and high intensity, [and] in the special case of science and engineering, there are issues of intrinsic aptitude, and particularly of the variability of aptitude, and that those

> considerations are reinforced by what are in fact lesser factors involving socialization and continuing discrimination. (Summers, 2005, p. 1)

The media's response to this statement was overwhelming, and debates concerning women's representation in science, gendered ability in science, and institutional discrimination dominated the print media for weeks after the event. The event spawned academic debates on whether men and women have innate differences in scientific ability (Brockman, 2005); and as reparation for the statement, Harvard University initiated the Task Forces on Women Faculty and Women in Science and Engineering, to investigate the situation for women in science at Harvard University and recommend policy initiatives to improve women's persistence in science degrees and careers (Report from the Task Force on Women in Science and Engineering, May 2005).

There have been responses specifically to this statement in the academic literature as well, with publications in science (Barres, 2006; Dar-Nimrod & Heine, 2006), psychology (Spelke, 2005), and popular culture journals (Pinker, 2005). All of this attention in the popular and academic press has turned the spotlight on studying science at graduate levels.

Doctoral physics education

Doctoral education in physics often leads to postdoctoral work and subsequently academic or industry positions. Thus, doctoral education as a site of identity transformation from student to professional is particularly interesting, and bears implications for the gendering of educational trajectories and identities (Fox, 2001). Studies that provide empirical support for many of the factors suggested to be a barrier to women in doctoral physics are often contradictory and ambiguous, and as such, the role that gender plays in students' experiences in science continues to be a source of controversy (Carlone & Johnson, 2007). For example, in a review of the literature on barriers to women in doctoral mathematics and sciences, Herzig (2004) identified numerous factors that can be regarded as structural barriers for women in science and math, including isolation, lack of confidence, pedagogical styles, insufficient mentoring and advising, competition, and insufficient financial and familial support. Wood (2004) identified similar barriers to women doctoral students in engineering, and highlighted cultural barriers such as requirements for sameness in engineering culture. While many of these barriers are noted as specific to women, they may also serve as barriers to any doctoral student in any discipline. Golde (2005) identified numerous factors related to attrition in four disciplines of doctoral education, none of which were aligned with gender. Carlone and Johnson (2007) also argued that factors relating to persistence are fairly static—either one has family support, or one does not.

Research that identifies factors related to persistence provides important perspectives for understanding barriers for women in science, but we remain in the dark about how discourses of physics are constituted, how gender factors into this, and how students position themselves around these discursive structures (notable exceptions are Danielsson, 2009; Tsai, 2004). For example, in the public discourse on women in science, we often hear of the incompatibility of women and physics, but we seldom hear of students who enjoy and find success in physics, and how they author spaces for themselves among discourses of masculinity, femininity, and the current regimes of truth in the hard sciences (Tonso, 1997, 2006; Wood, 2004). The experience of being successful in a field that poses so many barriers to women has only been discussed by a handful of researchers (Gilbert & Calvert, 2003; Henwood, 1996; Walker, 2001). While many view the symbolic masculinity of the field as a deterrent, this does not mean that men will be attracted to the field because of its masculinity, nor does it mean that women will be deterred (Phipps, 2007). This warrants considerable interrogation, and provides a rationale for exploring the experiences of persistent students in doctoral physics programs, and for including both men and women in this study.

Personal motivation

This dissertation emerged from my personal history with science, and thus has also entailed an examination of my own personal relationship with science. Both my undergraduate and master's degrees were done in molecular biology and genetics in the mid to late 1990's. My master's project entailed characterizing the effect of chromosome position on gene expression in fruit flies with a view to expanding our understanding of nuclear architecture and chromosomal mechanics. During my time as a genetics student, I worked in a molecular genetics diagnostics lab in a hospital in Toronto and for many years as a teaching assistant and sessional lecturer for a human genetics course at the University of Guelph where I completed my MSc. Afterwards. I was employed as a curriculum developer for a private company that provides hands-on science-education programs for youth. My new job did not employ the skills I developed as a geneticist, but was not a huge step away from science. While I worked, I also began pursuing a part-time Master's of Arts in Education, which eventually morphed into a full-time PhD once I quit my job. I was not exactly a scientist anymore, but I was not a science dropout either.

My identity as a scientist is no longer defined by what I do, but rather is now defined by how others interact with me, refer to me, and sometimes defer to me. Friends who know my background often refer to me as the resident scientist, or more often science nerd, and will often ask me medical-, health-, or science-related questions in conversation. I also believe that I am generally expected to have an interest in all science-related topics (whether in my former discipline or not), and am expected to have a science-oriented aesthetic (i.e., love for art, television, or films that are science related, nature oriented, or mathematical in nature). More often than not, these expectations and assumptions are not accurate portrayals of my preferences and orientations—something that made me realize that my identity as a scientist is recognized most often by the views of my interlocutors rather than one that I recognize myself (Carlone & Johnson, 2007). Thus, my own experiences in science, and later in science education, have bolstered my interest in the gendering of science, and more recently, the gendering of physics.

Organization of the Dissertation

In the following chapters, I will construct a story of physics and physicists, detailing the experiences and trajectories that led 11 doctoral students to physics, their ideas about the forms of physics and who physicists can and should be, and how physics identities are constructed around these forms of physicist. In Chapter 2, I present trends in research on gender and science education ranging from the liberal feminist agenda of achieving parity in science to the radical feminist call for a new order in science epistemology. This is followed by a discussion of the more recent turn to sociocultural frameworks of identity in science education and the merits using such an approach in science education. I also review some of the relevant literature addressing issues of gender in science education at the tertiary level, in particular, studies focusing on physics and engineering. The literature review focuses on these two disciplines because they are closely related and are considered hard sciences and because these two disciplines represent those with the greatest disparity in gendered enrolment and persistence.

Chapter 3 provides an in-depth discussion of discourse and identity and how these concepts will be used, among others, to understand how students negotiate available subject positions in physics. A theoretical justification for the analytic approach chosen in this study is also provided, along with the theoretical conceptualization of gender, and the importance of post-structuralist understandings of gender for this study. Chapter 4 introduces the methodological approach used to explore the guiding questions of this research and details the methods used and the process of analysis leading to the findings presented in Chapters 5, 6, 7 and 8. Chapter 5 provides profiles of the participants involved in the study to highlight or foreground the varied trajectories of past history and present experiences of gender and physics. In this first-order analysis I address the first research question and construct profiles that explore participants' stories about of forms of recognition, influences, and role models. From this, I identify the experiences and contexts that have contributed to their educational trajectories.

Chapters 6 and 7 explore the ways that participants construct discourses of physics and physicists in their various disciplinary subfields. These chapters are guided by the second and third research questions and examine the ways that participants constitute their community through discourses of physics, by delineating who can be physicists and what counts as appropriate ways of being physicists. Chapter 8 presents findings in response to the fourth research question. Here, I use the analytical tool of positioning to explore how women participants in this study accept, reject, or negotiate the subject positions offered to them as physicists, as described in Chapter 8. Throughout Chapters 6, 7 and 8, I refer back to the participants' experiences and contexts detailed in Chapter 5 to identify schema and resources that may influence the ways that women participants accept, reject or negotiate the subject positions offered through Discourses of physics and physicists. Chapter 9 will present an analysis of the findings from Chapters 5-8 and will refer to continuities or inconsistencies with similar studies in the existing literature on gender and physics education. Chapter 10 concludes with a discussion of contribution, limitations of the study and recommendations.

Throughout the dissertation, I aim to challenge the conventional wisdom that has until now constructed and guided the arena of activity around the so-called problem of women in science (Gilbert & Calvert, 2003; Phipps, 2007). This dissertation aims to challenge normative categories of gender, and contributes to a body of research seeking to move beyond questions of parity, and rather to examine, instead, the co-construction of gender and physics. This research invites conversations among researchers concerned with sociocultural issues of identity in science education, and those investigating doctoral education to reconsider the approaches to understanding the gender gap in physics. This study may be of interest to those concerned with issues pertaining to women and non-traditional career choices and also adds to the body of research already existing on women in science, particularly the scant research on gender and physics. Finally, this research may be of interest to science educators concerned with the theoretical and methodological application of identity frameworks, to understand how students navigate the discursive terrain of science, and what implications this journey has for the concomitant construction of gender and science identities.

Chapter 2

Situating this Research

> Science is the name we give to a set of practices and a body of knowledge delineated by a community . . . Similarly, masculine and feminine are categories defined by a culture, not by biological necessity. Women, men, and science are created together, out of a complex dynamic of interwoven cognitive, emotional and social forces. (Keller, 1985, p. 4)

The overarching goal of this chapter is to present different approaches to studying issues of gender and science, while at the same time calling these approaches into question and presenting an alternative. I do this by arguing that the conventional categories that we use for women/men and science/physics are limiting the ways that we can conceptualize the problem by their typically unchallenged associations with masculinity and femininity. As such, I argue that the incorrect conflation of masculinity with men and femininity with women creates problematic categories that are then positioned in line with or in opposition to physics. To address the issue of gender in science, we must first decouple these terms.

I begin with a discussion of a range of feminist critiques of science and conceptualizations of the issue of gender and science that represent a change in focus from problems attributed to women towards a problematization of science itself. I subsequently consider how the *women question in science* has been explored by researchers, particularly at the tertiary level of education. I then take up the necessary discussion of the problems inherent with a view of women as an essential unified category. Finally, I introduce the turn to sociocultural theories of learning in research that examines issues of gender and science, and I discuss the value of this recent trend in science education. This review of the contemporary issues that construct research questions and activism around gender and science is necessary to situate the research questions I pose in this study and to provide context for the theoretical lens I will be turning onto the issue.

The Science Question in Feminism

More than two decades ago, Harding proposed that feminist studies in science shift their attention from the "woman question in science" to the "science question in feminism" (Harding, 1986). This redirection of attention de-emphasized how to get more women into science and instead queried what was inherent in the culture of science that appeared to be so unwelcoming to women. Since then, there has been a plethora of feminist research scrutinizing the ideologies inherent in science, and the masculine, Eurocentric nature of scientific practices, texts, and products of modern Western science (Harding, 1991, 2006; Keller, 1985; Whelan, 2003).

Harding's (1986) proposal to shift the critical lens from the lack of women in science to the epistemology of science itself was helped by Keller (1982) influential work which detailed a range of critiques (broadly, from left to right on the ideological spectrum) around which activism, research, and theorizing can take place. She suggested that there are four points around which researchers and theorists may begin to take up criticism of science. The first is the perspective that science, as it was in the early 1980's, is largely dominated by men, and as such, practices unfair employment policies, which should be repaired for the purposes of equity. This stance is most often taken up by federal agencies and funding institutes (e.g. in Canada, the National Sciences and Engineering Research Council [NSERC] has established a Chair for women in sciences and engineering that has increased participation of women in science as one of its main goals[i]).

Keller's (1982) second point extended the first, and posited that the predominance of men in science has led to an androcentric bias in science wherein the questions of scientific inquiry are generally posed from a male's perspective. The third point built on the second and suggested that the development of methods and techniques to address these questions also have an androcentric bias. Keller provided several examples from the health sciences wherein the effects of these technologies may be detrimental to women, and we can see how these criticisms are easily applied to the life sciences, e.g., the preponderance of clinical testing for medications that excluded women from their samples, often alleging that women's reproductive cycles would complicate data sets (Keller, 1982). However, Keller argued that these criticisms are most often targeted at the softer sciences, and that it is much more difficult to "locate androcentric bias in the 'hard' sciences, indeed in scientific ideology itself" (p. 592). Thus, the fourth and most radical of Keller's points criticized the very assumptions of objectivity and rationality that underpin modern Western science.

Keller (1992) also pointed out that the foundations of science rest on the mind/body, subject/object, and mind/nature divisions, which leads to a valuing of detachment, objectivity, and rationality in science, and a devaluing of intuition, feeling, and connectedness. Where this becomes problematic for gender politics is the subsequent association between those scientific characteristics and masculinity, and the non-scientific characteristics with femininity. Keller suggested that we decouple masculinity and maleness and, by extension, masculinity and science—or, in her words "learn to count past two" (Keller, 1992, p. 51).

Following Keller, perhaps the most influential of the feminist critiques of science have come from those feminist writers engaged in the articulation of feminist standpoint theory. Harding (1991) provided justification for the development of this theory by describing science as it is understood in modern Western society and the role that women play in it. Harding described the differing perspectives of feminist criticisms of science. First, there are the criticisms of what Harding has labeled *bad science*. That is, science that is conducted by what is seen as an incomplete scientific community wherein women and minorities are under-represented, and as a consequence, subjects of interest and consequence to women and minorities are under-represented. From this perspective, it stands to reason that a simple injection of women or people of colour into the scientific community would solve the problem of bad science. In part, the argument can be made that women turn out to be feminists more often than men, so it doesn't hurt to encourage the social group most likely to become feminists to enter the field. However, Harding suggests that this approach is not critical of science itself, just critical with the lack of women entering the field.

Thus, the *add-women and-stir* method of changing the demographics of the field of science is not sufficient to change the status quo of science.

Second, Harding's (1991) criticism of *science-as-usual*, targets science as an enterprise. Rather than simply promoting equitable pedagogical and subsequent employment practices in the science, this criticism challenges the ethics, goals, and functions of science, and sees adding more women and minorities to the scientific workforce as complicit with our culture's failure to do so. Troubled by the tension inherent in these two agendas, Harding constructed a framework from which we can conceptualize participation in science that operates to change the status quo in science, not only by increasing the number of women and minorities in the workforce, but also by challenging the assumptions, purposes, and practices of science. She highlighted two contradictions that are particularly relevant for this chapter. First, if science-as-usual is the problem, then feminism should not be encouraging women and minorities to do science and thus become part of the problem. Second, and conversely, it would be particularly distressing if a consequence of this criticism should be the further alienation of women and minorities from science. So, Harding lamented, we are faced with a conundrum: critics of bad science ignore that the social structure of science is "created as part of the bourgeois, racist, imperialist—and androcentric—ruling groups of society" (Harding, 1991, p. 55); but on the other hand, critics of science-as-usual indirectly foster scientific illiteracy among women and minorities by discouraging them from entering the field.

Harding (1998) develops this argument using a feminist post-colonial perspective to illustrate how science's claims to objectivity has attempted, falsely, to render its system as culturally neutral. By asking whose interests are served in modern progress, and whose knowledge counts in science, Harding argues that no knowledge is ever culturally neutral. Rather, she demonstrates how science has been used to serve the interest of Europeans, through the subjugation of the Other. Harding's expanded argument to include this post-colonial perspective still, however, suggests that science will not become better by adding a more diverse workforce. Rather, the internal workings of science need to be interrogated to reveal the shared (racist, sexist, classist) assumptions of that community.

Harding (1991; 1998) suggested that a feminist science can come about through methodological and epistemological changes. Her theory of strong objectivity requires an examination of the scientists' beliefs, values, and positionality *vis-à-vis* race, class, gender relations, etc. In societies stratified by race, class, gender, ability, and sexuality, the activities of those in the dominant class or at the top of society determine and set limits upon the activities of the rest of society. To mitigate this, Haraway (1989) argued, it is necessary to acknowledge the situatedness of knowledge, and in all cases, the partial perspective of knowers. She suggested that "[f]eminist objectivity is about limited location and situated knowledge, not about transcendence and splitting of subject and object. It allows us to become answerable for what we learn how to see" (p. 190). Thus, Keller, Harding, and Haraway all privileged the local and situated perspective for the production of knowledge, wherein scientists are encouraged to acknowledge not just partial perspective, but an awareness of which voices are missing.

An understanding of the feminist perspectives of the construction of science provides a foundation for exploring how the discourse of science is constructed in contemporary physics departments and research groups. Feminism encourages us to look critically at the perspectives from which science discourses have arisen, and to challenge the historically-constituted practices of science that have until recently operated to exclude and marginalize women and minorities. However, I would argue that feminist critiques of science have often been misappropriated for research on gender in science education, and run the risk of essentialism and reification of the problem due to the liberal agenda of getting more women into science. It is from this perspective that much educational research around women in science has been conducted—a reversion to what Harding (1986) had termed the *woman question in science*.

The Woman Question in Science

As mentioned in the introduction, over the last 30 years, a large body of research has undertaken to explore the problem of gender and science. In this section, I will outline research on three different approaches to addressing this issue, and I will discuss some of the pitfalls encountered in the models on which they are based. Initially, this research began to address the striking under-representation of women in scientific disciplines, starting with low participation of girls in elementary and secondary school science, and low enrollment of women in tertiary levels of schooling. Much of this research depends on a definition of the problem as one of numbers—women, especially in physics, are under-represented at staggering numbers relative to other academic fields. Coinciding with the first two waves of feminism, there have been broadly two approaches to understanding the problem of under-representation: the *equity model* and the *difference model*. The equity model seeks to achieve parity by eliminating the structural obstacles women face that result in fewer chances and opportunities for women in science (Sonnert & Holton, 1995). This model looks for obstacles external to women themselves to understand why they are prevented from persisting, but overall, women and men are thought to do science similarly. The difference model emphasizes that men and women have different relationships to science because of their "deep-rooted differences in [their] outlook and goals" (Sonnert, 1996, p. 3). According to this model, the source of gender disparities in science is women themselves, and the differential gender socialization they encounter throughout their lives.

The equity model. Studies focusing on higher education that have examined gender and attrition in sciences from the lens of the equity model believe that men and women have similar approaches to science, but that inequality in science and science education is caused by structural factors residing in institutions (Sonnert, 1996). From this perspective, the gender gap in science is most often explained by institutional discrimination, lack of role models, inflexibility in institutions for balancing career and family life, and scientific practices that are based on male cultural norms (Ferreira, 2003a, 2003b; Fox, 2000; Lovitts, 2001). Researchers using this model have paid particular attention to the departmental and institutional climate that women face in graduate school

(Fox, 2000; Hall and Sandler, 1984). The descriptions of women's experiences in science often emphasize the persistence of what Hall and Sandler termed the *chilly climate* in academic science, a metaphor representing the environment that causes the dearth of women in most disciplines of academic science. This phenomenon is said to lead to the *leaky pipeline*; the notion that as women progress along the educational pipeline of science, they leak out at various transitional periods—between undergraduate and graduate school, for example (Barinaga, 1992). Sonnert (1999) used this metaphor to position women as passive drips in the pipeline, suggesting that "if the structural and cultural changes for the leakages are ignored, attempts at increasing the representations of women at various pipeline segments will fall short" (p. 39). Sonnert's report provided an overview of why [we should] care about women in science that sees women as an untapped human resource, and points to the contributions of prominent female scientists such as the work of Jane Goodall and Dian Fossey as reasons to include women in the pipeline. This argument is typical of that set by the liberal agenda, which places an emphasis on the economic imperative to get women and minorities into science as they represent untapped labour resources. Phipps (2008) criticized this approach as an instrumentalization of women's education for the purposes of capitalist gain.

Studies that follow the liberal agenda set by Sonnert (1996) and others (Fox, 2000; Herzig, 2004; Sax, 2001), seek to identify structural barriers, and provide models of persistence that encourage the integration of more women into science. Some researchers have worked closely with institutions to identify social and organizational features of departments that may pose limitations for women in science, such as decentralization, supervisor and student relationships, and women's status within research groups (Fox, 2000). Fox suggested that these are all areas where interventions and policy recommendations may be made. In a review of the literature on women's under-representation in graduate science, Hollenshead, Wenzel, Lazarus, and Nair (1996) determined that most science graduate programs are constructed around assumptions about work, careers, family, and productivity that ignore the reality of women's lives. These assumptions can lead to structural obstacles to women that contribute to their attrition. Structural discrepancies identified by Hollenshead et al., (1996) include

- amount and quality of interactions with (male) faculty or advisors were lower for women;
- few female faculty mentors;
- demands and routines that ignore safety considerations (for example late working hours and laboratory environments that are hazardous to pregnant women); and
- expectations that ignore family responsibilities, often the purview of women.

A later review by Herzig (2004) revealed that significant factors related to women's retention in science were departmental, institutional, and professional activities that allowed for student involvement and student integration into the social structure of the profession. This review also highlighted individual contributors to the attrition of women in science including a lack of confidence and a sense of conflict with family responsibilities (Etzkowitz, Kemelgor, & Uzzi, 2000; Sonnert & Holton, 1995), relational factors such as relationships with supervisors (Etzkowitz et al., 2000; Girves & Wemmerus, 1988; Wood, 2004), patterns of isolation (Herzig, 2002), and a sense of competition (Ferreira, 2003a, 2003b).

As might be anticipated, initiatives built on the equity model focus on removing those external obstacles (Sinnes, 2006). Removing obstacles is thought to contribute to building a critical mass of women that can challenge the cultural practices of science (Etzkowitz et al., 2000). As such, the problem was constructed as one of recruiting more women into science to balance out the gender ratio and to provide role models for women who are interested in pursuing a career in the field. However, this approach to achieving gender equity in science has been criticized for not adequately challenging the discriminatory practices within science (Harding, 1991), and for relying only on the development of compensatory strategies for women to measure up to the male standard in science (Eisenhart & Finkel, 2001).

The difference model. Studies that have relied on the difference model assumed that women and men do and experience science differently. Seymour and Hewitt (1997) reported that women in science often feel as though they do not belong in science, and suggested that this is a large reason for attrition of these groups in the sciences. From this perspective, the under-representation of women in science is often attributed to a cultural ideology of gender that associates masculinity with scientific competence and femininity with scientific incompetence (Keller, 1985). This association has led to the exclusion of women from the development of scientific knowledge and is thought to require women to reconfigure their own identities in order to appropriate the identity of the dominant group through a process that Subramaniam and Wyer (1998) coined *dementoring*. They suggested that one of the unwritten rules of doctoral training in science is the requirement that women lose their sense of femininity or be “un” trained as women and “re” trained as scientists. Traweek (1988) described the climate for graduate students in science as “a culture of no culture” (p. 162), which implies an emphasis on the researcher as rational, objective, and decontextualized. Subramaniam and Wyer (1998) suggested that as a result of this perception, the valued attributes in science are often associated with masculinity—the paradox being that these attributes are regarded both as disembodied and male (Keller, 1985). Subramaniam and Wyer suggested that to persist in the sciences and be successful, graduate women must be trained to let go of their feminine identity and adopt a more scientific identity—i.e., the identity of the white, male scientist.

The response to the difference characterization of the problem was a reformist approach to science education to make it more appealing to girls and women (e.g. Howes, 1998; Rosser, 1990, 1997). Initiatives intended to encourage more women to enter science played up the female-friendly approaches to science education—approaches that reinforced the stereotypes the campaigns attempted to challenge (Brickhouse, Lowry, & Schultz, 2000; Phipps, 2008). Further criticism of this approach suggested very limited and controversial evidence that the differences actually exist, and further evidence of greater variation in ways of thinking about and doing science among the sexes than between them is required (Erwin & Maurutto, 1998; Hughes, 2001). The essentialist assumptions are not just applied to women in the difference model; there is also the assumption that the white, male scientist is a monolithic category. Additionally, Gilbert and Calvert (2003) argued that among the cumulative effects of these initiatives was the devaluing of inclusive science, which then came to be seen as low status or diluted. This begs us to look further and re-envision our characterization of the problem.

While the question of—why don't more women choose physics?—may address the economic imperative to saturate the potential labour workforce, we should be careful of its implicit presupposition: that women don't choose physics because they are women. This tendency to treat women as a monolithic category that bears problematic relations with science (also a unified category) obscures the many varied and complicated relationships that students have with science, and at the same time, reifies the presumption that appears to keep women out of science: that women as an essential category are not suited for science. To address this concern, recent approaches to research into issues of gender and science education have employed sociocultural frameworks of identity to explore possibilities for a gender-inclusive science.

A third model: Gender inclusive science. Sinnes (2006) suggested that beyond the equity and difference models exists a third way of understanding gender and students' participation in science, one that she labeled the *gender-*

sensitive approach. Gilbert (2001) challenged science educators and researchers to reconsider the terms science and gender, so that more women and girls may begin to see science as part of their identity. She argued that the category *woman* in science education research has been discussed extensively by feminist philosophers of science, but has often been left unexamined in research focusing on the under-representation of women in science or initiatives established to attract more women to science. This neglect bears the significant danger of essentializing all women and again incorrectly conflating femininity with womanhood—a problem that creates discrete categories of what constitutes normal gendered behaviours and has the heterosexist result of marginalizing those who do not conform to those gender norms.

Harding and Parker (1995) promoted what they called *gender-inclusive science education*, describing such a curriculum as, "one which values what both boys and girls bring to the science classrooms and one which challenges existing definitions of science. It must probe the social construction of both gender and science" (p. 539). Reforms to science education that take into account a gender-sensitive approach suggest emphasizing the political, social, and cultural dimensions of science (Sinnes, 2006). Barton (1998b) described four characteristics of science that are acknowledged in a gender-inclusive classroom: scientific knowledge is culturally and socially constructed (i.e., Harding, 1991); scientific knowledge reflects the complexity, context, and holistic existence of nature (i.e., Keller, 1985); scientific contributions of marginalized groups are incorporated into a historical analysis of scientific knowledge (i.e., Longino, 1990); and science is practiced through multiple ways of knowing that are not limited to women's ways of knowing.

Recent trends in science education have pointed to the adoption of sociocultural theories of learning to address questions around how to conduct gender-inclusive science education (Barton, 1998b; Brickhouse, 2001). These approaches have brought issues of identity into focus and have sought to examine the multiplicity of ways that students can learn to become insiders to science cultures and scientific knowledge, or to explore reasons why they might not see themselves as scientists (Barton, 1998a; Basu, 2008; Carlone & Johnson, 2007). Identity research in science education has also been useful in demonstrating how school science has acted to reproduce the historical view of science as an objective, universal approach to knowing, a perspective that may benefit or disadvantage certain groups of people (Carlone, 2004). The following sections review how a sociocultural lens on identity construction has been used in relevant science-education literature.

A Focus on Identity in Science Education

In education literature, identity is often employed as a tool for exploring how students and teachers learn, participate in, and understand science, and has figured prominently in sociocultural studies that address issues of why certain student populations are marginalized and underrepresented in science (Roth & Tobin, 2007). Brickhouse and Potter (2001) suggested that identity

> refers to the ways in which one participates in the world, and the ways in which others interpret that participation. Identities are maintained in

> performances in which one makes a claim on identity and then judges the viability of that idea against the reaction of others. (p. 966)

This approach to science education research has gained prominence in recent studies seeking to explore the intersection of gender, class, and ethnicity in the development of students' science identities (see Barton, 2001; Brickhouse & Potter, 2001; Carlone & Johnson, 2007; Hughes, 2001; Tonso, 2006). Identity frameworks have shown how students who have schema and resources (socially acquired practices and dispositions) that do not correspond with the traditional view of science presented in schools, can experience significant difficulty engaging with and seeing themselves in science (Barton, 1998a; Basu, 2008; Carlone & Johnson, 2007). Identity frameworks have the potential to be transformational, as they demonstrate how maintaining traditional approaches to science education risk pushing minorities even further toward the margins and allow us to consider alternatives (Tobin, Seiler, & Walls, 1999).

Identity theories offer the possibility of understanding forms of social reproduction that take place through the interaction of social and scientific structures in students' lives. Gender is a social structure that plays a role in the construction of student identities. Faulkner (2007) argued that while it is important to highlight issues pertaining to gender, it is likewise important to highlight the diversity within gender groupings as a way to break down the essentialist approaches to studying gender that often result in reifying the gender binary.

Uses of identity in relevant physics and engineering literatures. Science education research that employs identity frameworks has the potential to subvert this binary system, however, the use of identity theory has only begun to trickle up to research in higher education in science within the past decade (Carlone & Johnson, 2007; Henwood, 1998; Tonso, 1997, 2006; Walker, 2001; Wood, 2004). Furthermore, its use in research on doctoral student education in physics is limited (Danielsson, 2009; Danielsson & Linder, 2008; Tsai, 2004).

There have been notable contributions to the literature that employ anthropological frameworks to examine participation in physics communities, but do not specifically refer to identity. Traweek (1988), for example, conducted a multi-site ethnography of high-energy physicists to explore how physicists (undergraduates, graduate students, post-doctorates, and professors) learn, produce, and reproduce the culture of physics across time, and how these cultural processes are highly gendered. Hasse (2002) similarly conducted an ethnographic study of physics classrooms to explore issues of inclusion and exclusion in physics communities. Hasse argued that physics education embodies an understanding of physics as a masculine activity, and that this manifests in a jovial brotherhood, characterized by playfulness, creativity, and initiative—characteristics that were more often attributed to men than to women. Nespor (1994) addressed issues of gender and participation in his actor-network inspired ethnography that characterized physics and management undergraduate programs over long time-scales. Issues of gender arose particularly when he examined the distribution of labour, and particularly in the marginalization of women from collaborative activities. Finally, Thomas (1990) compared the disciplines of physics and English literature from the perspective of undergraduate students in the minority gender of women and men, respectively. She identified boundary construction between disciplines and genders as the primary way that students identified themselves as physicists or English majors. While these studies all examined what it meant to be a physicist or physics student in a particular community of physicists, none of them explicitly employed a sociocultural perspective of identity.

In contrast with the above, the following section reviews some of the studies that use identity frameworks and outlines their contributions to research on gender and science education. I have included only studies conducted on science majors, either undergraduate or graduate, that have a particular focus on gender. Because of the relative paucity of studies focusing exclusively on physics as a disciplinary setting, I have included studies that examined a variety of disciplines in science (e.g., Carlone & Johnson, 2007) and studies focusing on engineering (Henwood, 1998; Tonso, 1997; Tonso, 2006; Tonso, 2007; Wood, 2004). This literature is particularly salient due to the use of sociocultural theories of identity and the relative epistemological closeness of the disciplines of engineering and physics, i.e., the hardness associated with the two, as well as the dearth of women pursuing engineering degrees, particularly at the graduate level. Nevertheless, engineering cultures are somewhat different from the physics cultures described later in this dissertation. In particular, the symbols used to signify belonging in engineering culture differ greatly from physics, as well as the objectives that students have when entering the field. As a professional degree, engineering students often enter the field with hopes of pursuing careers in industry, although at the doctoral level, this is not always the case (Wood, 2004).

Carlone and Johnson: A recognition model for science identity. This study had the theoretical intention of developing a model for science identity that could help to make sense of the experiences that women of colour had in their undergraduate and graduate education in science. Carlone and Johnson (2007) conducted ethnographic interviews with 15 women of colour, and followed up with the women many years later to get a sense of their educational career trajectories. In the development of their model, Carlone and Johnson argued that science identities are composed of three elements: competence, performance, and recognition. That is, one must perform like a scientist, demonstrate the competence of a scientist, and be recognized as a scientist in order to feel like and be regarded as having a science identity. They suggested that the only element of science identity accessible through interviews are stories of recognition. They also suggested that competence is implied through grades or successful completion of degrees and that performance is something that cannot be assessed outside of the laboratory.

The results of this study demonstrated that to acquire a scientist identity, it was important for women to be recognized as scientists by meaningful scientific others. The authors drew on Gee's (2000) notion of recognition and argued:

> One cannot pull off being a particular kind of person (enacting a particular identity) unless one makes visible to (performs for) others one's

> competence in relevant practices, and, in response, others recognize one's performance as credible. (Carlone & Johnson, 2007, p. 1190)

The ways that they could be recognized fell under three general identity trajectories: research scientist, altruistic scientist, and disrupted scientist. Those with research scientist identities sought and received recognition by science faculty for their laboratory performances. Importantly, these women also recognized themselves as scientists. Those with altruistic science identities redefined meanings for recognition of themselves as scientists and who could be counted as a meaningful scientific other. In this way, they were able to be recognized as scientists, but under new terms of recognition. Finally, those with disrupted science identities made bids for recognition, but these bids were not acknowledged due to interactions of factors related to gender, race, and ethnicity.

This study provided a grounded model of science identity that highlighted the importance of different forms of recognition by meaningful scientific and non-scientific others. The authors suggested that while they have developed the model for recognition, more work needs to be done on how students take up, resist, or transform the practices of science and how these influence science-identity construction.

***Danielsson: Doing gender/doing physics*.** In her dissertation using a narrative approach combined with discourse analysis, Danielsson (2009) examined how undergraduate and graduate physics students constituted the practice of physics in research laboratories, and how they constructed their identities in relation to these practices. Danielsson's theoretical framework combined situated-learning theory with post-structural gender theory to explore how physics students' doing physics was intertwined with their doing of gender. Danielsson interviewed 22 students, giving particular attention to laboratory work, with the purpose of illustrating the range of possibilities for constituting identities and for constituting the physics community. She determined that femininity in the physics community was characterized by traditional gender norms of diligence, neatness, and rule-following, whereas masculinity was characterized by a range of possible attributes including technical and logical skills. However, she also determined that men and women did not fit neatly into masculine or feminine categories, and often women occupied (somewhat unexpectedly) identity categories reserved for masculine practices. This thesis thus demonstrated the complexity inherent in the gendered negotiations of becoming a physicist, and begged researchers to move beyond simplistic binary constructions of men/masculinity and women/femininity when considering issues of gender and physics, and rather to look critically at the practice of physics as a site for the production of gender.

Tsai: The othered women who other. In her dissertation, Tsai (2004) explored how Taiwanese women doctoral students and physics professors constituted their identities as physicists in relation to dominant discourses of masculinity in the academic workplace. Tsai explored how women physicists position themselves within the available discourses in a physics community in Taiwan and how they constructed meanings of *women in physics* in such a male-dominated environment. Tsai argued that women physicists' choices about the course of their careers were restricted by the kinds of identities they were able to construct as physicists. Among her notable findings were the tensions between discourses of *ordinary women* and *normal physicists* and the implications these discourses had for identity construction (Tsai, 2004). Tsai found that often women physicists did not want to be singled out as a woman in physics, as it signaled their difference from normal physicists. But just as women rejected the notion of being a woman in physics, and rather opted to position themselves as normal physicists, they also positioned themselves against discourses of ordinary women (who could not be identified as physicists). The result of this was the reproduction of the idea that ordinary women could not do physics, thus producing a new discourse of *exceptional women*. Tsai also determined that feminist thought in Taiwanese culture, as expressed by these women physicists, was met with hostility and suspicion, and the women in her study did not want to be associated with efforts to bring a feminist perspective to their practice. This positioning against feminism was interpreted as a fear of being cast as women physicists, a position considered even by the women in this study to be inferior to normal physicists.

However, Tsai emphasized that not all women positioned themselves against discourses of feminism or against the women physicist discourse. Some women took up these discourses in ways that allowed their identity as women and as physicist to be coherent and confluent. Tsai's focus on the international discourse of women in physics (derived from a Western context of activism around the issue of the under-representation of women in physics) versus the local feminist discourse, points to the tensions between culture and feminist thought in research that examines women's experiences from a global perspective without giving thought to local productions of gender. This interpretation highlights the importance of context and resources when exploring issues of identity and gender in physics. To locate the variation of identity construction within genders speaks to the contextual nature of experience and resists universalist claims to common experiences among women in the same disciplinary and cultural context.

Faulkner: The technical/social dualism. Faulkner (2007, 2009) sought to address the question of how professional engineering work spaces were more comfortable to and supportive of men than they are of women. Her study sought to examine the ways in which engineering practices are gendered, or favours certain kinds of masculinities and femininities. Her 2007 ethnographic study emphasized the technical/social dualism that she found was predominant in engineering cultures. This dualism relies on the cultural notion that engineering is a technical profession, apart from social aspects—a dualism that relies on the association of masculinity with the technical and femininity with the social. What Faulkner found was that the practices of engineering are deeply social, and that the promotion of these more heterogeneous images of engineering practices would break down the technical/social and masculine/feminine dichotomy associated with the discipline.

Faulkner's 2009 study moves further into the realm of assessing the ways that women engineers deal with the social aspects of engineering in order to be visible as engineers but at the same time to enact authentic gender identities in the field. Faulkner highlights the contradiction between pressures for women to be like one of the guys, but at the same time to not lose their femininity, what Faulkner terms the *paradox of in/visibility*. Faulkner's evidence points to a greater availability of masculinities in the field of engineering than femininities, requiring women to become one of the guys in order to be recognized as an engineer, resulting in the experience of *gender in/authenticity*. Her study points to the need to move beyond the technical/social dualism in order to attract more women to engineering. She suggests that continuing to construct all things technical as masculine and all things social as feminine, the liberal feminist agenda only serves to reproduce the gender binary—a problem that is likely related to women's under-representation in engineering in the first place.

Henwood: Constructing difference. Henwood (1996, 1998) explored the dominant discourses underpinning both engineering cultures in a college in the United Kingdom, and approaches to encourage more women to enter them. Henwood (1996) identified the Women into Science and Engineering (WISE) discourse that relied on liberal accounts of equal opportunities. This led to conclusions that the problems women face in engineering include limited information about careers in the field and masculine images of who can do engineering. It follows from this reasoning, then, that the remedies to these problems are to inform women about career opportunities and to change the masculine images of engineering into feminine ones. But Henwood argued that this leaves the dominant gender ideologies of the field intact. In addition, Henwood (1996) found that some women were attracted to the symbolic masculinity of the field of engineering, calling into question efforts to feminize the field in order to attract more women.

Following up on this research, Henwood (1998) criticized what she called the dualistic individual and structural approaches to the question of women in engineering. Henwood argued that approaches to the problem either look to structural barriers in the culture of engineering as reasons why women do not persist in the field, or seek to find individual factors such as how women engineers are different compared to other women. The results of these approaches are to position women as Other to engineering, and to reinforce the gendered barrier in engineering culture.

In her study, Henwood (1998) distinguished between three forms of identification with dominant discourses of gender and engineering using Pécheux's (1982) notions of identification, counter-identification, and disidentification. Identification is the process of freely consenting to dominant discourses; counter-identification is the rejection of the dominant discourses; and disidentification is the act of working against the dominant discourses. The first two of these leave existing power structures in place, while the third allows one to formulate new identities in the culture that "offer the potential for the transformation of gendered power relations" (Henwood, 1998, p. 40). The women participants in her study either identified with discourses of gender that reified the naturalness of gender differences, or they counter-identified with these discourses and positioned themselves as the same as men. Henwood argued that without disidentification, as observed in her study, the obduracy of engineering culture remains intact as no real alternative to the dominant gender regime is offered.

Tonso: Cultural forms for engineer. Tonso (1997, 2006, 2007) conducted an in-depth ethnography of an undergraduate engineering campus to unearth site-specific cultural forms for engineers. By cultural forms, Tonso (2006) referred to the local structures "against which student engineers thought about themselves and performed themselves *as engineers"* (p. 274). Tonso explored the different ways that engineering students identified forms of engineers, the cultural resources they used to recognize engineers, and the positioning that engineering students did around these recognizable forms of engineering student. To explore these forms of positioning, Tonso discussed how engineering students compared campus-engineer identities with their ways of performing engineer through team projects. In this way, Tonso created an inventory of campus-engineer identities—what she later framed as cultural forms for engineers—and then examined the ways that engineering students were positioned around these cultural forms (in social hierarchies or hierarchies of power within the campus-engineering community), as well as how they authored spaces for themselves within these cultural forms of engineers in practice.

Tonso's (2006, 2007) determined that there were few cultural forms available for women in engineering that were not specifically constructed for women. That is, the default cultural form for engineers was the male cultural form—of which Tonso identified myriad variations. Men could unproblematically occupy one or many of the subject positions offered by these cultural forms, but women were limited to restrictive subject positions offered by cultural forms like *woman engineer*, *sorority woman*, or *Betty* (a good-looking woman). The cultural forms available for women were most often deemed incompatible with engineering. Tonso (2007) also examined how students performed engineer selves in ways that subverted the dominant discourses of engineering, but not in ways that were recognizable by the engineering community. Women performing engineering selves often did so in ways that were recognizable by small working groups or engineering teams, but this recognizability did not carry over to being recognized as a competent engineer in courses or in recruitment of graduates for jobs. Men who performed engineer selves in non-gender-conforming ways similarly found recognition for their abilities within the engineering teams, but these performances of competence were not recognizable by faculty or administration because they did not conform to the dominant cultural forms of engineering. Thus, Tonso explained that these local performances of engineering selves, while recognizable in micro-environments, were not sufficient for one to be recognized as an engineer in macro-environments, therefore cultural change is unlikely to happen. Tonso attributed the obduracy of engineering culture to this inability to recognize alternate forms of engineer identities.

Wood: Becoming engineers. Wood (2004) interviewed seven women doctoral students in engineering programs in Canada. Using life history interviews, Wood gathered narratives and constructed a collective case-study to understand the experiences of these women, and how their non-participation in cultural practices of engineering affected their identities. The main themes or tensions that emerged from this study included: altruism versus elitism as motivations for pursuing engineering; competence as the currency of engineering; Othering of women; and a culture of sameness that was defined by the default masculine gender performances.

Wood (2004) found that women reported desires to pursue altruistic career paths, but were relatively uninformed about engineering upon entering the field. A tension then arose between what women saw as altruistic motives for entering the field and the notion of intellectual superiority dominant in engineering culture. The elitism of the field was most often associated with masculinity, and Wood described reports of women acting aggressively in order to be noticed within the elite culture. Displays of competence were regarded as necessary to be recognized as engineers in this study. Women described performances such as asking unintelligent questions as undermining their competence in engineering. Symbolic displays of competence, such as receiving awards, were also valued in the engineering community. Wood discussed the threat that women's displays of competence posed to the men and masculinity in the culture of engineering. To appropriately perform competence, Wood argued that women often were positioned as "one of the guys" (p. 242). This posed a conundrum for women—on one hand they were viewed as competent enough to be considered one of the guys, but by being one of the guys, they were stripped of their identities as women and were, for example, considered not to be viable dating partners.

Finally, Wood identified a culture of sameness in engineering.

Characteristics of sameness included “perseverance, patience, self-confidence, and time management skills. Some doctoral women even felt that a dress or appearance ‘code’ characterized all engineers, male and female” (p. 244). Wood reported a brotherhood of engineering that new students are apprenticed into, signified by the iron ring ceremony. Wood also identified several differences that came into conflict with the culture of sameness, including sex-roles, ethnic or cultural differences, and language and sexuality. Importantly, Wood’s study provided insights into the educational experiences of doctoral women engineers in the Canadian context, and demonstrated how experiences with engineering culture are generally problematic for individuals who are not White or male. Wood argued that practices that could disrupt the imperative for sameness in engineering cultures may generate a more inclusive environment for the participation of women and minorities.

Summary of relevant themes.

Emerging from this review of the literature were a number of salient themes identified by researchers exploring identity, gender, and science education. The importance of *recognition* emerged in several studies. Carlone and Johnson (2007) emphasized recognition as an important element of identity construction. Tonso (1997, 2006, 2007) also identified recognizing oneself as an engineer, being recognized as an engineer, and performing that engineer identity as components of identity construction for engineers. Tsai examined what she called the physics discourse and suggested that the kinds of *subject positions* offered for women to take up in physics were limited by the kinds of discourses available in a community (Tsai, 2004). In all of these studies, competence emerged as a critical characteristic that scientists and engineers required as currency for recognition as scientists or engineers (Carlone & Johnson, 2007; Tonso, 1997, 2006, 2007; Tsai, 2004; Wood, 2004).

The problem of *difference* arose in a number of studies, wherein women struggled between acting like one of the guys in order to be recognized as doing science competently, and compromising their identities as women (Henwood, 1998; Wood, 2004). This resulted in a counter-identification with discourses of gender-difference and a refusal to be positioned as a woman physicist (Henwood, 1998; Tsai, 2004). Finally, the localized meaning of gender performances was discussed in almost all of the studies reviewed, leading to a general conclusion that variation in gender performances are as great or greater within genders as between them (Danielsson, 2009). These findings suggested a need for studies to take into account local contexts and resources (acquired through experiences and participation in a variety of contexts) that students bring with them into science and engineering disciplines. It also highlighted the need to lend importance to the particularities of individual experiences in science education research as a way to better understand these variations.

Chapter Summary

This chapter situated this study in the growing field of science-education research using sociocultural approaches to identity, with a particular focus on gender as an analytical lens. I began by discussing feminist approaches to the issue of women in science and presented three models for understanding the so-called problem. I developed ideas from the third model (gender-inclusive approaches to science education) and provided an overview of research that employed sociocultural theories of identity to address issues of gender equity in science.

This chapter provided the context for the subsequent theoretical framework that draws heavily on sociocultural theory, particularly the ideas of discourse and identity. Next, I will discuss the construction of a framework to explore how discourses of physics and physicist offer available subject positions for particular kinds of students to become physicists. I will also discuss the theoretical conceptualization of gender in this research, and how a post-structuralist understanding of gender as performance can add to a framework that seeks to explore the co-production of gender and discourses of physics, and the implications this has for doctoral students' identity construction.

Chapter 3

Theoretical and Analytical Framework

In the previous chapter, I identified a number of issues emerging from previous studies on gender and science education that warrant further research. These included an emphasis both on local and individual contexts, which provided resources that students bring to their practices in physics (Danielsson, 2009; Tsai, 2004); a need to further our understanding of the co-construction of discourses of gender and discourses of science, and how they limit subject positions available to women (Henwood, 1998); and the importance of recognition and competence as key elements for identity construction as scientists (Carlone & Johnson, 2007; Tonso, 2006). The theoretical framework I will present here attempts to address all of these demands. The first part of this chapter introduces the terms *discourses* and *identity*, and discusses how I am using these terms. Then I discuss the usefulness for this study of a range of related theoretical concepts, including *positioning* and *recognition*. The second part of this chapter defines what I mean when I refer to gender and gender expressions of masculinity and femininity. I outline various post-structuralist perspectives on gender and come to a synthesis that presents gender as an ongoing project with both fluid and durable elements, much like the notion of identity that will be discussed presently.

Sociocultural Theory

This study is informed by sociocultural approaches to science-education research. At its most elemental, a sociocultural approach refers to an understanding that science education is a "human social activity conducted within institutional and cultural frameworks" (Lemke, 2001, p. 296). In a sociocultural approach to research, it is not possible to understand human activity without understanding the context in which that activity occurs. We may understand the activities humans engage in as being shaped by and shaping discourses in that context, discourses which in turn shape and are shaped by the identities of people engaging in those activities.

Discourses. Discourses are accepted patterns of interaction that are used in ways that manifest the values, norms, and beliefs of the individuals who utter them and the social contexts that sanction them (Lemke, 1995). Due to their dialectic relationship to human activities, discourses have the potential to regulate behaviours, define social categories, or produce meanings for words like *masculinity* or *objectivity*. According to Foucault (1977), discourses are "practices that systematically form the objects of which they speak . . . Discourses are not about subjects; they constitute them, and in the practice of doing so, conceal their own intervention" (p. 49). Thus, discourses are constructed through human activity and do the work of defining, constituting, and positioning human subjects, often in hierarchies or social categories such as race, gender, and class that bear material effects on people (Luke, 2009).

Gee (2000, 2005) made a distinction between discourses and Discourses, suggesting that discourses are what people are actually saying, whereas Discourses are the social habits that people form by doing the same things in the same ways over time. Little *d* discourses refer to "language-in-use or stretches of language (like conversations or stories)" (Gee, 2005, p. 26). Big *D* Discourses can be thought of as the combination of language, action, practices, values, beliefs, symbols, objects, tools, and attributes of places that are associated with being a certain kind of person (Gee, 2000). If you can use your resources in such a way that they are recognizable to others, then you have "pulled off a Discourse" (Gee, 2005). It is this understanding of d/Discourse that I will be using throughout the dissertation. Thus, big-*D* Discourses refer to the storylines about being a physicist that provide the backdrop against which students learn to become physicists—since being a physicist in a way that is culturally recognized involves more than simply doing experiments or solving theory.

In order to participate in interactions that constitute and are constituted by Discourses, individuals draw on resources that they have acquired throughout their lives through their participation in social contexts. These resources might be thought of as an individual's *schema and resources* (Sewell, 1992). Schema are the internalized codes, beliefs and understandings about culture that individuals develop through prior experiences. Sewell describes these as the unconscious "rules for social life" (p. 8), and they may include rules that govern etiquette, ideas about gender norms, or an individual's sense of what it is possible to be in a culture (e.g., schema about gender roles in the family might lead to understandings about career possibilities for women). Key to Sewell's concept of schema is that they are transposable to or usable in new situations.

Resources, the other type of durable goods that we have, can be material or human (Sewell, 1992). Material resources are objects that can be used to enhance or maintain position, for example, the correct clothing for a particular situation or a scholarship to fund education. Human resources can be thought of as non-material things possessed by a person, such as, knowledge, emotions, physical strength or skill that can be used to enhance or maintain position. Human resources can be used to gain material resources (e.g., knowledge and communication skills might be used to obtain funding in the form of grants). Schema and resources are characterized by Sewell as durable in the sense that we carry them with us, but our set of schema and resources are not obdurate. New resources may be acquired in every new situation, new schema may be developed, or extant resources and schema can be changed or used in innovative ways or in new contexts. Important to the understanding of resources is that they are unequally distributed and their availability is often under the control of the powerful institutions and social norms.

As individuals participate in activities in social contexts, they use resources in predictable and novel ways as they position themselves and attempt to be recognized as certain kinds of persons (Gee, 2000). These recognizable positions are what are referred to here as *subject positions* (Davies & Harré, 1990).

Subject positions. There may be several or many Discourses that construct what it means to do physics, and within these Discourses are a number of available subject positions for individuals to occupy that are associated with certain social spaces and temporal locations (Weedon, 1988). Davies and Harré (1990) provided the following description of subject positions:

> A subject position incorporates both a conceptual repertoire and a location for persons within the structure of rights for those that use that repertoire. Once having taken up a particular position as one's own, a person inevitably sees the world from the vantage point of that position and in terms of the particular images, metaphors, storylines and concepts which are made relevant within the particular discursive practice in which they are positioned. At least a possibility of notional choice is inevitably involved because there are many and contradictory discursive practices that each person could engage in. (Davies & Harré, 1990, p. 46)

Thus, subject positions may be regarded as *structuring*, in that there are a limited number of available positions within a Discourse, but there remains the possibility for individuals to negotiate or reshape these positions.

Discourses construct subject positions by defining the appropriate content for physicists, that is, they give a sense of "what is possible and not possible for us to do, what is right and appropriate for us to do, and what is wrong and inappropriate for us to do" (Burr, 1995, p. 380). In physics communities, some of the positions offered are recognizable positions that have been cultivated in broader cultural contexts (e.g., positions related to race, gender, and class).

Others might be more local positions with meanings specific to a community, for example, stereotypical images of geeky physicists (Rahm & Charbonneau, 1997; Traweek, 1988). The way that individuals negotiate the subject positions offered by Discourses of a community is referred to as positioning. Davies and Harré (1990) described positioning as “the discursive process whereby selves are located in conversations as observably and subjectively coherent participants in jointly produced story lines” (p. 48). They suggested that positioning can be interactive whereby one positions another, or reflexive, wherein one positions oneself. In both cases, the authors argued that the positioning is not necessarily intentional, but an individual might still invest in a subject position.

When people are positioned or position themselves, they do so by accepting, rejecting, negotiating, or modifying the subject positions available to them, while using the schema and resources they bring to the social situation (Holland et al., 1998; Sewell, 1992). This work is done when individuals make a bid to be recognized as a certain kind of person. In this way, we can regard Discourses as constituted by and constitutive of normative ways of doing physics. However, as Gee also pointed out, if the performance of the Discourse is different from those performances available in a context, but “similar enough [to be] still recognizable, it can simultaneously change and transform Discourses” (Gee, 2005, p.27). This allows for some conceptualization of how negotiating the available subject positions in a community might allow for the transformation of the community.

Subject positions in science. Studies of physicists have shown the predominance of uniform notions of "physicist" that rely on stereotypic forms (Nespor, 1994; Traweek, 1988). These studies revealed that the subject positions available to physics students are limited, relatively consistent, and cross age groups. For example, Traweek described floor or desk physicists as subject positions of the elite, male, high-energy, experimental or theoretical physicist. She also noted that these appear as unitary, accepted notions of who physicists can be and who are formed in a "culture of no culture" (Traweek, 1988, p. 103). The Discourses that construct Traweek's physics community purported a science that was apolitical, without culture, and dealt with a subject that was abstracted from societal influences such as race, gender, or class. This yielded subject positions for physicists that were dispassionate, rational, and objective—characteristics associated with notions of hegemonic masculinity. Nespor (1994) found similar subject positions generated among undergraduate physics students. Rahm and Charbonneau (1997) discussed the geeky, White, male, stereotypic form of the scientist identified by youth. Additionally, the available subject positions are constructed in relation to notions of masculinity that are unproblematically associated with the cultural ideas of physics (Hughes, 2001).

These studies showed that cultural ideas of who can be a physicist construct narrowly defined available subject positions for students entering doctoral physics programs. Thus, it is a concern of this study to determine what kinds of persons students believe it is possible to be in the culture of the physics department at Eastern University[ii], and the ways that participants use schema resources and available subject positions to make bids for recognition as physicists.

Recognition. Gee (2005) argued that in order to pull off being a kind of person, one needs to perform or enact an identity that is recognized as competent and appropriate. Elaborating on recognition, Gee suggested that:

> If you put language, action, interaction, values, beliefs, symbols objects, tools, and places together in such a way that others recognize you as a particular type of who (identity) engaged in a particular type of what (activity) here-and-now, then you have pulled off a Discourse (and thereby continued it through history, if only for a while longer). Whatever you have done must be similar enough to other performances to be recognizable. (p. 27)

A successful bid to be a certain kind of person (i.e., physicist) by meaningful others, and especially meaningful scientific others, aligns students with subject positions in ways that influence whether or not they begin to think of themselves as scientists and make choices to pursue that kind of subject position. Carlone and Johnson (2007) took up this notion of recognition and suggested that while criteria for credibility or competence may vary based on context, a key component of science identity is that these performances are recognized as credible both by the individual doing the performing and by other recognized members of the field. Tonso (2006, 2007) similarly suggested that campus engineering identities are produced in a complicated process that entails thinking about oneself as an engineer, performing an engineer self, and being thought of as an engineer. Tonso (2006) used Holland et al.'s (1998) framework of identity to explore how self-understandings are related to performances of the self and recognition of those performances.

Identity. Considering the nature of the performances through which identity is constructed makes it clear that identity is composed of both durable and fluid elements—the schema and resources that one brings to a new community or situation and the constant negotiations of identity in relation to the Discourses of the community. The durable aspects (schema and resources) can be thought of as what a person brings with them from their prior experiences and with which they interact in the current context (Sewell, 1992).

Identities are the link between the personal realm (schema and resources) and the collective understandings (Discourses) that are embedded in culture (Holland et al., 1998). As individuals engage with, enact or construct Discourses, and thus accept, reject or negotiate subject positions, they use the schema and resources the have acquired through their previous life experiences.

To Holland et al., (1998), identities are improvised in social relations and persons are then caught in the "tension between past histories that have settled in them and the present discourses and images that attract them or somehow impinge on them" (p. 4). Similarly, Hall (1996) discussed identity as the meeting point or suture between the discourses that "hail us into place as the social subjects of particular discourses, and the processes that produce subjectivities, which construct us as subjects which can be 'spoken'" (p. 5). He emphasized that identities are temporary attachments that persons with histories make to the available subject positions that are constructed by Discourses. However, while we may regard identities as always in process, Holland and Lave (2001) argued that there are also durable dimensions of persons—what I refer to here as the schema and resources that individuals bring to new situations that help them make sense of the world. Schema and resources can mediate individuals' participation in local practices, and they can be understood through the stories they tell of experiences. There is interplay between the "local formation of persons in practice and the (mediated) place of historical subjectivities" that come into play in the process of identity construction (Holland & Lave, 2001, p. 9). Thus, when we make a bid for a certain kind of identity, or when we position ourselves, we draw on our schema and resources and the ideological elements embedded in Discourses with which to represent ourselves. Locating these elements might better help us to understand the ways that participants construct and position themselves around subject positions made available via the Discourses of the physics community.

Attending to the subject positions made available in Discourses allows us to regard Discourses as constraining or enabling the kinds of identities a community supports. How students negotiate subject positions within these structural constraints then permits an understanding of the complexity of gender issues within science in ways that do not rely on essential gender categories (Faulkner, 2007; Hughes, 2001). The schema and resources that a person brings to a new community, in addition to the subject positions made available by Discourses of that community, may also limit identity construction (Holland &

Lave, 2001). For example, identity construction for a woman in physics might be limited by schema such as durable images of physicists, ideas about the incompatibility of femininity and physics, resources such as disciplinary language use, and requirements for physical skill or availability of funding. The availability of local subject positions for students in physics and how individuals negotiate these, in light of their schema and resources as they develop identities as physicists is a central concern of this study.

Although I will be using this theoretical approach to understand how students accept, reject, or negotiate the subject positions made available through Discourses of physics and physicists, I do not mean to imply that physicist is the only, or even the most salient, identity that students construct day to day. Doctoral students engage in a multitude of practices that construct identities around ethnicity, nationalism, sports teams, religious affiliations, families, etc. (Gee, 2005). Through this “nexus of multimembership” people develop identities that are complex, varied, and dynamic—shifting across time and space (Wenger, 1998, p. 158). By examining the construction of physicist identities, I am exploring one dimension of what it means to be a physicist within a certain time and space for these students, taking into account the schema and resources students bring with them. The following section discusses another dimension of identity development, the development of gendered identities and how these may be co-constructed with physicist identities.

The Social Construction of Gender

In order to clarify how sex and gender are approached in this study, I provide a brief account of contemporary theoretical approaches to this concept. As discussed in Chapter 2, the women-and-science question has been examined in educational research using equity and difference models for many years without resolve. As a result, researchers have turned to post-structuralist gender theory to find new ways of framing the problem that can take us beyond the liberal agenda of parity in physics (Danielsson, 2009; Tsai, 2004). Post-structuralist theorizing of gender is in line with sociocultural theories of identity construction, and thus this approach fits with more recent approaches to exploring issues of gender and science education as outlined in Chapter 2. In the following sections, I discuss the emergence of the idea that gender is something that we do, through our interactions with others and with our social and physical environments, rather than something we are born with or assigned. West and Zimmerman (1987), Paechter (2003a, 2003b, 2007), and Butler (1990, 1999) each provided a theory of gender that has elements that are important to the way gender is conceptualized in this study. These theories of gender are linked to theories of performing identity, and thus challenge us to think about gender as a fluid, ongoing process of identification, rather than a fixed category. Because performances of gendered Discourses require recognition in order for a gendered identity to be realized, I will conclude with a discussion of the links between my theoretical conception of gender drawn from post-structural gender theory and the ideas of positioning and recognition detailed earlier in this chapter.

Doing gender. In their influential article, West and Zimmerman (1987) constructed a theory of gender that entailed a doing of stylized acts in the "virtual or real presence of others who are presumed to be oriented to its production" (p. 126). Thus, the doing of gender renders it less a property of individuals and more "a complex of socially guided perceptual, interactional, and micropolitical activities that cast particular pursuits as expressions of masculine and feminine 'natures'" (p. 126). West and Zimmerman deliberately distinguished between sex, sex category, and gender. Sex, they argued, is a constructed category that is made through the application of socially agreed upon biological criteria, such as genitalia or chromosome complement, for classifying people as male and female. Placement in a sex category is achieved by taking up the "identificatory displays that proclaim one's membership in either category" (p. 127). They argued that it is possible to claim membership in a sex category even if the sex criteria are absent, but they conceded that a sex category is presumed to follow sex and will often stand in proxy to sex when sex is indeterminable. *Gender* then, is "the activity of managing situated conduct in light of normative conceptions of attitudes and activities appropriate for one's sex category" (p. 127). This situated conduct may entail behaviours, interests, attire, speech patterns, or even gestures that are recognizable to others and which others respond to, that signify one's membership in a sex category. In other words, as explained in Chapter 2, a person's gender is not something that one inherently is, but is rather something that one does, continuously, in interactions with others.

Masculinities and femininities as communities of practice. The emphasis on situated conduct in West and Zimmerman's theory of gender brings us to the idea of localized masculinities and femininities. Paechter (2003a, 2003b,

2007) provided an account of what it means to *do* boy and girl, or man and woman, through her description of masculinities and femininities as "ways in which we, through our behaviour and attitudes, actions, thoughts and dispositions demonstrate to ourselves and others, how we are male or female" (Paechter, 2007, p. 12). Paechter noted that the ways in which it is possible to successfully do gender are limited by the acceptable forms of masculinities and femininities in a community, and potentially, by the body one has. In the development of her theory, Paechter made the important distinction between masculinity and femininity as collective ideals about what it means to *be* a male or a female in a particular local context, and masculinit*ies* and femininit*ies* as the way that people *do* boy or girl, or, man or woman. She argued that there can be masculine femininities and feminine masculinities, but that the normative assumption is that most people will construct masculinities and femininities in relation to their assigned sex.

To conceptualize this, Paechter (2003a) suggested that masculinities and femininities are communities of practice to which individuals are assigned as infants, depending on sex categorization, and then grow up negotiating practices as newcomers to these communities of practice (Lave & Wenger, 1991). External social forces including schools and home environments may support or constrain the construction of normative forms of masculinity and femininity and encourage or discourage children's engagement in gender non-conforming masculinities and femininities. Therefore, membership in a masculine or feminine community of practice is gained through particular (socially localized) normative and recognized understandings of masculinity and femininity.

At this point, it is appropriate to give an explanation of what is meant here by the terms masculinity and femininity. To understand this, Butler's (1990) concept of the heterosexual matrix is a good starting place. This theory posited that gender constructs women and men as distinct kinds of people, and subsequently, the categories woman and man, become defined in terms of their difference and also by the relationship between them—dominance and subordination. For Butler, the relationship between the categories woman and man is central to hegemonic gender relations. The terms that define the distinctness of these gender categories are symbolic, and dictate what a man should be like, and what a woman should be like. It is underneath these defining terms that we find masculinity and femininity—an abstract set of ideals for what members of the categories of men and women should be like.

Connell (1987) described masculinity and femininity as structuring positions in social relations. My understanding of these is that they are symbolic. The categories of man and woman, as they are constructed by masculinity and femininity, are phantasmic—they are the qualities that are believed to be assigned to the people who occupy the social categories of man and woman. I regard masculinity and femininity as cultural ideals, constructed and maintained by modern Western societal notions of what it is to be a man or a woman that are mutable across cultures, but are structuring. Connell (1995) referred to hegemonic masculinity, and emphasized femininity as relational objects wherein hegemonic masculinity is the "configuration of gender practice which embodies the currently accepted answer to the problem of the legitimacy of patriarchy, which guarantees (or is taken to guarantee) the dominant position of men and the subordination of women" (p. 77). Hegemonic masculinity may also be dominant over other forms of masculinity such as complicit and subordinate masculinities, which help to maintain the gender order and are often conflated with femininity. In Western culture, hegemonic masculinity encompasses heterosexual desire, physical prowess, and authority. Connell also argued that there is not hegemonic femininity, but rather emphasized femininity that is defined around compliance with the subordination to hegemonic masculinity. However, it is important in this study to also conceptualize femininity as multiple and hierarchical, and while Connell refuted the possibility of hegemonic femininity, I would suggest that the features of emphasized femininity including heterosexual desire again, physical weakness, vulnerability, and compliance are sufficiently oppositional to hegemonic masculinity that they themselves are hegemonic. The hegemony of masculinity and femininity is that they are constructed as normal and normative, natural and ideal, and as such, they reify the gender hierarchy and male dominance.

Paechter (2003a) argued that women and men may be socialized to ideal Discourses of femininity that are specific to different communities (local contexts), and women or men construct their identities in relation to these types. Thus, femininity and masculinity are not monolithic terms; rather, they are relational and contextual, but they are also normative and recognizable terms that men and women can make generalizations from, and thus construct their own femininities and masculinities in relation to alignment or opposition. Paechter (2003a) argued that communities of practice of masculinities and femininities do not operate with explicit rules for membership, but rather their members define masculinities and femininities by the Othering of outsiders, by defining the boundaries of what is masculine or feminine and what is not, and vice versa. Paechter provided the example of middle-class men who define their masculinity partly through the rejection of the macho. What is important here is that these masculinities are developed locally, and thus inform a wider gender regime. In an argument that draws on Foucault's (1978) notion of power, Paechter suggested that power and gender do not emanate from above, but instead are local, and thus we can understand wider conceptions of ideal types of masculinity and femininity as locally governed through dominant local practices.

Gender as performativity. Butler's (1990, 1999) theory of gender adds another layer onto the constructivist notion that gender is socially constituted by asking: "What happens to the subject and the stability of gender categories when the epistemic regime of presumptive heterosexuality is unmasked as being that which produces and reifies those ontological categories?" (1990, p. xxviii). Butler's radical theory proposed that anytime we impose gender on a body, we do not reference anything real or natural other than the signs such as attire, hairstyle, mannerisms, and speech that have already been constructed to determine the gender of the body. Butler (1999) asked: "Does being female constitute a 'natural fact' or a cultural performance, or is 'naturalness' constituted through discursively constrained performative acts that produce the body within categories of sex?" (pp. xxviii-xxvix). Therefore, in Butler's framing, "'female' is no longer a stable notion as its meaning is as troubled and unfixed as 'woman'" (1990, p. ix).

One of the ways to think about gender that helps to deconstruct the heterosexist matrix in which our commonsense understandings of gender is produced is by recognizing it as performative. By performative, Butler did not intend to suggest that gender is a performance of sex. Rather, she argued that it is a performance of itself, an argument that she illustrated with a discussion of drag, wherein gender can be performed by anyone of any gender identity. Thus, the gendered body is performative, which Butler argued "suggests that it has no ontological status apart from the various acts that constitute its reality" (1990, p. 136). These acts constitute an identity that is constituted over time through a "stylized repetition of acts" (p. 140), the effect of which is the stylization of the body. So, to Butler, gender is not to be regarded as a stable identity from which gendered acts follow, but rather it is a set of meanings which act concurrently with the stylization of the body to give the illusion of an interior gendered self.

Intersections Between Theorizing Identity and Theorizing Gender

The common line that runs through each of these theories of gender is that gender is socially constructed, that it is something that we do in practice, through repeated acts, and that it is not the property of sex and therefore should be decoupled from it (Butler, 1990; West & Zimmerman, 1987). These theories of gender also sought to reveal those properties of social life that appeared natural and objective, but were in fact "situated accomplishments of societal members, the local management of conduct in relation to normative conceptions of appropriate attitudes and activities for particular sex categories" (West & Fenstermaker, 1995, p. 31). This perspective on gender makes it possible to study how it operates to produce and maintain power and inequality in social life in local practices. Thus, what counts as appropriate Discourses of masculinity and femininity are highly contextual and vary across social contexts and over time, and for an individual, over and across the contexts of their lives.

Thus, this conceptualization of gender, as localized performances of appropriate Discourses of masculinities and femininities, aligns with the theoretical construct of identity employed in this dissertation. Both West and Zimmerman (1987) and Paechter (2003a) discussed gender as the doing of Discourses that are recognizable to the self and to others, while Butler (1990, 1999) called this a performance of gender. In all cases, masculinities and femininities, or gender expressions, can be regarded as big-*D* Discourses as they are behaviours, interests, attire, speech patterns, attitudes, or even gestures that are recognizable in local contexts. As Butler suggested, these Discourses can construct subject positions that are available to members of either sex, although these subject positions become limitations in local contexts that value the sex and gender connection. Thus, Discourses of gender can reify a heterosexual matrix by limiting the subject positions available only to men or women, and by being recognizable only when those subject positions are taken up by males or females respectively.

However, as Gee (2005) argued, Discourses have the possibility to be transformed when individuals perform Discourses in ways that are not exactly as expected, but are still recognizable. Hence, there is the possibility to transform localized meanings of masculinities and femininities as they are done concomitantly with the doing of physics, if the doing of these are still recognizable performances. This opens up the possibility of exploring the heterogeneity of gender performances within the practices of physics, among a variety of physicist identities (e.g., Faulkner, 2007). Following Butler (1999), it is no longer sufficient to talk about men and women in science without talking about the codified ways that masculinity and femininity are constructed within the Discourses of physics and the variety of ways that students may position themselves around these Discourses.

Theoretical Limitations of Gender as an Analytic Lens

One of the limits of doing research on gender is that gender is only one lens through which we can examine systems of social oppression, while, in actuality, these various systems including race, class, ability, age, religion, nationality, and sexuality, do not operate independently of each other. Rather, they interact, creating an interlocking matrix of oppression that operates intersectionally (Collins, 1990). Butler (1999) herself challenged research that employs gender as a category of analysis, and indeed discussed the limits of her theory of social construction of gender as it may be applied to race. Butler recognized that this theory is not simply transposable onto race, but she also questioned what happens to our notions of gender when they intersect with race. Thus, she argued “the sexualization of racial gender norms calls to be read through multiple lenses at once, and the analysis surely illuminates the limits of gender as an exclusive category of analysis" (p. xvi).

I have dealt with this by following Butler's assertion that what counts as masculinity and femininity is highly contextual and varies across social contexts and over time. Thus, we can consider a local (micro) component as well as an historical (and therefore macro) component by attending to identity trajectories as well as the social conditions in which those trajectories are carved out (Mishler, 1999). In examining masculinities and femininities in physics culture, I do so on the local level as a way of taking into account the various local practices related to identity construction around gender, while recognizing that it is impossible to separate gender from the cultural intersections in which it is produced and maintained. Gender is but one unit of analysis that we may explore when considering how identities are constructed through practices of physics. Complicating this, even on a local level, are other factors that represent systemic features and are also represented in Discourses and available positions.

Chapter Summary

Chapter 2 discussed the need for studies exploring gender issues in science to adopt sociocultural frameworks that move away from essentialist thinking about gender and science. In this chapter, a theoretical framework was constructed that foregrounds the importance of Discourse in the constitution of communities of physicists as mechanisms that shape behaviours and define social categories for members to occupy. Gee's (2000) notion of big-D Discourse was introduced as the social habits that create recognizable subject positions made available to members or newcomers to a community. Because Discourses only have meaning when they are understood by other individuals I highlighted the importance of recognition in the doing of Discourses.

Identity was discussed as the link between schema and resources and the collective understandings or Discourses of a community. The theoretical concept of identity is important to this study, as it gives us a way to think about how individuals use their resources to negotiate subject positions through positioning. Post-structuralist theories of gender were then discussed, especially with respect to their relation to the sociocultural theory framing this research. Others have used sociocultural frameworks to explore issues of gender and identity in doctoral science (Danielsson, 2009; Tsai, 2004; Wood, 2004). This study draws on these, but is also distinct those because it seeks to explore how schema and resources interact with Discourses in ways that allow individuals to accept, reject or negotiate subject positions.

Chapter 4

Methodology

In this chapter, I address the methodological considerations taken in the design and implementation of this study. I begin by discussing the research paradigm in which this work is situated, and then I describe the research design and a justification for the variety of methods used including observations, photo-elicitation, and interviewing. In the latter half of the chapter, I will give a detailed description of the data sources and methods for data collection, and I will describe how the data were managed and analyzed.

Research Paradigm

In conceptualizing my research, I draw upon Guba and Lincoln's (1994) definition of a research paradigm: "[T]he basic belief system or worldview that guides the investigator, not only in choices of method, but in ontologically and epistemologically fundamental ways" (p. 105). Articulating a research paradigm helps to achieve coherence between theoretical perspectives and the actual research methods used (Abraham, Gonsalves, Jackson, Peters, Pozzer and Seiler, 2010). Ensuring coherence requires the researcher to continually consider the ontological and epistemological underpinning of the research goals and processes.

This study is situated in the constructivist paradigm, which regards reality as fluid, changeable, and "local and specific in nature (although elements are often shared among many individuals and even across cultures)" (Guba & Lincoln, 1994, p. 110). Thus, the purpose of research is not to seek the truth, but rather, to seek understanding. A constructivist worldview permeates my research and informed all of the decisions made with regard to construction of the research questions, modes of data collection, handling of data resources, and analysis and presentation of findings. For example, the research questions evolved throughout the research in response to what was learned in and about this context, as this informed my theoretical understanding of the construction of gender and identities in this place and time. Accepting reality as local and specific, I could not have constructed the research questions in advance. In the constructivist paradigm, the traditional line between ontology and epistemology disappears, and the investigator is deemed to be implicated in the construction of findings (Guba & Lincoln, 1994). This is exemplified in the personal reflections on science and my role as a researcher that I compiled throughout the research and the inclusion of some reflections in the dissertation. While the doctoral physics students in this study are regarded as participants in the research who co-constructed the data along with me (the researcher), I also recognize the power of my voice in the construction of the story told through the data. Therefore, I used criteria for trustworthiness that Lincoln and Guba (1986) suggested for researchers in the constructivist paradigm. These and other efforts to ensure that the research was guided by the underlying paradigm of constructivism are described in the following sections.

Regarding reality as “local and specific in nature” (Guba & Lincoln, 1994, p. 110), I constructed a case-centred qualitative research study, which drew upon a combination of strategies for data collection and analysis as they were needed in the context of the unfolding research situation (Creswell, 1998; Mishler, 1999). In this case-centered approach, I regarded the physics department as a *bounded system* within which several sub- or embedded cases or individuals were examined (Creswell, 1998). This allowed me to study how the participants' life-history narratives and engagement in the community dialectically shaped both their own identities and the setting in which the case study was conducted (Mishler, 1999). Following Creswell (1998), I employed multiple sources of data collection to provide a detailed picture of the case setting and participant backgrounds. I began with taking observational field notes and writing a reflective journal in order to construct research questions. This led to the use of photo-elicitation and semi-structured interviews to address the research questions. Aligned with the epistemological imperative that participants are regarded as co-contributors to the research process, I shared details of my data analysis with participants and solicited their feedback on parts of the analytic process. In the following section, I will describe the research design so that I might provide a solid grounding for the theoretical and methodological choices I have made.

Research Design

The research methodology is the inquiry strategy or design of a research project. According to Denzin and Lincoln (2000):

> [a] strategy of inquiry comprises a bundle of skills, assumptions, and practices that researchers employ as they move from their paradigm to the empirical world. Strategies of inquiry put paradigms of interpretation into motion. At the same time, strategies of inquiry connect the researcher to

> specific methods of collecting and analyzing empirical materials . . . Research strategies implement and anchor paradigms in specific empirical sites, or in specific methodological practices, such as making a case an object of study. (p. 22)

Congruent with a constructivist paradigm, this study used a qualitative inquiry approach, in which the design was fluid and subject to change in response to the ongoing work. As research progressed and themes emerged from the data, research questions were refined, data collection tools were used in new ways, and new tools of inquiry were employed (Denzin & Lincoln, 2000).

The goals of this study were to: identify trajectories of belonging to the various sub-disciplines of physics and the sociocultural factors in the form of background resources that contributed to those trajectories; to identify the Discourses of physics and physicists (that is, appropriate ways of doing physics and being physicists); and to understand how participants are positioned and author themselves around these Discourses or, how they construct identities as physicists when presented with a limited availability of subject positions. These goals demanded a research approach that could help me to craft life-history stories of participants, to construct and analyze participants' characterizations of the Discourses of physics and physicists, and to explore the ways that participants accept, reject, or negotiate the subject positions offered to them through Discourses. Since I was most interested in the Discourses particular to physics, I regarded a case-centered approach focusing on participant narratives to be most appropriate (Mishler, 1999).

A case-centred approach. In my research, I was repeatedly dogged by questions of representation: how can I represent individual experiences while still generating insights about physics culture that have significance to the field of science education? Mishler (1999) pondered this tension between individual and collective identity formation and emphasized the importance of culling narratives of sociocultural significance from the data, such as those related to social class, gender, and race, while retaining an emphasis on variability in identity trajectories. He asserted that it is desirable to move away from the dominant model of variable-centered research, which emphasizes universal events and stages of development that are influential to human identity formation, but leave little room for examining variation, and towards a model of case-centered research that emphasizes individual trajectories. Mishler (1999) discussed life-course trajectories as the experiences a person has throughout their life and career that contribute to their identity construction. Rather than suppressing variability across these trajectories through the development of coding systems that construct totalizing categories, individual stories are retained in the analysis to emphasize the contingent, contextual, and dynamic nature of identity construction (Mishler, 1999). Thus, although my theoretical use of the concept of identity differs from that of Mishler, I draw on certain aspects of his case-centered approach by using narratives as an organizing feature in this study.

According to Creswell, (1998) a case study is:

> an exploration of a bounded system or a case (or multiple cases) over time through detailed, in-depth data collection involving multiple sources of

> information rich in context. This bounded system is bounded by time and place, and it is the case being studied—a program, an event, an activity, or individuals. (Creswell, 1998, p. 61)

This approach suits the goal of understanding aspects of physics culture as instantiated in this local and specific context. I regarded the physics department at Eastern University as a bounded system or a single case study with embedded subunits of analysis, the individual participants (Yin, 1994). These individuals emerged as important figures in the case analysis, not to be regarded as representative of others in their disciplinary subfield, but rather to be seen as participants demonstrating particular insights into the bounded system and the research questions I was exploring.

Although I will be drawing comparisons between how participants construct the Discourses of physics and physicists, I will not be looking for cases that have predictive value or to confirm a theory among cases (Stake, 1998; Yin, 1994). Instead, I have allowed for the contributions of participants from three distinct disciplinary subfields in physics, constructing a case (the physics department) that is bounded not by the disciplinary subfield but instead by the physical environment, time period of the study, and the multiple sources of data collected (Creswell, 1998). Focusing both within and between three different disciplinary subfields allowed me to explore both the general and specific construction of Discourses of physics and physicists and the gendering of these Discourses, while at the same time maintaining a focus on individual trajectories by attending to background resources and goals of individuals and recognizing the contingent and contextual nature of those experiences. However, the focus of the study was not on the contextual differences between subfields, although these particularities were noted when they arose.

Mishler's (1999) case-centred approach provided an analytic framework within which we may examine individual's narrativizations of self through stories. In the findings sections presented in Chapters 5 to 7, I explore participants' stories that construct Discourses wherein certain kinds of people are constructed as physicists and where certain kinds of behaviours are appropriate to be recognized as physicists (Gee, 2005). Thus, narratives may be able to shed light on what students believe is possible within the Discourses that define their scientific communities (Holland et al., 1998; Mishler, 1999).

Building rapport. Designing a study in line with the epistemological requirements of the constructivist paradigm requires the researcher to self-disclose, and to share emotional and historical information with the participant so that the participant feels more comfortable and the power relationship normally constructed in interviews is disrupted (Ellis & Berger, 2002). To achieve this, I involved myself in the physics community by attending social events (parties, softball games, defenses), as a way to build rapport with the participants.

In addition to fulfilling a paradigmatic commitment to recognizing my construction of the research findings and the story they tell, disclosing aspects of my own personal history with science in interviews with participants enabled me to construct a rapport and collegiality that may not have been possible had I been unable or unwilling to share my experiences. Thus, the formal portions of the research, predominantly the interviews, were imbued with a comfortable lightness and collegiality—even friendship.

Methods

Reflecting the imperative of the case study to obtain thick descriptive data of the problem and the context (Creswell, 1998), multiple data collection methods were used in this research. In this section, I begin by detailing how I gained access to the research site and recruited participants to the study, and then I describe the data collection methods employed.

Gaining entry. My entry into the research field and my ability to recruit participants were facilitated by two key connections I had in the physics department at Eastern University. One of the connections was a friend who had just finished his PhD in the department and another was a professor who worked closely with the Faculty of Education. These two people were insiders who helped introduce me to people in the physics department. I conducted pilot research to familiarize myself with the research setting and to determine if it was feasible to utilize some of the methods I had hoped to employ (i.e., shadowing; see Appendix A). However, there were other benefits to conducting a pilot study that were related to my constructivist approach. The piloting of interview questions allowed me to refine some of these and then in turn reconsider my research questions in a recursive manner; and my presence in the department for several weeks before the full study began provided numerous informal conversations that were not retained as sources of data, but were useful in that they familiarized the participants in the study and those around them, with the goals of the research. As a researcher committed to a constructivist epistemological paradigm, establishing my presence in the department before beginning to collect data helped me to develop relationships with individuals in the physics department, both those that would eventually participate in the study and others. I knew many of the professors and research assistants by name, and after a while, my presence in the department was no longer regarded as a curiosity.

Recruitment of participants. Upon having gained research ethics board approval to conduct the study (See Appendix B for ethics certificates), I drafted e-mails that were sent to the principal investigators of the groups I was interested in studying, and to the chair of the department. Upon receiving confirmation of their approval, I began my recruitment efforts. My recruitment of participants was *opportunistic* in that I took advantage of the pre-existing connections I had in the physics department and then used snowball sampling to find other potentially interested participants (Miles & Huberman, 1994). The sampling I used was purposeful or *information oriented* in that I was looking for people who might be interested in the study and who felt that they had stories to share about their experiences with physics (Flyvbjerg, 2006). While I conducted the pilot study, I was able to discuss my research with a variety of students in the department. Often they presented themselves to me as interested in participating and with particular stories to share. After the pilot, I refined my research questions and methods and then returned to the research site four months later.

Once participants were enrolled in the study, I scheduled an informal meeting to provide them with information about the study. Participants were invited to convene as a group or individually in order to protect their anonymity. All of the participants attended the first group meeting. The meeting detailed the goals of the research, the procedures including the photo reflexivity project, and the timeline. At this time, informed consent forms were explained and distributed, and left with the participants for a period of one week before I returned to collect the signed forms (see Appendix C). At that time, I met with each participant individually to go over concerns about informed consent and anonymity and to answer any questions they had about the study. Observations and interviews were not conducted until all of the consent forms were returned. Appendix D provides a chronology of data collection and analysis and Appendix E outlines the sources of data collection that will be elaborated on in the following sections.

It was important that participants in the study agreed to participate in two interviews and a period of observation. Some of the participants were unsure about journaling or photographs, and in that case I allowed for some negotiation of participation. As I was using *snowball sampling* (Miles & Huberman, 1994), my access to participants was limited to those who knew others who were participating and thought they would be interested. It was important to me that participants be enthusiastic about participating in the study, as participation entailed a long-term commitment and some potentially intrusive observations.

Table 1 describes the composition of the participants in the study, their field of study, year, gender and the types of data they contributed. I have indicated gender as distinct from sex to emphasize that I was not interested in reifying a sex-gender connection when sampling, but was interested in how individuals identified themselves. For example, if individuals wished to identify themselves as neither gender, I would have indicated this. In this case, there were seven woman-identifying participants, and four participants identifying as men. I have not indicated sexuality or ethnicity to retain the relative anonymity of the participants, although in some cases cultural backgrounds are discernible from the pseudonyms used for the participants.

It is notable that there are more participants from Condensed Matter Physics and Astrophysics than from Theoretical Physics. Research group structure is different in theoretical subfields and students in that field tended to operate as individual researchers rather than a team. Thus, it was difficult to access a greater number of participants from this research group. Additionally, while I approached two more women (one from theoretical and one from condensed matter physics), and another man from theoretical physics, these three potential participants were not interested in giving their time to the study. I did not regard this as problematic for the study, given that the goal was not to generate average or representative cases, but rather to explore critical cases that might give the most insight into the research questions.

Observations. The three disciplinary subfields in which I conducted research were all physically structured differently, which complicated my observations. The experimental condensed matter group was spread out over two buildings, on several floors, and only convened as a group once a week for a seminar presentation by group members. The theoretical physicists had offices spread out around the department and sometimes came together for seminars, but they only met every two weeks and the meetings were often cancelled. The astrophysicists' offices were located on two separate floors, but they had regular weekly meetings and journal clubs. I conducted observations in each of the research teams belonging to that group and attended weekly seminars and small lab group meetings with supervisors wherever possible. A detailed description of the setting in which the research took place can be found in Chapter 5. Table 2 details the seminars and meetings I attended.

My observations were recorded in field notes written into a notebook that I divided into two portions: the right-hand page for actual field notes of who, what, and where and the left-hand page for my personal thoughts about what I was observing. Because I did not have permission to video or audiotape meetings, I initially attempted to include a transcription of dialogue as closely as possible to verbatim on the right-hand page. However, I recognized that my attempts to record conversations verbatim were marred by confusion and incompleteness, so instead I began recording on the right-hand page when certain individuals spoke, generally what they were talking about, and if an incident occurred that I felt was of importance,

On the left-hand page of the field notes, I attempted to reflect in the moment upon the recorded observations, for example, why I had thought that a particular event or interaction was important. In this way, upon returning to the field notes I would have a reflective account, as well as the specific details, to build upon in the reporting of the data.

As Hammersley and Atkinson (1995) pointed out, "one can never record everything; social sciences are truly inexhaustible in this sense" (pp. 179-180). I followed Hammersley and Atkinson's suggestion that "records of speech and action should be located in relation to who was present, where, at what time, and under what circumstances" (p. 185). These organizers helped me to make sense of the field notes when it came to analysis, and the reflective notes attached to the observations helped me remember the why of what I had noted.

The observation portion of my study extended over four months and involved attending meetings in the various research groups, reading groups, and informal affairs such as parties and softball games. Attending these events allowed me to make note of details that helped to provide context to interview conversations and also provided data that could address Research Questions #2 and #3 dealing with the construction of physics and physicist Discourses. Most of my time in the physics department was spent in venues for collaboration, such as department seminars, lab meetings, experimental labs, research group meetings, and special guest lectures. During this time, I also engaged in informal conversations with participants discussing the details of their projects and sharing anecdotal experiences with science. At times when I attended parties and other informal events like softball games and coffee breaks, I did not take notes and I regarded these events as opportunities to build rapport with participants. These informal conversations that I had with participants in my study rarely figured into the analysis in specific ways, but did help provide context to the interview conversations and also helped me to understand the content and jargon that was used during meetings. These informal interactions that I participated in and observed, helped familiarize myself with a field about which I knew relatively little and established me as a peripheral member of a community to which I was previously an outsider, which was an important part of gaining understanding of the physics culture in the department.

Reflexive photography and photo-elicitation. Using photographs in qualitative research is a relatively new methodology that has its origins in visual sociology (Collier & Collier, 1986). Harper (1998) suggested that the photographic methods employed in visual sociology can be used to study social processes such as the social realm of laboratories or research groups, and as a starting point for interviewing that is grounded in the perspective of the participant. The use of participant-produced photographs has been referred to as photovoice (Wang & Burris, 1997), photo-novella (Wang & Burris, 1994), and reflexive photography (Douglas, 1998; Harper, 1998; Harrington & Lindy, 1998). In particular, reflexive photography, like other visual images such as drawing or concept mapping, involves the participant in the making of meaning from images during interviews (Harper, 1998). In their justification for and evaluation of the use of this method, Harrington and Lindy (1998) suggested that the photo-reflexivity technique allows for a more creative representation of participant's experiences.

My purpose for using this methodology was to elicit stories of recognition—stories where participants recognize themselves and others as physicists. Stories elicited by photographs in interviews were intended to address all four of my research questions. As such, I designed the photo-journal (Appendix F) to allow participants to record thoughts about their everyday practices as physicists or thoughts about events and images that make them feel like physicists. In this dissertation, I refer to the overall project of participant-directed photography as photo-reflexivity to acknowledge the role that the participants played in taking the photographs and guiding the reflective process, and the actual use of the participants' photos in interviews as photo-elicitation (Harper, 2002).

Photo-reflexivity. Photo-reflexivity, photographs that are produced by study participants, allowed a window into the participants' lives, through the eyes of the participants. Bach (2001) suggested, "visual narrative research makes 'visible' different parts or narratives of…stories—their subjectivities" (p. 2). I adopted the approach advocated by Bach (2001) and Douglas (1998) and asked the participants to provide images of what it means to be a physicist or a doctoral student in physics through photographs that they composed and took. All but one of the participants agreed to participate in the photo-reflexivity activity. This participant (Laura) claimed that she was "not a visual person" and did not feel that she would do an adequate job with the photography project. She agreed to keep a journal instead—and addressed all of the same questions that the photo-journal posed, but provided anecdotes instead of photographs.

Initially, I offered my participants disposable cameras for this purpose, and all but one refused the disposable cameras. Most of the participants rejected the disposable cameras for environmentally-conscious reasons, and one participant (Ruby) claimed that she felt uncomfortable photographing on film since she found the idea of having a negative to the image distasteful. The remaining participants all used their own digital cameras to document their experiences. Drawing on the work of Douglas (1998) and Sampson-Cordle (2001), a photo-journal (see Appendix F) was drafted and provided in paper to each participant with guiding questions such as “Does this photograph represent an object or event that makes you feel like a physicist? Why or why not?”, “Does this photograph represent an event or a place that you identify with or that you feel alienated from?” and “Why did you take this photograph?” (Mitchell & Larkin, 2004).

The participants in this study took an average of 12 photographs each. In Chapters 5 to 7, I use some excerpts of text from participants’ photo-journals. Where they are included, entries from participants’ photo-journals are transcribed verbatim, including the original punctuation, grammar, and spelling. At the end of the excerpt, the participants’ name is indicated along with an indication of the page of the photo-journal (e.g., Lily, photo-journal, p. 3). The photo-journal text was coded in the same way as the interview transcripts. The photographs themselves were used during the interviews in a process called photo-elicitation (Harper, 1998). In keeping with the purpose of the photography exercise, Laura, who declined to take photographs, wrote a number of journal entries for me detailing instances that made her feel like a physicist or that discussed what doing physics entailed for her. Three other participants did not give permission for their photographs to be shown publicly. Those photographs were used for elicitation purposes in the interview and then deleted from my computer's hard drive. While my data analysis did not include interpretation of photographs, the photographs and their accompanying journals were useful resources for photo-elicitation in the interview process, as they became jumping-off points for interview questions.

Photo-elicitation. In making the case for photo-elicitation interviews, Harper (2002) suggested that "photo elicitation mines deeper shafts into a different part of human consciousness than do words-alone interviews. It is partly due to how remembering is enlarged by photographs and partly due to the particular quality of the photograph itself" (pp. 22-23). The photo-elicitation portion of the interviews allowed the participants to initiate discussions about how they positioned themselves around Discourses of physics and physicists by responding to cues in the photo-journals. In the interview, I asked participants to show me the photos they took and to discuss why they took them. Sometimes they chose to speak longer about some photos than others, and some they skipped over. During this time, I did not guide the interview but rather let the participant say what they wanted to say about their practice as physicists. In some cases, the photographs sparked interesting discussions about their experiences, that led us to conversations I had not anticipated (e.g., Lily's photographs of manipulating tiny objects). Thus, photo-reflexivity and photo-elicitation were useful for side stepping the preferred story that often arises in interviews by "getting at the point of view of the subject" in an innovative way (Harper, 1998, p. 66). The photo-journal was particularly useful because it provided some structure to the photography. Asking participants to photograph situations that made them feel like a physicist, or situations that they felt strongly connected to doing physics helped me to elicit stories of recognition, both of self and other, in the interviews.

The qualitative research interview. Following the observational period, and after they had sent me copies of their photographs and photo-journals, each participant was interviewed twice, for a period of 60 to 90 minutes per interview. Four out of the ten participants taking photos did not send me their photos ahead of time due to technical reasons. The one participant (Laura) who declined to take photos sent me her journal (with no photos) beforehand.

Before each interview, I looked through my field notes and the photo-journals when available and generated themes that I wished to address in the interview. A semi-structured interview format[iii] was used, which allows one to capture unexpected issues or information that may lead to the construction of the image that people have of their realities. My goal was to approach each interview as a conversation that would generate knowledge (Kvale, 1996). Thus, I attempted to allow the interviews to unfold naturally as much as possible, and each interview eventually took on its own individual form.

The first interview, the life part, concerned questions about the participants' history with science and physics and included the use of photo-elicitation techniques. The second interview, the society-part asked more academically-oriented questions around participants' perceptions of who physicists are, who can be physicists, and the role of gender in becoming physicists (Gee, 2005).

First interview. The first interview began with the background portion that involved asking the participants how and why they first became interested in physics (approximately 20 to 30 minutes), progressed to photo-elicitation (approximately 20 to 30 minutes), and then to questions about their present experiences with physics and whether their experiences met their expectations coming into the field (approximately 20 to 30 minutes). This process was guided largely by my first two research questions.

The background portion of the interview was guided by Mishler's (1999) life history narrative, and participants were asked what influenced them to pursue doctoral degrees in physics and to elaborate on experiences from their childhood or undergraduate years that cemented their interests in the field. In pursuing these kinds of questions, I elicited much information about how participants saw physics and physicists in their younger years and learned much about the events or people that influenced their decisions to pursue physics at the doctoral level. In particular, students were asked about previous experiences they had with physics that they thought might have helped or hindered their progress.

As described previously, in the photo-elicitation portion of the interview I allowed the participant to take over and guide the interview. They described to me what they had taken a photo of and what it represented to them in terms of their daily activity, events that they felt a part of or marginalized from, things they liked or disliked about doing physics, and events or objects that made them feel or not feel like physicists. These descriptions were generally guided by the photo-journal, but often the conversation diverged into story telling (i.e., photos of conferences and trips often yielded stories of experiences). Following the photo-elicitation, the interview proceeded in a semi-structured format (see Appendix G for interview guide).

Second interview. The second interview followed approximately two weeks after the first interview. After the first interview, I listened to the audio file and selectively transcribed the portions that I felt were incomplete stories, needed clarification, or that I wished to pursue in greater detail (Gilbert, 1993). For example, I conducted selective transcriptions of stories that were interrupted due to a tangential digression in the conversation, or stories that were incomplete due to time constraints. Some participants came to the interview wishing to follow-up on a topic from the previous interview.

Each of the second interviews began with follow-up questions from the first interview (approximately 10 minutes), and then I asked questions about whom they considered to be their ideal physicist or what that might look like and subsequently moved on to more explicit questions of gender and physics (approximately 20 to 30 minutes). My third research question was a guiding construct for the second interview. The second interview was generally more unstructured than the first, which allowed the participants time to ask their own questions or give their impressions of the conversations we had thus far.

Transcription. The interviews typically lasted between 60 to 90 minutes each and were audio recorded and transcribed verbatim, but with some extra notations as described below. Each interview transcript ranged from approximately 17 to 23 single-spaced pages in length. In excerpts of the data, the interviewer (me) is indicated by AG and the name of the participant is shown. I did not indicate changes in intonation. Other than pauses and overlaps, punctuation is set to be grammatically correct.

The following transcription rules were applied to the interview data:

- In cases where there is a break in the transcript, this is indicated with an ellipses [. . .]. I indicated breaks in the transcript because there were times when the sentences following a breaks appeared as a non-sequitur. These breaks may have been pauses, stutters or excessive use of filler terms such as “um”, “uh”, “like” and “you know”. These were removed for clarity and to improve the readability of the transcript.
- Some of the transcript excerpts have syntactical errors that I have left true to the tape to reflect the pattern of speaking.
- If I have interpreted a statement as an aside, I have bracketed it with hyphens.
- If I have modified the transcript for clarity or anonymity, I have included my modification in square brackets.
- If a gesture was made at a particular point in the interview that I felt clarified meaning in the text, I indicated the gesture in my notes and transferred it into the transcript with square brackets (e.g., [air quotes]).
- After each transcribed excerpt, I indicate the participants’ name, followed by the source of data (e.g., Laura, Interview #1).

Reflective journaling. To ensure dependability I kept a researcher's journal to document decisions about methodology and ideas that I wished to follow up on with participants in interviews. During observations, reflective journaling took place most often at the same time as field notes on the left-hand page of my field journal. My experiences for the day were also summarized in the same journal at the end of the day. Again in the same journal, after each interview, I summarized my thoughts and feelings about the interview and highlighted issues I wished to pursue either in the second interview or via e-mail. Thus, my field notes also contained notes about interviews, summaries of my experiences doing the research, and reflections on my role as a researcher (Russell & Kelly, 2002). Furthermore, journaling was used as a place to document and reflect on my methodological choices, and changes that arose during data collection. Often these reflections entailed making concept maps to draw theoretical and methodological connections, or to connect an observation I had made with previous research on the topic. These reflections were recorded on the left-hand page of the journal, opposite the field notes to which they corresponded. Excerpts from my own field notes are differentiated from participants' photo-journals with italics.

Informal and electronic communication. Informal communication described in this dissertation entails conversations I held with participants outside of the context of the interviews. These conversations were not recorded but were occasionally noted in my field notes and journaling. Often, informal conversations took place at the physics department while I was attending seminars, meetings, and workshops. Occasionally, informal conversations occurred at parties or other social events such as gatherings at bars or cafes to which I was invited; rarely, they occurred during random meetings on the street, in the metro, or on the bus. Invariably, participants would ask how my research was going and often jokingly, if I had any conclusions yet. Very often these conversations revolved around their own work—frustrations might be aired or small successes shared.

Often, participants communicated with me via e-mail. Most of the time this was for the purpose of arranging interviews, but sometimes this occurred as follow-up to an interview. This indicated to me that sometimes in the interview there remained topics the participant wished to discuss and either forgot to raise or felt were out of the bounds of the interview, or perhaps the participant did not think of the topic until after the interview. E-mail communication with participants is indicated as such and is annotated at the end of the passage with the participant's name and the date of the communication (i.e., Laura, e-mail communication, January 17, 2010).

Anonymity and Other Ethical Considerations

Before conducting interviews and observations, I met with each participant individually to discuss the study and to obtain their informed consent. I read through the consent form with each of them and assured them that they were free to leave the study at any time. Most of the participants did not express concerns about anonymity, but because some did, I have made efforts here to conceal the identities of all of the participants, although they remain recognizable to each other. There were only three disciplinary subfields involved in the study, and due to the size of the physics department, news traveled quickly about the study. Most of the members of each disciplinary subfield were aware that the study was being conducted and also were aware of who the participants were. I discussed this concern with all of the participants. I have used pseudonyms that were chosen by the participants. In the life histories of each participant, I have made efforts to conceal their hometowns, previous universities, and other identifying information.

There are particular features of individuals that I have not shared in the findings of this dissertation in the hopes that I can help retain some level of anonymity for the participants. To this end, I have left out some important pieces of information about participants' gender presentation and sexuality, which would immediately identify the participants. I often felt that this anonymity came at the expense of a more nuanced discussion of localized masculinities and femininities, and I often felt that I was simplifying the experiences of some of the participants by keeping this information confidential.

Additionally, while photo-elicitation proved a promising method to invite participants to construct stories that would ultimately be distilled into Discourses of physics and physicists, the setting in which to take these photographs presented problems. The first problem was with confidentiality, an issue that presented itself as a limitation overall. Many of the participants in the study wanted to take photographs of colleagues at work or in meetings, but were unable to do so because of consent issues. Also, at times taking photographs would have been, especially during meetings, and many of the participants reported feeling shy or awkward about photographing social situations. Moreover, two of the participants took photographs but did not feel comfortable with having their photographs publicly displayed or published, which meant that I was not able to incorporate them into the dissertation. These are noted in Table 1.

Trustworthiness. To establish rigour in qualitative research, Lincoln and Guba (1986) established four general criteria that can be employed when understanding is the focus rather than truth seeking. Rigour was addressed in this research by attending to the trustworthiness in the form of: credibility, transferability, dependability, and confirmability.

Credibility. This aims to "establish the match between the constructed realities of respondents and those realities as represented by the [researcher] and attributed to various [participants]" (Guba & Lincoln, 1989, p. 237). Credibility in this research was established through prolonged engagement with the participants (the study continued for well over a year, including four months of almost daily contact in the physics department) and member checks—the continual solicitation of reactions of participants to the ideas I entertained throughout the observation, interview, and analysis periods. In addition to this, after I conducted analysis of the data, I sent a preliminary draft of the analysis to the participants. Of the 11 participants, six replied with feedback on the analysis, and of them, two had substantive feedback. In particular, I had extended e-mail conversations with Laura and Molly, who gave significant amounts of feedback, some of which I incorporated into the body of this dissertation (Chapter 8). To ensure fairness in the reporting of the data, I made sure to include their assessments in the analysis, often directly citing our e-mail exchanges. Subsequent drafts of the dissertation were not shared with participants for the purposes of soliciting feedback, however, e-mail communication with several participants was maintained over the course of drafting and redrafting the dissertation.

Transferability. According to Lincoln and Guba (1986), transferability is the extent to which research findings may be applied to a different context. The study undertaken here—in a case-centred format—is situated in its own context and therefore the findings are not expected to be generalizable to new situations. Additionally, as described previously, research in the constructivist paradigm regards reality as locally constructed, fluid and changeable, thus it is impractical to regard a set of findings as generalizable to new contexts. Rather, given the importance I attach to the local and background resources, I provide rich descriptions that readers may use to determine if the interpretations presented here are credible and thus might be relevant in thinking of another context. In this way, readers may be encouraged to raise similar or related questions about their own research context, teaching practice, or learning environment based on the *thick descriptions* provided here (Lincoln & Guba, 1986).

Dependability. This is determined by the ability of the researcher to follow the evolution of the research process and to ensure the coherence of methods, track shifts in methods, and document the progression of the research (Guba & Lincoln, 1989). To address this concern, I recorded and reflected on methodological changes in my field notes, along with concept maps to ensure that changes in methodology were coherent with the theoretical framework I worked with. These concept maps were constructed as tree-like diagrams and were used as tools to explore how theoretical concepts were connected to both methodological constructs and observations I was making in the field and during analysis of transcribed data (Miles & Huberman, 1994). Also helpful in promoting dependability was peer debriefing through engagement with a peer writing group and my supervisors with whom I discussed my methods and thoughts about the analysis as I planned and proceeded with the research.

Confirmability. This measure of rigor requires assuring that interpretations and outcomes are rooted in data and are not figments of the researcher's imagination (Guba & Lincoln, 1989). Thus, I have provided readers with excerpts from transcripts to make it possible for them to also track and interpret the empirical data emerging from this study. Providing transcript excerpts and detailing the process I used to gather these, provides some empirical context to the analysis, making it possible for readers to connect the analysis to the findings. Additionally, throughout the research process, I consulted with my supervisors, dissertation committee, and other research colleagues about my analysis to assure the close association of assertions with the data.

Analysis

The iterative project of data analysis began during data collection, as consideration of data informed the theoretical framework and the research questions, which in turn guided the data collection process, for example, by shaping the kinds of interview questions posed to the participants. However, the organization of data once it was collected required a process that would include thematic coding and the distillation of stories from narrative episodes. Thus, my data analysis process entailed breaking the data into manageable and comprehendible stories, bringing meaning to these stories, and displaying them to the reader (Marshall & Rossman, 2010).

My analysis was conducted in three stages detailed in the following sections:

1. Constructing participant trajectories from life history narratives (addresses Research Question #1; findings presented in Chapter 5);
2. Thematic analysis across the data sets to identify Discourses of physics and physicists and the subject positions these make available (addresses Research Questions #2 and #3; findings presented in Chapters 6 and 7);
3. Generating stories of participant positioning around subject positions (addresses Research Question #4; findings presented in Chapter 8).

Given that the goals of the study were both to identify the Discourses that constitute the community of physicists and the individual trajectories and positionings around those Discourses, I conducted an analysis of the entire case, and embedded analyses of individuals within the case (Yin, 1989). Thus, the overall analysis yields themes that run across the cases, and presents stories from embedded sub-units of analysis (individual participants).

Generation of participant profiles: Trajectories of becoming. Once all of the participant interviews were transcribed, I began the job of constructing participant profiles. These were essentially digested versions of the life history stories the participants shared with me in the first set of interviews that shed light on participants' prior experiences with physics and, in some cases, reasons for their interest in science. Stories in this case did not need to be well-formed stories organized around characters, settings, or plot (Labov, 1982), but rather, could follow Gubrium and Holstein's (1997) notion of stories as short accounts that are used to make sense of events. The purpose of compiling individual profiles was to highlight the variability across the cases in the trajectories and to emphasize the contingent, contextual, and dynamic nature of trajectories (Mishler, 1999). I generated these profiles from the preliminary data coding in which I analyzed interview transcripts and photo-journal text for stories that detailed the background resources students acquired through their experiences with physics, and for stories of recognition, either by self or by others.

Using HyperRESEARCH coding software I first coded the data broadly to reveal stories of early experiences with physics or science, either pre-university or university experiences that influenced participants' choices to pursue physics, and their goals for the future. I then generated sub-themes to identify experiences and contexts the participant had related to physics. These were regarded as salient events, individuals, or contexts (e.g., family background, cultural background, transnational experiences, prior research experiences) that may have influenced the participants' trajectories. These were highlighted and presented in the dissertation as themes (Chapter 5) that might be compared to the goals that individual participants had for their academic trajectories in physics. In addition to experiences and contexts, I also examined the data for stories of recognition (Gee, 2000). These were stories that participants told of being recognized as a physicist, or recognizing themselves as a physicist. Table 3 outlines the categories for inclusion into stories of recognition of self and recognition by meaningful others.

Where there was confusion about a story, particularly in cases where the story involved technical descriptions of a physics activity or the use of physics jargon, I then referred to my field notes to help with the explanation. For example, my field notes contained much information pertaining to acronyms that physicists used freely without explanation. Often, I had spent time looking these up on the Internet and learning about the instruments they referred to so that I might better understand the stories participants told about working with these instruments.

Identifying Discourses. To answer my second and third research questions, I was interested in identifying Discourses that participants constructed or used to characterize the appropriate ways of doing physics and being physicists. To do this, I went back to the coded stories of recognition, for a second iteration of thematic coding. Here, rather than looking at individual participants, I conducted a thematic analysis across the sets of data using HyperRESEARCH.

Drawing from Gee's (2005) Discourse analysis, I examined the interview transcripts of individual participants for examples of talk that conveyed characterizations about *appropriate* ways of doing physics and being physicists.

This entailed looking for episodes in the data where participants discussed appropriate ways of acting, interacting, talking, writing, communicating and dressing, appropriate beliefs and values, and appropriate ways of doing research (Gee, 2005). As I identified stories of appropriate ways of doing physics that individuals constructed, I continued to look across the narrative data to determine if these were discussed by other participants, and then I grouped these into categories in HyperRESEARCH and crafted these into accounts of the big-Discourses of physics.

Theoretically, I understand Discourses as constructing available subject positions for participants in the disciplinary subfields of physics. Thus, when examining the Discourses models students use to describe the field of activity in physics, I paid attention to the way that students discussed who it was possible to be as a physicist in their various subfields. This allowed me to understand the local meaning that participants make of the Discourses that constitute the practice of physics, and to construct categories that allowed me to see the kinds of actions and behaviours that were necessary to be regarded as a physicist. In constructing stories that detailed these Discourses, I also referred often to my field notes to clarify questions that arose in interview data or to highlight coherences and contradictions with interview data, and to participants' photo-journals where appropriate. Figure 1 shows the concept map of Discourses that was generated by thematic coding across interview data. This figure is divided into three sections: section I shows the codes generated around the Discourses of physics; sections IIa and IIb are the codes relating to Discourses of physicists. IIa shows the

Discourses of competence and IIb shows Discourses related to images of physicists. In each case, the related sub-themes are connected with solid lines, each sub-theme is connected to a section in the findings chapters. In cases where there were sub-sub-themes, I have indicated these with dotted arrows, these do not appear as separate findings sections in the chapters.

Examining positioning. Guided by my fourth research question, I conducted a third round of coding in which I looked back at individual participant's stories of recognition of self by self and by others to examine stories of positioning and authoring of selves in response to the Discourses previously identified in the data. Gee (2005) described the doing of Discourses as recognition work and suggested that we can examine texts (e.g., participants' stories) as "attempts to get oneself and others to *recognize and relate* people and things [like physics] *in a certain way*" (p. 91, emphasis in original). In re-examining the narrative texts grouped into stories of recognition, I paid attention to relationships between how participants talked about themselves as physicists, and how Discourses of physics and physicists influence how participants recognize themselves or are recognized as physicists. This was done by returning to the original codes (e.g., recognition of self, recognition by others) and looking for stories that included depictions of the Discourses and available subject positions identified in the second round of coding. I then constructed stories of positioning to understand how participants either accepted, rejected, or negotiated the subject positions made available through Discourse (Holland et al., 1998).

An iterative process. Analysis was an iterative task that took multiple readings of interview data with references to photo-journals and field notes. This recursive analysis occurred in a looping pattern causing a refinement of the research questions guiding the analysis, requiring me to return to the theoretical concepts guiding the analysis and also refining the analytical tools used to organize and interpret the data.

In the first and third stages of the analysis, I focused on portions of the interview that are stories—not necessarily stories that have a well formed beginning, middle, and end, but rather stories that are "accounts that offer some scheme, either implicitly or explicitly for organizing and understanding the relation of objects and events described" (Gubrium & Holstein, 1997, p. 146). The analysis and writing of the stories that follow are not simply a retelling of stories that were told to me. The analysis discussed here indicates a recursive process that connects theory-methodology-analysis-theory in a looping manner that directly implicates me, the researcher, in the construction of the stories shared here. In this way, the theory I have used to understand the data is also informed by the data, such that the conclusions I draw from this analysis may provide a more theoretically informed approach to the study of Discourse and identity in doctoral physics.

Chapter Summary

The methodology employed in this study was constructed in response to the particular demands of the research questions, which sought to describe participants' trajectories and the background resources influencing these (Sewell, 1992, Wenger, 1998); the Discourses and subject positions participants identify as constituting the community of physicists (Gee, 2005); and the individual stories of positioning around these subject positions (Holland et al., 1998). True to a case-centered approach, a variety of data collection methods were employed in ways that respond to the data collection needs of the research environment (Yin, 1994). Personal histories and storylines were constructed using Mishler's (1999) life history narratives, and Discourses that constitute the communities of physicists were identified using constructs drawn from Gee's (2005) tools for analyzing interview data. Trustworthiness was established by using multiple data collection methods, participant verification, and researcher journaling to keep track of methodological changes and coherence. Overall, the primary source of data was interviews collected using life history narratives and photo-elicitation. Participant photo-journals were also used as data. Observational field notes and reflective journaling were kept as sources for verification and clarification.

By examining individual accounts of recognition along with a cross case thematic analysis, I was able to explore how students positioned themselves relative to the Discourses of physics. Ultimately, there were three steps to the analysis, each responding to the demands of a research question:

1. The generation of profiles of the participants in the study (Chapter 5): Background resources stemming from sociocultural factors and experiences as well as stories of recognition that contributed to students' trajectories in and out of physics careers were identified. Narrative data in the form of interview transcripts and photo-journal excerpts were used to

depict various forms of trajectories. The decision to examine individual's stories as embedded case studies was to make the data more manageable, but also to attend to the particularities of individual's stories (Luttrell, 2000; Yin, 1994).

2. The identification of Discourses for physics and physicists (Chapters 6 and 7): Here, I relied on a cross-case thematic analysis of narrative data predominantly from interviews to describe the Discourses that students use to make sense of doing physics and being physicists, and the subject positions that these Discourses make available.
3. An examination of how students position themselves around the available subject positions (Chapter 8): Here, I returned to stories of recognition to examine how the Discourses interact with participants' background resources in ways that permit them to accept, reject, or negotiate subject positions offered to them through Discourses.

Chapter 5

Setting and Participant Profiles

As discussed in Chapter 3, understanding how participants construct identities as physicists entails identifying the schema and resources that participants bring to their practice as doctoral physics students; and how they use their schema and resources to negotiate subject positions made available through the Discourses of the physics community. In this dissertation, I understand schema and resources to mean the practices and dispositions individuals acquire from experiences in different contexts (Sewell, 1992). To identify schema and resources and to understand how these mediate participants' interactions with Discourses, we must first examine the individual experiences and contexts that have contributed to their trajectories into and through doctoral physics. The research question guiding the presentation of data in this chapter was:

1). What are the experiences and contexts that have contributed to doctoral physics students' academic trajectories?

This chapter summarizes the past experiences that participants revealed and enables us to see how these experiences have contributed to their academic trajectories. As Sfard and Prusak (2005) pointed out, their stories cannot directly reveal identities, because identity is constructed in interactions. Instead, I used them for other purposes. I presented the individual profiles to enable the reader to begin to know the participants as I came to know them. In addition, these profiles foreground Chapter 8, as they provide insights into when, where, and how participants may have acquired schema and resources that they draw upon in accepting, rejecting, or negotiating available subject positions in physics. What follows are profiles of each of the participants, highlighting experiences and contexts that they report as salient to their trajectory into and through doctoral physics. These experiences and contexts were identified through analysis of stories of recognition that they shared.

From these early experiences, the influences of family, peers, mentors, and role models, and messages received about science and physics participants acquire the schema resources that they bring to the community of physics (Sewell, 1992). I have provided brief stories of participants' trajectories in and through physics that I constructed primarily from each participant's interview data. Following Mishler (1999), I constructed life history narratives and then examined these narratives for salient experiences or contexts that were identified within stories of recognition of self or by others (see Table 3 for rules of inclusion). The experiences and contexts emerging from these narratives are organized into four general areas:

- Recognition (of self as physicist, by others)
- Influence of significant others (parents, teachers, university professors, and other mentors)
- Personal contexts (family responsibilities, health, funding, job expectations)
- Institutional contexts (expectations vs. realities, practices of physics)

Also along the way are important factors that may act as gatekeepers to obtaining a tenure-track position including acceptance to graduate programs, qualifying exams, obtaining master's and doctoral funding, publishing research, the defense, and awarding of post-doctorate funding. Participants' stories revealed some of these institutional gates that acted as significant positive or negative elements influencing their trajectories. From these stories and based on Wenger's (1998) notion of identity trajectories, I identified three distinct academic trajectories: inbound, peripheral, and outbound.

As discussed in Chapter 4, photo-journal entries from participants were varied in length and depth and were used primarily as forms of information elicitation in interviews. Therefore, I referred mostly to interview data. In cases where journals proved informative, I have included excerpts. Table 1 provides an overview of the participants in the study, their disciplinary subfield and topic of study and the forms of data they contributed to this research.

High-Energy Theory Group

Laura and Victor were two participants completing their doctorates in the field of high-energy theoretical physics. In high-energy theory, there are presently only two female doctoral students out of approximately 20 under various supervisors in this subfield. This research field at Eastern University is diverse and is comprised of three distinct theoretical subfield topics—particle physics, field theory, and cosmology. Furthermore, the range of topics researched under these three topics is vast. Because of the diversity of research in this field, and due to its theoretical nature, research is rarely carried out within groups in this subfield. Students and professors collaborate on research papers, but it is not possible to find a research lab in this subfield. Because students in high-energy theoretical physics often work in their offices, it was not possible to spend any significant time observing theoretical students without interfering greatly in their daily routine. Students tend to be dispersed among offices, often mixed in with other students studying completely different topics—for example, string theorists may share office space with particle theorists, often with very little communication occurring within that shared space. Master's and doctoral students and post-doctoral fellows are dispersed in offices around the department, which I noticed in my field visits, are remarkably quiet. Students are very respectful of each other's workspaces, and for many, their entire days are spent quietly working on computers. As noted earlier, I recruited two participants in high-energy theoretical physics, neither of whom worked in a research team per se. Laura conducted her research on a subtopic of field theory known as string theory, while Victor did his doctoral research within cosmology. Due to the theoretical nature of the work, students invariably can be found at their computers generating code, poring over printed equations attempting to solve problems, or looking for an errant -/+ sign that appears to be throwing off their calculations.

The disciplinary subfield of high-energy theoretical physics at Eastern University is one of largely independent research and a graduate experience that appeared to be quite nebulous—having little daily structure and scant collaboration. High-energy physics was the only disciplinary subfield that I studied in which members did not operate in research teams that had weekly meetings, lunches, or teas. In general, the high-energy field had seminars scheduled weekly but these actually only occurred sporadically. These seminars consisted of research presentations, or guest speakers, but were never thematic in nature. The seminars that I did attend had a qualitatively different feeling to them than those of the seminars in condensed matter or astrophysics. A summary of my field notes from one meeting in particular described the scene:

> Laura tells me that these seminars have a high degree of participation, in terms of attendance. But what is different about these meetings from those in astrophysics or condensed-matter physics is that people don't participate as much in discussion. The man who presented a journal article today was unsure of a number of concepts and results in the article. However, none of the students seemed prepared to offer either praise or criticism of the paper. This is in stark contrast to the papers that are dissected at the neutron-star coffee [seminars in Astrophysics]. One of the professors engages the presenter by asking a lot of questions, but the rest of the audience is silent. (Paraphrased from field notes, November 26, 2007)

Of the three disciplinary subfields I studied, high-energy physics was the most difficult to understand, both intellectually, and in terms of understanding what the day-to-day activities of the theorist entailed. This is because there was very little structure in the theorists' activities. The seminars that were scheduled to bring theorists together were often cancelled, and students often had staggered work schedules.

Laura. At the time of this study, Laura was in her mid-twenties and was entering the third year of her doctoral studies at Eastern University. Laura identified as a White woman who grew up in South Africa. Her parents were both academics, her father, a professor of economic history, and her mother, a professor of children's literature. Laura discussed being very interested in both science and languages as a child. When she entered university, she applied to a general arts and science program, but due to the availability of courses, ended up taking a majority of science courses. Laura's field of study is string theory and string cosmology, with a research focus on the intersection of string theory with cosmology and particle physics.

During her undergraduate degree, Laura became interested in physics courses and did a research project with a professor in experimental condensed-matter physics. A bad experience at a conference deterred her from continuing in that field, and at the same time, she took a quantum course that she enjoyed. The professor of that course encouraged her to do a master's degree with him and that led to her present interest in string theory.

Laura's intent is to pursue a post-doctoral fellowship, and then a professorship, although she claims to be unsure about whether she will be able to take it that far. Her field is highly competitive and she recounted stories about friends who applied for 80 or more post-doc positions and were only accepted to one. At the time of our follow-up communication, Laura had finished her doctorate and was completing a post-doctorate overseas.

Recognition of self. Laura discussed the early indications that she had the makings of a physicist by describing the many projects she undertook as a child including inventions, poems, and short stories. She described this to indicate that she was interested in both arts and science at a young age. She recounted one particular memory of setting up a weather station in a tree and measuring wind speed and direction at regular intervals for hours on end. She also recalled being "utterly absorbed" by the project—one of the many solitary activities she described having engaged in, due to the fact that she was not "the most socially successful child" (Laura, Journal Entry #3). This memory of Laura's is one that she holds on to when she doubts her abilities in physics. She suggested that, among these earliest memories, many are of specific scientific endeavors "which may have been signs from an early age that I could be a physicist" (Laura, Journal Entry #3).

Laura went on to discuss how her involvement with physics since a young age has shaped her worldview. She described physics as not just a vehicle for solving scientific problems, but a way to approach her life:

> The way that I think changed hugely during my undergraduate and then master's degrees. I mean, you don't see it happening, but you're learning a whole lot of things that aren't covered in exams when you are going through. And, I think things like that mostly come from my university education. I don't think I was applying logic to everything when I was sixteen. (Laura, Interview #1)

Laura described having developed a logical approach to everything, something that she acquired over her years of scientific training. Laura's immersion in her field has caused her to think analytically about most phenomena she encounters, as she writes in her journal:

> I often wonder on the bus why people keep bags on their backs and expect to be able to barge through past people when it seems obvious that people are bulkiest around the middle and that there would be more room if people carried their bags at leg level. It's not that I feel more intelligent than other people in everyday life; it's just that they seem to approach things very differently, and I think my approach has been greatly

> influenced by my training in science. (Laura, Journal Entry #1)

Here, Laura made a distinction between her way of thinking about the world and other people's non-scientific way of thinking, in her estimation. She suggested that she has developed an analytical approach to understanding the world, and she described this by comparing her way of thinking to others'.

Influential others. Laura's parents, particularly her mother, figured prominently in our interviews. Laura discussed her parent's academic backgrounds as influential, but also contrasted that with their lack of scientific background. In a journal entry, Laura wrote:

> Neither is scientific, or even particularly sensible. My mother once sent me a text message asking, "What's the third dimension again? There's time, and space and then what?" My point being that I was not raised in a scientifically literate household, with mathematical problems being posed as games all the time or circuits being mended with a soldering iron, as some of my friends did. (Laura, Journal Entry #3)

However, from the interviews with Laura, it is clear that her parents' were both supportive and influential. Regardless of their scientific backgrounds, Laura stressed that they always encouraged her intellectually:

> My parents I think always treated me as if I was an adult. They would listen to what I had to say as if it was as valid as what they had to say. And OK, they never got me the chemistry set but they did get me the, you know, the Fisher Price garage and the tool box and the doctor's sets, and I read whatever I wanted. (Laura, Interview #2)

Laura's parents worked at the university in her hometown, so it was assumed that she would at least do an undergraduate degree, although she left her options open and did not declare a major until late in her program.

In her fourth year, she had a course with a professor in quantum theory who later became her honours project and master's supervisor:

> He started teaching us, like, basically quantum field theory, and he is the most inspiring person I know in like, well, in general, and is also one of the most intelligent, and he just [. . .] What he was doing sounded so cool that he made everything sound so exciting and so deep, and I really like and respect him, so I asked him if I could do a project with him, and he is the reason I did a master's degree, and he is the reason I am doing a PhD, I would say. (Laura, Interview #1)

This experience is presented in opposition to her experience with experimental physics, which was mediated by a professor who did not inspire or support her. Her experience with quantum field theory led her to choose this subfield and to continue her graduate studies in theoretical physics. When I asked her further about the kind of role model this professor was for her, Laura described him as "infinitely interested":

> He thinks really carefully about things, about everything, even about interactions with people. And he has just always got that sheer curiosity that without it being adulterated by politics of academia or just getting tired by his teaching load and stuff. He thinks really carefully, and like, honestly about things. (Laura, Interview #1)

The carryover of a physicist style of thinking from his professional life to his interactions with other people is a characteristic that Laura recognized in herself, and this seemed to be an important element of being a physicist for Laura. However, when I later asked if Laura wished to model herself after his example, she proclaimed that he was "altogether too obsessive" (Interview 1), and that:

> He goes home in the evening, has dinner with his kids, and puts them to

> bed, and then goes out to a coffee shop to work until late at night, and then comes in very early in the morning. So he doesn't sleep very much; he definitely doesn't have time to take care of himself physically, and I don't think he spends as much time with his children and family as I would want to do in that situation. (Laura, Interview #1)

Personal context. Laura brings to her practice, recognition of herself as embodying characteristics of a physicist, but a desire not to let physics consume her life. This becomes apparent in discussions about her activism around animal rights and her lifestyle choices. We discussed her conflict with pursuing a career that does not have altruistic ends or even practical applications. Laura suggested that, were her career in physics not to work out, she would be interested in pursuing something more applicable:

> Like environment physics or this AIDS stuff that I, yeah, I worry quite a bit about the environment. I mean, I spend quite a lot of my mental energy thinking about that, so if I found some way that could use physics, that could be an option. I would like to remain more or less in academia, but we'll see. (Laura, Interview #1)

While she expressed concerns that her career choices do not align with her social and environmental justice concerns, her plan is to continue as far as an academic career in physics will take her. Laura finds space in her personal life, however, to address her more altruistic concerns. She is a strict vegan, and also contributes significant amounts of time to community services like tutoring and organizing for animal rights groups.

Victor. At the time of the study, Victor was in his late twenties, in the second year of his PhD and about to write his comprehensive exams. He identified as a White man who grew up in Western Canada. His field of study is cosmology, a subfield of theoretical physics that he became interested in towards the end of his undergraduate degree. He claimed that there was not one particular incident that drew him to physics, but rather that his present situation was the result of a culmination of random life events—" a whole life story kind of thing" (Victor, Interview #1).

Like many participants in this study, Victor's decision to pursue a master's degree and then a PhD in his topic began when he was awarded a grant to do a summer research project on his topic. Victor spent a great deal of time discussing his goals for his PhD, which were uncertain at the time of the interview. He enjoyed his field a great deal, but claimed to not know if he would be successful in it. He liked teaching and thought he might be interested in pursuing a professorial position but was unsure if he would be competitive. He discussed feeling as though teaching might be a better fit for him than the private sector, and he suspected that his draw to academia has a great deal to do with inertia and familiarity.

Victor discussed extensively the feeling of being at home in the physics department. He completed his master's degree in the physics department with the same supervisor, and has been in the office longer than most of the other students. However, as a relatively new PhD student, Victor seemed to be working out the goals he had for himself in academia and used the interview time to articulate these. He was unsure if he would persist and seemed to think that he would go wherever academia would take him, but that he was not the kind of person who planned out a career trajectory for himself. Several times Victor discussed an inability to commit to a career trajectory on a long-term basis and discussed not wanting to sacrifice other important "life stuff" to academia (Interview 1). At the time of our last communication, in the fall of 2009, he was still enrolled in the same program and had plans to graduate soon.

Influence of significant others. I did not identify any episodes in the interview data where Victor told early stories of recognizing himself as a physicist. He did not speak to his own ability in physics as a young person, but rather discussed physics as a subject he enjoyed. However, forms of recognition did emerge in our conversations when he referred to his ambivalence about physics as a teenager. Victor did not discuss any childhood experiences that influenced his interest in physics or decision to pursue it at university. In fact, he explained that his high-school physics experiences did not particularly attract him to the field. However, he did suggest that he had ability in physics that was recognized by his teachers in high school:

> I'd say in my case it's funny because in high school I was pretty sure I didn't want to do it. I remember just writing exams in math and physics in high school and not wanting to do it but my teachers telling me, 'oh yeah you're really good at this. Did you ever think about going to university and doing this more?' And I was like, 'no I don't want to do that.' (Victor, Interview #1)

Victor described his early exposure to physics with ambivalence however, he also described physics as a subject that became very attractive to him when presented in a university setting. Victor discussed the professors he had during his undergraduate degree as being influential in his love for the discipline and his pursuit of a graduate program in physics:

> There was one math class and one physics class, just because those profs were really good. They were really good at sharing their enthusiasm for the material with us. I felt very engaged at that point. Those were second year courses that really turned me on. Actually, my interest in mathematics stayed with me. When I was done and applied to grad school four years later, I applied to math and physics departments and chose to do cosmology. I did have ideas of becoming a mathematician. (Victor, Interview #1)

Victor continued to discuss physics as a discipline that he was enthusiastic about, but he rarely made references to the kind of career he wished to pursue with physics. He emphasized that as long as he continues to enjoy physics, he will stay with it. Victor's family members back home often perceived this as a lack of direction:

> I don't know what they think. They probably think that I'm wasting my time with something that I'm not going to get a job [in]. No, not my Mom, but there are probably some people who don't really get what I'm doing, which is to be expected. My Mom is pretty supportive of whatever, as long as [. . .] yeah, I think she's pretty supportive. She doesn't really know what I'm doing but trusts that I'm doing something that I like, so that's good enough for her (Victor, Interview #1).

Although Victor described the support he received from his mother, he suggested that she would support him in pursuing whatever would make him happy.

Personal context. At this point in his graduate career, Victor seemed reticent to make pronouncements on future options for himself once he had finished his PhD. We discussed the possibility of teaching or entering the private sector, and both of these options were met with some ambivalence. Directly following the conversation about the support he receives from his mother, Victor described his thoughts on his academic future, declaring that he had avoided a vision for where he would go for his entire life.

> It's funny ‘cause I've been in [an academic] environment for quite a long time. Like I said, I'd been doing these undergrad summer research terms, and then I went to work at [UABC] for a year but I did kind of drag my heels on grad school. Maybe part of it was just a fear of commitment to something so long term. So then I just made sure to just apply to master’s programs and not be committed to something for more than two years. Then it was another big decision, half way through my master’s if I was going to stay and do a PhD, and I decided I should do that, but yeah, ten years from now? I'll be 37 years old. I don't know what country I'll live in, what I'll be doing, or anything. That's fine, I'll figure it out. (Victor, Interview #2)

Victor referenced his girlfriend twice in the interview, but did not allude to any other personal contexts that might influence his trajectory. At the time of the interviews, he did not have any plans for the future, and rather expressed that he would see where life took him. His focus was on his studies, and at that time, he was consumed with preparation for his comprehensive exams.

Institutional context and recognition by others. At the time of our interviews, Victor was taking several months off from research to study for a mandatory preliminary written exam, taking place over the course of two days. Victor regarded this process as a hoop he needed to jump through in order to gain recognition as a physicist:

> You’re only a student, and if you’re not able to jump through this hoop then we don’t even want you. It’s a little harsh, I think. People freak out about it, and I think it’s kind of serious business I think, you know? It’s kind of negative reinforcement; if you don’t pass this, then we’re kicking

> you out. […] If they don't want you around anymore, the prelim is a good excuse for them to kick you out of the department. (Victor, Interview #1)

Although later he suggested that the exam is meant to show how much you know about physics, Victor clearly regarded the preliminary exam as a weeding out process designed to identify the physicists worth keeping around. Victor did not express any concern about his performance on the upcoming exam, but he did regard it as a demonstration of competence that is assessed in a narrow fashion.

Another form of institutional recognition that Victor discussed is funding. In a photograph, he showed two letters, both from funding agencies (Figure H1):

> The one on the left I didn't get, the one on the right, I did. About a month ago, I found out that I didn't get the [federal grant], and I was pretty bummed out about that because I felt like I had a pretty good shot. I was kind of upset by that. I've been a non-scholarship student for two years. I wrote a master's which I was pretty happy with. Also, I have come to know that not only the best students get [federal grants] necessarily, but it's probably political. [It's about] who your supervisor is, who your supervisor is friends with. I think the Canadian physics community is a pretty small one; everybody knows everybody. I was pretty upset when I didn't get the [federal grant]. It was the first time I applied for it since my second to last year of undergrad when I applied for it the first time, which, OK, is the validation thing. You wanted to get it because it's good for your CV, but also in terms of just the cash. But then yesterday, I found out that I got this [provincial grant] thing, which is also a lot of money. So that was the opposite reaction. (Victor, Interview #1)

Victor identified funding as an important source of validation in his studies. This was the only form of institutional recognition that Victor identified throughout our interviews, as he had yet to publish in his field. Similar to his description of the preliminary exam, Victor described the process of obtaining funding to be a political one. These experiences may have contributed to Victor's ambivalence towards a career in the field at the time of the interview. Nearing the end of his degree, Victor was looking for post-doctoral fellowships in his field and planning to continue on with academia.

Condensed Matter Experimental Group

Research in condensed matter at Eastern University comprises several subfields including bio-physics, magnetism and superconductivity, soft condensed matter, quantum electronics, and nanoscience. Research in this field is considered both fundamental and applied, depending on the field, but is becoming increasingly interdisciplinary, particularly in the subfield of nanoscience.

The condensed matter students involved in this study conducted research in an interdisciplinary research team focusing on scanning probe microscopy and nanoelectronics. The research space was spread out over the campus, with one large lab in the physics building and another in the engineering building. The requirement for space was notable, given the size and weight of the scanning tunelling microscope (STM) that the research team worked with. There were three variations of this instrument that occupied a considerable portion of the lab, and in one case, it was suspended from the ceiling to avoid ground tremors emanating from traffic noise and other disturbances outside the physics building.

Certainly, the connection to engineering was most evident in this research group. Doing physics here entailed not only fine manipulation of microscopic samples that needed to be housed in an ultra-high vacuum, but also the gross manipulation of these incredibly large instruments. The participants from this research team—Lily, Carol, Saïd, and Peter—worked in two different labs within the larger research group. Saïd and Peter worked together on the STM, Lily made her home in the engineering building where she worked on another STM and Carol did work in the same lab as Saïd and Peter, but had a separate office and worked on an entirely different instrument. While there was considerable overlap between many of their projects, the students worked in subgroups that operated as distinct entities, and were guided by the primary investigator (Paul) and one post-doctoral researcher in the lab. In the nanoscience and scanning probe microscopy group, there were ten active graduate students (eight doctoral students, two master's students). Of the eight doctoral students, three identified as women. One research assistant was a doctoral graduate from a different department who also worked in the lab and was present for a number of my field visits.

It is notable that of all the research groups I engaged with in this study, the condensed matter group was not only the largest, but also the most interdisciplinary, with connections in biophysics and chemistry. It also required students to sometimes problem-solve like engineers, since it was the only research group that involved direct manipulation of instruments in order to collect data; therefore, the daily regimen of a student in condensed matter physics often looked very different from the regime of students in theoretical high-energy physics or astrophysics. While a lot of work entailed rendering images and performing calculations on the computer, there was also a lot of preparing samples and manipulating instruments.

Lily. At the time of this study, Lily was in her late twenties and was the student in the condensed matter group who was furthest along in her studies. Lily identified as a White woman who grew up in the Canadian Maritimes. Lily's office and lab were in a separate building, and she shared her space with two other graduate students also working on the scanning tunnelling microscope. She was in her fourth year and was working on the characterization of gold atoms. She was already considering the offer of a post-doc in Germany, and was at the dissertation writing stage of her doctorate. Lily was also quite keen to participate in the study and was very interested in photography, so she was particularly excited about generating photos for the interviews.

Through high school, she excelled at science and in particular, physics, and thought she might do physics at university to become a teacher. However, her experiences at a Maritime university undergraduate program led her to research, and she began to explore possibilities for master's and PhD work in nanophysics. Lily described being attracted to the field because of the imaging aspect of the work, but also because of its interdisciplinarity and the intersections her work had with physics and chemistry.

Lily is married and although she discussed the "two-body problem" (Interview #2) she did not appear to be worried about the possibility of pursuing an academic career and finding related work for her husband who is also in physics. In fact, she discussed how the post-doctoral position she had lined up had already presented the possibility of a job for her husband. When I followed up with her in the winter of 2009, Lily had secured a job as a professor and had a substantial start-up grant and her own lab.

Recognition. In my interviews with her, Lily indicated that she "showed signs" (Interview 1) of being interested in science at an early age. When discussing her family's influence on her interest in science and her decision to pursue a career in science, she stated:

> Um, I think when they sort of looked back on my childhood, they were like 'Oh, it makes sense now'. 'Cause I played a lot with Legos and I used to take everything apart, and they were always amazed that I was able to get it back together again. But I mean nobody in my family really did higher education. My parents both have undergraduate degrees, but nobody did more than that, and they were the first generation of their families that went on. (Lily, Interview #1)

Rather than regard her choice of physics as unusual, Lily suggested that her decision to pursue graduate studies was regarded as a significant divergence from career paths of others in her family. However, Lily indicated that her decision to pursue a career in physics was not surprising to her family, who recognized her ability and interest early on. To emphasize this, Lily referred to herself as always having had an interest in scientific things. She recalled a childhood fascination with how things work:

> I liked taking things apart and putting them back together and seeing how things worked, and I think in Grade 3 or 4, I wanted a book and the book order was called *The Way Things Work*—I still have it on my bookshelf and it was like 21 bucks or something, and my parents wouldn't buy it for me. They didn't like the book orders, they were like, 'oh yeah, sure, show kids shiny pictures in books,' they are going to want them and get the money from the parents, so they were really against the whole book order thing. So I like scrounged together my allowance money cause I wanted it

> so bad and I would spend hours looking at it. (Lily, Interview #2)

Lily professed an almost natural curiosity in physics, which she suggested led to the obvious choice of an undergraduate degree in physics.

Influence of significant others. Despite the fact that her parents were not scientists or academically oriented, Lily described them as being very supportive, "My family has always been very supportive of anything—they were willing to let me be a musician, which is another thing I was thinking of, they never tried to stop me in any way" (Lily, Interview #1).

However, Lily did not cite her parents as inspiring her to go into physics. She claimed to have developed these interests on her own, and then her curiosity was nurtured by some very influential teachers she had in high school. Coming out of high school, she planned on an undergraduate degree that would lead her to teaching—a career she had planned on since elementary school. The physics teachers she had in high school were positive influences for her, and Lily planned on following in their footsteps:

> Yeah, I had some really fantastic high school physics teachers, and that was a huge part of it. Yeah, I was really lucky. I thought I wanted to be a teacher. It was something that I really like—conveying information to a younger group of people—I really enjoy doing that. And, so, when I got to high school and had these really great physics teachers, I thought, wow, maybe I'll be a physics teacher! (Lily, Interview #1)

Even through the first years of her undergraduate degree, Lily did not envision herself as a physics researcher until a professor encouraged her to apply for an undergraduate summer research award, and she got it. Lily pointed to this moment as the turning point for her:

> And so he got me to apply and I got one of these NSERC undergraduate summer research award things, and I did research with him for the summer, and I was just totally hooked. And I thought, well, maybe I could be a professor, and I could do research and teaching and stuff like that. And that's how I ended up doing the whole graduate program. (Lily, Interview #1)

Throughout the interviews, Lily discussed her undergraduate years as a very influential part of her trajectory into doctoral physics. She referred to some professors that allowed the students to have a hands-on approach to physics in the laboratory:

> We thought our labs in undergrad were just horrible because all of the equipment was always broken and we were always hacking things together and we thought, 'Oh, this is such crap!' But now, looking back, I'm like, wow, we learned so much from having all that equipment broken and finding some way around to get something done within the month that you had to do the experiment. (Lily, Interview #1)

Lily regarded these moments of hands-on learning as spurring her abilities in physics. Later she referred back to these moments as helping her to problem-solve and get creative with equipment, a skill she regarded as critical in her field, and one that she felt is often stymied by many undergraduate programs (to be elaborated upon in Chapter 6). Lily described these resources as among the most important that she brings to her practice.

Peter and Saïd. I have decided to introduce Peter and Saïd together, because although I interviewed them separately, and they constructed separate photo-journals for me, I spent all of my observation time with the two of them together, and our interactions primarily occurred as a threesome. They also have a unique working relationship, wherein each is dependent on the other for the construction, operation, and completion of their dissertation research on a scanning tunelling microscope. The project that Peter and Saïd worked on entailed the characterization of gold atoms using a probe that required them to construct a 3-atom diameter tip that would scan the surface of a gold leaf. In addition to inviting me to attend research team meetings and seminars with them, Peter and Saïd invited me to observe them operate the microscope one day when they intended to test out the tips they had constructed. That afternoon helped me to understand the complex relationship the pair had, and the benefits and frustrations associated with constructing an experiment that two students would carry out together. This type of co-dependent research was unusual in the physics department; I did not encounter it elsewhere, although many students did collaborate on experiments (albeit with different research questions), and equipment was necessarily shared. At the time of the study, Peter was in his third year of his PhD, and Saïd was in his fourth. Saïd in particular expressed a great deal of concern about already doing extra semesters in his doctorate beyond the usual four years, particularly, as up until the time of the study and some time afterwards, they had not generated any publishable data from their experiments.

Peter. Peter was in his mid-twenties and identified as a White man who grew up in Germany. He discussed having a fairly easy path to physics out of high school, and described enjoying physics in university, particularly how it was taught, and that it was foundational, unlike other subjects like biology.

Peter did not describe any childhood experiences that affected his aptitude or interest in physics. He took a science major in his undergraduate degree in Germany because he felt as though it was the natural thing to do. His experience in his doctorate, however, frustrated him and made him consider alternatives to an academic career. Peter struggled with the do-ability of his project. He felt a great deal of frustration, first, with not being able to get the kinds of publications his colleagues were achieving, but also with not making progress towards generating data for his dissertation. The limitations he experienced here are partly due to the equipment he is working with (on which he spends a great deal of time troubleshooting), the materials he is attempting to characterize (generating images of gold molecules has been difficult due to the delicate nature of the material), and his collaboration with Saïd. While the collaboration is beneficial because it often requires more than one person to set up the experiment and to do the troubleshooting, conflicting schedules had become a limitation to their progress, and this was frustrating to Peter.

During his doctorate, Peter became active in the physics graduate student society, taking on the role of social event organizer. He discussed getting involved in extracurricular activities like student government, ice hockey, and softball as important socializing events for him as a newcomer because he came directly from Germany and wanted to build community during his time at Eastern University. However, he began to regard these activities as constraints and suggested that he should have instead focused on completing his coursework during his first year and not involving himself in student-life activities including touring his new city or attending student-run events. At the time of the study, Peter was considering pursuing a career in industry, although exactly what he wished to do in the future was vague and his plans were largely in response to the constraints of his doctoral project. In the winter of 2009, Peter was getting closer to achieving publishable data from his project.

Influence of significant other. Peter was very influenced by his father, who holds a PhD in condensed matter physics. Peter indicated that he had not yet decided if he wanted a career in academia or in industry, but that from a young age, his father had exposed him to physics, so the possibility of a career in physics always seemed like a logical next step:

> You can call it, like, family tradition, but I think if I hadn't liked it, I would have done something else. He did also solid state [physics]. But that's not the reason why I chose solid state physics. I had a good experience during my university degree—one person really showed me OK research can also be fun. So, that's why I chose this nanoscience project. (Peter, Interview #1)

Peter described this university professor as someone who was “relaxed and also really working hard” (Peter, Interview #1), which were qualities that were important to him when considering a field in which to continue his studies.

Institutional context. In our interviews, Peter spent a great deal of time discussing the expectations he had coming into the PhD at Eastern and the realities he met upon arrival. One of his first stumbling blocks was the course work that was expected. As an international student, Peter came to Eastern with hopes of forming a community and learning about the city. What he experienced when he arrived was a barrage of coursework leading up to the preliminary exam. Looking back, he thought he might have conducted himself differently had he been aware of the demands of the program:

> I could have started half a year later because I graduated from Germany two weeks before I came and so I just had to pack up two suitcases, come over, and find an apartment. I think that's the thing. I would also cancel a lot of activities, like, [city] exploring activities, like, do them later. I wanted to play ice hockey so bad and here is a good opportunity. But I would have cancelled everything and basically for eight months just do the class work because it's so important for later on. (Peter, Interview #2)

Along with the overwhelming coursework and adapting to a new city and culture, Peter also struggled with the do-ability of his project. Both he and Saïd were worried about getting publishable results out of their research, and Peter described that in order to graduate, he needed to have at least one first-author publication. When discussing his project, Peter laughed and asked me if I thought I would ever finish my PhD:

> Do you think your PhD will come to an end? [laughing]. Actually, I think 50% of people who start a PhD wonder if it's going to work out. Basically the project that I took on, it's about the judgment thing. I didn't look at it in the beginning very much because I thought if your supervisor sells you the project, it sounds super—but it's not easy to tell. I would look at this publication stuff. When my progress is done you can always look up publications on the system. Just look up how frequently they are, if they are very similar, then only one thing works on this system. If you come in as a PhD freshman, then you don't have all these skills. You trust people a lot. I hope it comes to an end at some point within the year. (Peter, Interview #2)

In the above excerpt, Peter referred to the fact that he and Saïd were having difficulty generating results from their experiments. They had some success in certain areas of their research, with the potential to generate an article or two, but they had considerable difficulties in many other areas. Peter suggested that this was not something he had anticipated. As a newcomer, he did not expect that he might run into this kind of trouble. He made the point that as a new PhD student, he did not know to ask these kinds of questions or to research the do-ability of his project. This was one of the factors that caused him to reconsider a career in academia. I asked him where he saw himself in 10 years, and he answered, “I think it’s not going towards physics professor, like trying to get a tenure position.” When I asked him “why not?” he responded:

> One thing is the project I’m working on right now isn’t working out very much. It worked out in the way that I learned a lot of stuff, but at some point you have to attach a lot of publications to your CV and also I think it’s weird, I don’t know if I’m made for this. You have to re-determine [. . .] career wise, you have to give up a lot of things and if you compare economic wise, like, for the money you get, you get a lot more money if you just work on a job that is offered to you by, I don’t know, companies or the industry in general. Yeah, and it’s also like, maybe I’m ready for something new. Maybe I would like something a little bit different. Stay on this science direction but also going towards business. (Peter, Interview #2)

Peter’s father was an experimental physicist working in industry, so the possibility of pursuing a job outside of academia had always been open to him (Field notes, February 8, 2008). Both Peter and Saïd came to the program with ambiguous feelings about careers in academia, and they both expressed feelings of frustration with their graduate program. Not surprisingly, both of them expressed interest in pursuing careers outside of academia. In the winter of 2009, Peter was still finishing his doctorate, but he did not respond to any of my follow-up attempts, so I could not report on his immediate plans.

Saïd. At the time of the study, Saïd was in his late twenties and in the fourth year of his doctoral studies. He had hoped to be graduating soon, but was not graduating on time due to the setbacks on his research and his involvement in student government. Saïd's story began with his childhood interest in becoming a doctor. Saïd is of North-African descent and identified as francophone Arab. He grew up in Switzerland and attended a high school in France that required students to focus on a subject early on. He described having a good physics teacher in his last year of high school that helped him get turned on to the subject. The school he attended was difficult to get into, and he was attracted to the elitism associated with the school. He described attending this prestigious school, "for the glamour, but I didn't really enjoy it, so I decided to, you know, leave the French system" (Interview #1).

Saïd returned home to Switzerland where he did his undergraduate degree in physics. He discussed feeling very comfortable with the non-hierarchical structure of the lab he worked in during his undergraduate degree, and disappointed with the competitiveness he encountered during his master's and doctoral degrees at Eastern University, claiming he preferred a more collaborative research environment. Saïd also expressed disappointment with the research project he collaborates on with Peter. The lack of publishable results was worrisome at the time for Saïd, and he partly blamed himself for his inability to devote himself full-time to the research project. Saïd became very involved with the graduate student society at the university and this took up a lot of his free time, and took time away from his research. During his involvement with student government, he became very interested in issues of sustainable development, and decided that this was an area that he wished to pursue. In the winter of 2009, Saïd was getting closer to achieving publishable data from his project.

Institutional context. Saïd's experiences with research in Switzerland were quite different from the experiences he told of at Eastern. In Switzerland, he worked in a laboratory that operated in a non-hierarchical manner, and encouraged collaboration among its members. Interestingly, Saïd is one half of the only fully collaborative project that I observed in the physics department at Eastern, but still the environment was not as collegial as Saïd would have wished. In the following excerpt, he explained the experiences he had in Switzerland, and the expectations he came with to the program at Eastern:

> Maybe the most obvious difference is, here there is a really obvious hierarchy and you don't really get an opportunity to sit down with your supervisor or working with technical staff as much as I did in Switzerland. We would go for coffee breaks pretty much every day. You know, the prof, the head of the institute, the technical staff, everybody basically, even the cleaners would all get together and have coffee together and you really felt like you all belonged to this thing that was the physics department, you know, and more specifically, the institute of research that I was working at. So, I just enjoyed so much being able to get help from technical staff, for example, and then explain to them how what they're doing is helping me and it was just such a positive environment. And I haven't found those positive, human aspects here as much. (Saïd, Interview #1)

Saïd expressed concerns about the time that he had been working on his doctorate, his lack of publications and his prospects for graduation:

> Yes [I've been working here] since September 2003, so almost 5 years and I don't have a single bit of publishable data. Um, and I think, it's sort of hard for me to accept that fact, but at the same time, the project that I'm involved in is sort of pursuing-the-Holy-Grail-type projects where the instrument has never been, or at least not in recent history, at a point where it can yield the kind of data that we're looking for. Now we're pretty confident that it's there or at least pretty close. But, so, we can reasonably assume that we're going to get some data in the next six months or so but we don't have any guarantees. What if it doesn't work? (Saïd, Interview #1)

This concern weighed heavily on both the minds of Peter and Saïd. Saïd's discussion of the Holy Grail refers to what Saïd described as a North-American standard, where one has to pursue this Holy Grail, and only when you've attained it can you graduate (Interview #1). This experience has caused some tension for Saïd as he regards the process he has participated in as scholarly and educational, but his graduation hinges on the production of publishable data. This experience ties into his frustration with the hierarchical system of research that Saïd described in his research group:

> We never, when I say we, I mean my colleague and I, we've never had senior people in our system that we've been able to rely on, so we had to sort of rediscover everything from the start, and it would have been really useful for us to have that. So that was definitely a big part of the frustration for us. We're really making sure that our supervisor gets a student this fall so that we can make sure to train them. We're taking thousands and thousands of pictures of our system, which we had none of before. (Saïd, Interview #1)

Saïd's experience with independent research coupled with a structure that he regarded as disconnected from human aspects has led him to explore other career options.

Personal context. Saïd now regards his doctoral degree in physics as a means to an end and his experience in physics as giving him the skills he needs to enter another field, although he won't be directly applying his knowledge of physics.

> **Saïd**: In ten years, I see myself not at all in the world of physics or academia. I see myself working with people on problems that are relevant to people.
>
> **AG**: Ok. Like, what?
>
> **Saïd**: Well some sort of consulting firm for example. Ideally something that is in line with my greater goals for humanity, sort of. Ideally, I would be leading some sort of team that works on projects related to sustainable development, something like that. (Saïd, Interview #1)

When I questioned Saïd about why he chose experimental physics if he was really concerned about environmental sustainability, he explained that these interests had developed over the course of his doctoral work, through his participation in student government:

> In the next two or three years, I see myself continuing my training, you know, in understanding the world and that is going to imply getting more involved with corporate America. Because if you really want to change things in the world, people will tell you that you have to change it from the inside. And that's true, but more importantly, I think you have to understand the inside if you dislike being on the outside. So I see continuing my training for another five years or so, working either for a big consulting firm, a big business consulting firm where I'll get to work for basically these clients, or for a bank, to understand macroeconomics. My five years [at Eastern] have allowed me to understand better and better

and all of it was due to the extracurricular stuff. (Saïd, Interview #1)

Thus, Saïd's career plans diverged considerably from the kind of work he is currently doing in physics, however, he regarded his training in physics as having provided him with the problem-solving skills he will need to enact change.

Carol. At the time of the interview, Carol was in her mid twenties and in the third year of her PhD, which was funded by a prestigious federal grant. Carol identified as White and grew up in Eastern Canada. Carol did her undergraduate degree at an eastern Canadian university, and was the first in her family to complete a university degree. She came to Eastern University for her master's degree and stayed on for her doctorate. Carol had finished the comprehensive exams and was conducting research, which she thought was going well. In the physics building, Carol worked in an office that was divided into cubicles and did not contain other members of her research group. In my visits, I noticed that Carol's office was remarkably busy with students from other research groups coming in and out, often throughout the day; however, she was a diligent worker and claimed not to be bothered by this activity. She spent a great deal of time in the lab, and wanted to focus on her job when she came to school.

Carol did not intend to pursue an academic career in physics, and instead thought that she might look for an industry or government job when she graduated. She had multiple reasons for this decision. First was Carol's desire to have job security. She was interested in finding a job that would facilitate her desire to have a solid domestic life which would allow her time to raise children, own dogs, and have a large comfortable home. Her boyfriend, who was also in physics, would likely pursue an academic career, and Carol felt that he was better suited for that career path than she was.

When I followed up with her, Carol was still enrolled in the doctoral program at Eastern and was finishing her dissertation. She had just earned quite a bit of media attention due to a publication that she was first author on. She intended to look for a job in industry, and was well-positioned to find one.

Recognition. Our conversation began with Carol's description of her interest in physics that began when she was in high school. Her first description of how she became interested in science began with a statement about her proficiency in physics:

> OK, so I have been interested in physics since high school. I am really good—well my best subjects were math and physics. Well, I was also really good at computer science as I was really good at all my classes but those ones were my favourite I guess. (Carol, Interview #1)

Carol described herself as a high achiever and someone who "likes everything" (Interview 1), but especially enjoyed math and physics. This intrigue in physical science was something that Carol identified herself as possessing from a young age:

> I was also very interested in astronomy. I'd go and look at the stars all the time. I had my star charts and [would] make my best friend go, you know, who hates outside [laughter] and she'd go and we'd go look at the stars. Yeah, I really liked that I had all the equipment and uh, we have a telescope now, but I didn't at that time. And, yeah, I was really interested in that, and I remember telling my friends I wanted to do anything, but that the Earth was boring. I had to see something outside the Earth. (Carol, Interview #1)

Carol recognized that she had the ability and the interest in physics from a young age. In the excerpt above, she described this early fascination with the stars and recognized this difference from her friends upon whom she imposed her interests.

Influence of significant others. Carol regarded both of her parents as highly influential in her decision to pursue physics for different reasons. Carol cited her father's involvement in her education as influential, helping her hone her math skills during long car rides with her brother:

> **Carol**: I was very good at all of that and I liked it and it is also something that I had always done when growing up because my dad always made me and my brother compete in math.
>
> **AG**: OK
>
> **Carol**: Like, 'what's three plus four?' Like when we are driving in the car and you are trying to get your kids to be quiet. 'Nine times two' [laughter] I started to learn how to—I had to travel a lot for hockey, cause I play a lot of hockey—and I started to be able to calculate like how far to go and how long it would take me to get there. So by the time I went into physics it was already pretty easy. I knew a lot of that stuff. And uh, then you could show it all with graphs, and I just really liked it. (Carol, Interview #1)

Her father's encouragement helped her hone her skills for the math and science courses she took in high school, but it was her mother's career in a telecommunications company that influenced her to choose the physical sciences as a degree major:

> I applied to this space communication program at [Y] University because it was harder to get into than just a physics program, but also it was like, wireless communication stuff, so I thought that, well my mum worked [at a large telecommunications company] at the time, so I could see somehow a job at the end of this program. (Carol, Interview #1)

Carol tailored her degree program to take courses that might lead her towards a secure job. Her mother was an example to her of job security, working for a large company that provided benefits and a retirement plan. When I asked her if that was always a goal for her, Carol responded: “Oh, yeah, for me, education has always been the means to get a job” (Carol, Interview #1).

However, despite the influence that her parents had on her career decisions, she emphasized that she was the only family member to study science or even to attend university. When I asked her if this affected her relationships with her family, she responded that:

> It just makes me feel like I have more education, which I do. None of them, or most of them didn't even finish high school. Yeah, so, none of them went to college. And they know that I took something like [physics courses] somewhere and in high school for a lot of them, you would take business or something. A lot of them took business, no math or no science or anything, yeah, so. It is completely different. (Carol, Interview #1)

Coming from a family that did not pursue tertiary education, Carol’s decision to pursue graduate school was rather unorthodox. She claimed to have chosen to go to graduate school because her boyfriend was doing graduate school, and she decided to do the same, but only if she could procure funding to do so.

Personal context. After her undergraduate degree, she was unsure what field she would continue to study, and decided to try for funding in a field where she could pursue a master’s studying “quantum stuff”:

> **Carol:** I thought, well, I'll apply for the scholarship and see what happens, and I got the [federal] scholarship, so I thought OK, well, what is like a year or two? I might as well get the master’s and then decide, and I was sure I wasn't going to do a PhD. I was so sure, but nevertheless I applied for the scholarship, cause I wanted to know if at least I could get it. If I

got it, I knew I would have a decision, if I didn't, fine.

AG: Why were you so sure that you weren't going to do a PhD?

Carol: Because I thought if I got a PhD, I would be harder to employ.

AG: Oh, OK.

Carol: And I am still worried, some people tell me no, that is not the case and other people tell me it is, so I won't know until I try, but I am always worried about that. But anyway, so I got this [federal grant] and not just any scholarship, only if I had gotten the [super federal grant] one, the big one, would I have stayed, you know. And the reason for that is because I am interested in having a family and stuff like that, and with a grad student salary I just couldn't fulfill what I had planned for my life. So I knew I would need more money. So anyway, I got that scholarship, so then I had this decision. So then I decided with the scholarship I would make the money that I needed to eventually like, get a house and have a family or whatever. So I decided I would stay in the PhD, because I enjoy my time there and I like it. But in the end I have to, yeah, I really want to make sure that everything is going to work out [laughter]. Cause yeah, my number one priority is really what I want for my life. You know, not, what I do for my job. (Carol, Interview #1)

Carol's decisions to carry on in graduate school all the way to the PhD level have been contingent on the procurement of federal funds. These scholarships are the most difficult to get, particularly the top-tier award that Carol was granted. However, she remained unsure if this was the right decision for her. Despite her recognized competence (determinable by the grants she has received), she remained focused on gearing her experiences towards getting a job, so that she may be able to pursue the kind of family life she hopes for.

Carol often discussed that her priority in educating herself was to get a good job at the end of her degree. She claimed to enjoy everything and could envision herself working in a government job (we had discussed recruitment at the Department of National Defense), an industry position, or teaching in college. Her career goals were to finish her PhD without debt, to get a good job, and start a family. Carol claimed not to have any plans to do a post-doc, and had no interest in an academic position because there was "too much paperwork" involved. Her career goals for herself bore the requirement of fitting into the domestic life she envisioned for herself:

> **AG**: OK, so where do you see yourself then in like ten years?
>
> **Carol**: Ten years. In ten years from now, I don't know what kind of job I will have, but I will probably be living in [Eastern Canadian town] with two dogs, [laughter] and a cat. Yeah, my [ideal] job to me, [is one that I] enjoy, the people are nice and not too much pressure. (Carol, Interview #1)

For Carol, her graduate degree in physics emerged from a combination of influences and events (such as earning fellowships) and her quest for a good job that could afford her the kind of lifestyle she sought.

Institutional contexts. A number of factors in her experiences of doctoral physics have shaped her desire to pursue a career outside of academia when she is finished her PhD. She sees her abilities as better applied in fields outside of academia (e.g., college teaching, industry), than within academia where the conventions of scientific language do not merge well with her understandings of scientific concepts. She struggled with what she called the jargon of academic physics, preferring instead to speak in laymen's terms, which often became a limitation for her at conferences or seminars. This will be discussed in further detail in Chapters 7 and 8. However, Carol insisted that her decision not to pursue an academic career has more to do with what she sees as administrative paperwork than it does with her preferences around the conventions of scientific communication:

> I don't like the idea of combining research and um, teaching. I don't like, like, when I look at people who are professors at Eastern, I don't like their jobs. They do a lot of paperwork and I have no interest in that at all. I want to be doing something that I consider fun and teaching is alright and research is fun, those things, but I never want to do a lot of paperwork if I can help it. (Carol, Interview #1)

Carol has no plans to do a post-doctoral position and rather would feel more comfortable pursuing a job with the government or industry.

Observational Astrophysics

Like high-energy and condensed-matter physics, astrophysics has theoretical and experimental components to the research field. However, uniquely, observational astrophysics falls somewhere nebulously in the middle of these two. At Eastern University, a large research group that focuses its attention on pulsars, neutron-stars, and magnetars carries out observational radio and x-ray astronomy. This research group is notable for its celebrated status, often making news in the mainstream national and international media for new discoveries and for obtaining regular publications in prestigious journals like *Science* and *Nature*. At the time of this study, the research team was comprised of the PI (notably one of the only four women out of 35 professors in Eastern's physics department) and eight doctoral students, four of whom also identified as women. Of the participating research groups, the PI for the astrophysics group (Veronica) was the only woman who was a full professor in the department. The astrophysics labs are more like research offices. There are two main offices for students and each student has her or his own desk and computer. There is also a super-computer where data is processed, and this is housed in a separate temperature-controlled unit. This computer is nicknamed The Borg. Computers in the astrophysics group are named after female characters from Star Trek—a response to Veronica's old lab members at MIT, who named their computers after male characters from Star Trek—a male-dominated show that provided only a few options for women's names.

The research group met as a team weekly for lunchtime meetings. The research group meetings were very lively, and during that time members of the group including graduate students, post-docs, and professors shared the work they accomplished for the week and discussed any problems they encountered. A direct quote from my field notes described the scene in the following way:

> Whenever someone shows a diagram or an image, the whole team crowds around. They are all troubleshooting the image together, equally. This happens every time someone presents results or a paper. The whole team works on it together (Field notes, November 15, 2007).

The pulsar group also met informally twice a week in the afternoon for journal club meetings called the *astro-tea* and another one called the *neutron-star coffee*. During these meetings, members from the experimental, observational and theoretical astrophysics labs are welcome to join in to discuss new articles and research interests, but predominantly those in attendance are from the pulsar research group. These meetings often entail convening over an article published by another competitor research group. I was invited to attend the research team meetings as well as the more informal coffee or tea meetings, which I did attend regularly over the course of one semester. In addition, students had private meetings with their supervisor (the PI) and among themselves as collaborators. Five participants in this study were students in the pulsar research group—Molly, at the time, a third year PhD student; Sandra, a fourth year PhD student just about to defend her dissertation; David, a fourth year PhD student finishing up his research and dissertation; Ruby, also a third year PhD student; and Alice, who had just started with the research group after leaving the math department.

Molly. I had known Molly prior to this study, having worked with her on committees through a student organization. At the time of her participation in this study, Molly was in her late twenties and in the third year of her PhD studies. Molly identified as a White woman who grew up in Western Canada. At the time, she was conducting research but was seven months pregnant and waiting to take a short maternity leave. Already, she had several article publications, and notably was co-author on a publication in *Science* magazine.

Molly grew up in a household that emphasized art. Her mother was a ballet teacher, and Molly talked about being "brought up in the ballet school" (Interview 1). She described dancing from a young age, and even received high-school credits for the ballet she studied. Ballet took precedence over other studies during her youth, but towards the end of high school, Molly had to decide to pursue either arts or science. Seeing that she had an aptitude for math and science, a physics teacher encouraged Molly to pursue an engineering degree, which until that time, she had not regarded as a viable career option. Molly enrolled in an undergraduate engineering program, but was quickly discouraged after a work-study placement in the summer following her first year. Citing the professionalization of the discipline and what she saw as an emphasis on business and making money, Molly switched programs to physics. She found that the physics program offered more of the science that she liked—that is, for her it entailed more thinking.

In the third year of her undergraduate program, Molly moved to Eastern University, and during that summer, took a position as a summer researcher in the astrophysics group. This experience turned Molly on to pulsar research and she went on to do her master's degree and PhD with the same supervisor. She described the experience of working in this research group as very supportive, right from the beginning.

Much of my conversations with Molly revolved around her feelings of not belonging to physics culture. At times it was because of the clothes she wore, the changing colours of her hair, or the kind of music she listened to. More recently, her feelings of difference came from her pregnancy that caused her to stand out among the others in the department. This was sometimes a struggle for Molly and sometimes had been beneficial, as it helped her to construct a recognizable persona in the department. Her experience with her research group permitted her to see a future for herself in physics, and she intends to continue to do a post-doctoral position and to seek employment as a professor. In the winter of 2009, Molly was just finishing up her doctorate.

Influence of significant others. Molly's parents influenced her career interests in dichotomous ways. For a long time, Molly imagined herself pursuing ballet like her mother, however, when the time came for her to choose a discipline in high school, she found herself leaning towards science. Molly discussed her father, who was a zoologist, and who had an influence on her scientifically:

> My dad is, his degree was in zoology. He still works for [Western] Environment, so he's a scientist, definitely not a physicist. I didn't know any physicists in my life before I got into physics at all. But definitely my father being a scientist was an influence. We'd definitely chat about science stuff while I was very little and I played with his microscope and stuff. (Molly, Interview #1)

This kind of exposure to science at a young age helped her to develop her interest in scientific subjects, but she did not credit her parents with influencing her choice of physics as a career option. In high school, Molly decided to take more science courses because it was something she was always good at, but it was a teacher she had in high school physics that made the field seem like a possible career option for her:

> Mostly he was pretty young and he was a cool guy and that was very rare. I hadn't had any of those kinds of teachers, really. He had actually gone through, he did exactly the same thing that I ended up doing. He went into engineering and then went into physics and did some grad school and then ended up being a teacher. He definitely made a big influence on me but I can't really remember why that was. He just seemed like a really nice guy. I definitely remember seeing that he had done that, that he had gone into engineering and was like, 'oh, I could do that too.' Just having someone who seemed, like, I think maybe my opinion of what a physicist

> was at that point was even more super geeky man that fits some stereotype and he didn't really fit that. (Molly, Interview #1)

Until meeting this young teacher, Molly did not have a sense that physics was a possible option for her as a discipline to study. This had to do with her stereotypic ideas of who physicists were, and that image did not fit with who she thought she wanted to or was able to become.

Institutional contexts. This theme of difference ran throughout Molly's interviews. Molly described herself as always being different from engineers and physicists. She discussed not really fitting in to the physics community for a variety of reasons, but predominantly for her differences:

> There are not so many girls. I was pretty visible. Actually, for a long time, I was dying my hair weird colors, which is extreme, and dressing really weird. I was more, sort of like punk rock, kind of, I guess? Wearing dresses and stuff. Just dressing sort of outside the norm, especially for physics, having bright orange hair, or blue hair. You're very visible, everybody knows who you are. Now, everybody knows who I am, again! [laughing] I'm the pregnant female grad student. (Molly, Interview #1)

Molly's expectation to be regarded as different came from her experiences in her undergraduate degree. She transferred to Eastern in her third year, and she immediately felt that her appearances made her stand out. However, additionally, she occasionally found herself in situations where she was the only woman present:

> So that felt a little weird. There was one class I took where I was the only woman. That was weird. I definitely had some weird experiences where I was the only woman and I felt like I was the only woman and everybody

> else noticed. There was comments that, just on fact that you're the only girl here (Molly, Interview #1).

She discussed this experience as one of the times when she not only felt different to her colleagues, but also felt singled out by other students in the class. She mentioned that the students in the class kept pointing out that she was a woman, and that she was the only one in the class. Molly stated that she thought this was weird and then recounted a particular story from that class which she remembered as being offensive:

> I was working on this assignment with this guy, and this guy said, I can't remember exactly what he said because it's a lot of years ago, but he basically said something like, 'Oh, do you find this class hard?' And I was like, 'yes!' because it's a very difficult class. 'Yes, it's hard.' He was like, 'you must find it particularly difficult because women can't visualize in three dimensions.' I didn't know that about myself! I was so flabbergasted by that, but he didn't realize that it was offensive. (Molly, Interview #1)

Molly described being shocked by this individual's comments, and claimed this to be the first time that she had "encountered anything about the fact that [she] was a woman" (Interview #1). She then wondered if he was actually "a sexist" or if this particular individual was just "a jerk". This experience might also be regarded as a form of negative recognition, where Molly was not seen as appropriate for physics because she is a woman.

Molly's negative experiences as an undergraduate were counterbalanced by very positive experiences as a graduate student in the physics department. Molly began her work in astrophysics as a summer student on a federal grant, and then enrolled as a master's student. Her master's study then morphed into a doctoral project, all with the same supervisor. She described this transitioning experience as very positive, and her advisor and colleagues as big influences on this experience:

> I was extremely lucky. I had this office with a post-doc and it was really great for my life in general, being in the physics department. I had access to computers where I could do all my research and type everything up, do all that. The post-doc was really really helpful in terms of just chatting about general pulsar stuff. When you come in, it takes a while to really understand all that's going on. He was super helpful. It was really good. The group is very friendly so you get to know people better. I guess I started off sort of shy in that situation. Everyone knows more than you, everyone's a grad student or a post-doc. You're pretty quiet at the beginning. Once you sort of realize that I'm not, I'm a bit further behind everybody else, but there's no fundamental difference between us. I started getting more confident and able to ask questions. Veronica's really good about, if somebody is talking about something and there's a new person, when there's a new person at the group meeting and other people are going to talk, she makes sure to remind everyone to give details. Don't use acronyms. Explain what it is that you're talking about. You're not just thrown into it and totally lost. People make an effort to bring you in. So that was really good. (Molly, Interview #1)

Molly regarded being integrated into the community of her research group as a positive experience, both academically and for her life in general. She discussed this transition as a turning point for her, both in terms of solidifying what she wanted to do for her career, and also in terms of learning how to be an astrophysicist. This experience was different to the alienating experiences she had as an undergraduate. Molly recognized herself as an important contributing member of the pulsar group, and attributed this to the welcoming environment that Veronica constructed as PI of the group. This positive experience encouraged Molly to continue on in astrophysics.

Sandra. At the time we scheduled her interviews, Sandra was in her late twenties, in the last year of her PhD and only a few days away from her defense. She had already published several articles on pulsars, one of them in *Science*. She was slated to start a post-doctoral fellowship at a western Canadian university in just a few short weeks after her defense.

Sandra identified as a Latina woman, and she grew up in Central America. Her family immigrated to Canada during her last year of high school. Sandra discussed always having an interest in science, and her parents, who were both in medicine, encouraged her interest in science a great deal. However, it was not until her family moved to Canada that Sandra began to see possibilities for herself in astrophysics. Sandra regarded her family's move to Canada as critical in her pursuit of a doctorate in astrophysics, suggesting that had she stayed in her home country, she likely would have become a psychologist, psychiatrist, or social worker, but she "definitely would not have gone into physics, for sure" (Sandra, Interview #1).

Sandra enrolled in a western Canadian university for her undergraduate degree and took a number of physics courses. When she registered for her courses, she had intended on taking Anthropology. However, when she tried to register for the class, it was full, so she signed up for astronomy instead, and that's when she got hooked. From there, Sandra did a master's degree in astrophysics, and then subsequently came to Eastern University to do her PhD in the pulsar group. Like Molly, Sandra discussed this experience as a very positive one, and she talked about her research group as though they were a very supportive family.

Sandra frequently stressed the importance of teaching and mentoring youth in science. She recognized herself as a physicist and saw this as a position of responsibility. She discussed frequently the importance of scientific literacy among youth, and the responsibility that scientists have to ensure that youth are educated so that they may make informed choices about science. In keeping with her experience of feeling very supported as a physics student, Sandra volunteers for an organization that conducts science classes for children in and out of school, which is in line with her desire to teach in the future as a professor, and to mentor others. In the fall of 2009, Sandra was doing a post-doctoral position in Western Canada.

Influence of significant others. When I asked Sandra what got her interested in physics, she responded that she always used to look up at the sky, and was fascinated:

> **Sandra**: I've always liked the sky, and looking up at the stars. When I was little, I would always go to the roof of my house and spend a few hours on the roof. This was in [Central American country]. At different times of year, I would see the different stars up there, just go out and see them changing.
>
> **AG**: Was there somebody that encouraged you to do that?
>
> **Sandra**: Oh, yeah, well my parents, were like, "what are you looking at, what do you think that constellation is there?" Just little stuff like that. (Sandra, Interview #1)

Although her father was a doctor, and her mother was a nurse, Sandra suggested that they were not "in science themselves. They were not in research, in medical research or anything like that. It was just general practice" (Sandra, Interview #1). However, although she had supportive and science-oriented parents, Sandra's school in [Central American country] did not support her learning in this regard:

> Well, not in [Central American country], not really. That's where I did high school, I did high school in [Central American country]. So it was [. .] I mean they were really good at teaching you science. We had really good math, compared to what I saw kids here doing in math in high school. We had similar or even higher level math over there. Science, well they didn't have that much money there for huge science labs or anything like that. But the schools were really good at teaching you that you should learn, that you should get an education in whatever it is that you want to, and you should go into that. So they didn't really have science related things over there. But that was high school and then we came here, to Canada. (Sandra, Interview #1)

By high school, Sandra saw "scientist" as a career option for herself, but realized that she needed to have different educational facilities in order to pursue a career in the sciences. When she moved to Canada, she finished high school and then enrolled in a general science program at university. She was unclear which discipline, but it seemed as though there was never any question that science fit into her academic trajectory:

> **Sandra**: I was going to science, I knew that I was going to science, for sure.
>
> **AG**: When did you know that?

> **Sandra**: Ah, well, basically, when I had to decide what to do [. . .] I knew that I was going into science but I hadn't decided on astronomy specifically until [my first] year. (Sandra, Interview #1)

Sandra described one particular course that she took in her undergraduate program as being influential in her decision to pursue astrophysics, a decision that led her to a master's degree and the PhD program at Eastern. Sandra was very positive about her experiences in astrophysics at Eastern and at the western Canadian university she attended for her master's. She attributed her positive experiences to the kind of mentorship she received as a student in the field. In turn, she also felt that mentorship and building a supportive community for students was an extremely important role of an academic (this will be discussed further in Chapter 7). She discussed the environment she works in as a supportive network that helped her through the PhD:

> I think when you go into it, it's like you're a second family almost. Everybody is in the same boat. You work with them day in, day out and sometimes you work with them night in, night out, you know, doing whatever you need to do. When you spend so much time with people, they do become like your second family. If you become stressed as a grad student, you know that the person next to you is in exactly the same boat. You can go for beers after afterward, you can wind down. When you're sharing the same experiences, you do get a lot of support from everybody and everybody is very understanding. (Sandra, Interview #1)

Sandra's description of the pulsar research group community is similar to Molly's description of the same group, as an understanding and helpful community or second family. This kind of description was common from participants in the pulsar group, and both Sandra and Molly attributed this to

Veronica's (the PI's) role in establishing a nurturing environment for students to learn. Both Sandra and Molly regarded this support network as fundamental to their successes in the doctoral program.

Recognition. In our interviews, Sandra spoke about institutional forms of recognition such as publications and funding. She had been a first author on a publication in *Science* and a co-author on a number of articles in similarly prestigious journals. In a photograph, she captured an image of her dissertation, however, she did not give permission for her photos to be publicly shown. Sandra described this to me as an indicator that she had gained membership into her community of physicists:

> **Sandra**: Now that I'm almost done with [my degree], it really makes me feel like I'm part of the field. So now I've done enough that I'm familiar with it, I understand the general thing of the field I understand my part of it really well. So it does make me feel like I'm part of it.
>
> **AG**: Is this the first time you really felt like you're a member of this field?
>
> **Sandra**: Well, I think publishing the first couple papers is when I felt like, 'Ok, I guess I'm part of this field now 'cause my name is there. You know when you go to conferences and they're like, 'Your science is neutron-stars? I read your paper,' and stuff like that. Or, you know, when you publish and people send you e-mails and say 'I just saw your paper on the pre-print server and I wanted to ask you something about this, blah blah.' So that is when it starts to feel like you're part of it. You're talking to people, you're collaborating with them. But then doing the thesis is like it's official. You have a degree from the university and you can officially say that you are part of the field. So I guess it's working your way to it, little by little, and then it's like, 'Ok, it's official. I'm here.' (Sandra, Interview #1)

Despite having published several articles already, Sandra claimed that she did not feel as though she was a bona fide member of the field until she had finished her dissertation. She described membership in the astrophysics as incremental, beginning with publishing reports on the pre-print server, and in recognized and prestigious journals, and finally the most important symbol of membership—completing the dissertation.

The issues of gender and recognition arose in our interviews. Sandra discussed applying for post-doctoral positions and the fact that she was going to do a post-doctorate with another woman supervisor. I queried about the trend (her master's supervisor was also a woman) and Sandra claimed it was coincidence. I then asked her if she thought academic jobs and funding seemed more or less available to women than in the past, to which Sandra responded:

> Well, many times when you apply for jobs, they do state that they welcome minorities and women and that people like that are very encouraged to apply. In that case I feel like I have an advantage to other people. I know why those clauses are in there in the first place, 'cause they want to encourage people to go into these areas and show them yes there's jobs for you if you want them, we're not going to discriminate. You will get a job if you're good. So they're pointing out the fact that they are treating everybody equally. It makes it more open that there is a problem that there are not that many women and there are not that many minorities that they want more. But if that has affected me, I'm not sure. Like, when I apply for [federal grant]. I don't know if I've gotten [federal grant] because I'm a woman instead of because I'm good at what I do. I would hope that it's because I'm good at what I do, but they have that statement saying that we encourage women and minorities to apply, so I know how their internal policies work, but what can I do? I just apply for

> these things and if I get it, I get it. And if I get it, is it because I'm a woman? I don't know, but it's there. (Sandra, Interview #1)

Sandra questioned whether she has actually benefited from being a woman of colour in the awarding of grants as a result of equal opportunity programs. She suggested that this is unlikely and hoped that it was not the case.

She later stated that due to Canadian multicultural policy, the issue of cultural background is moot at this point in history because “[her] classmates have been around people for so long that it’s not an issue”. She suggested that at work in the physics department, she did not experience her ethnicity as something that made her stand out:

> I really like that about Canada in general. At least my generation and probably the generations to come, I hope, and my supervisor’s generation, they’re all very accepting of everybody from different cultures. I think a lot of it may be, if anything that sets you apart is that you’re a woman, doesn’t matter if you’re from here, from there, it’s the fact that you’re a woman. (Sandra, Interview #2)

Rather, Sandra thought that gender might be the most significant force of Othering in physics. However, Sandra also mentioned that she has not had any negative experiences directly related to her gender, although she has heard that some women have experienced problems.

David. At the time of the interviews, David was a mid-twenties PhD student in his last months of dissertation writing. David identified as White, francophone, grew up in Eastern Canada, and did all of his schooling in a francophone environment. He had already garnered several publications, one in *Nature* and was working on another publication for either *Science* or *Nature*.

David remembered becoming interested in astronomy at a young age, learning about the stars at Scouts camp, and also learning about the technology associated with star-gazing. He cited these as his early influences, but conceded that his real interest as a child was sports, and he had no ambitions for a career in science when he was young.

When he entered high school, David showed proficiency in physics, and was encouraged by some teachers to enter science fairs, but he was reluctant to do so given the nerdy image that physicists projected. A positive role model in physics helped David overcome his perceptions of physicists, and encouraged him to enter physics in his undergraduate. David discussed the recognition he received for his research in the form of publication and positive recognition from colleagues at conferences. He viewed these aspects of physics research to be most important in the development of his career. Like Sandra, David emphasized teaching, rigour, and integrity in research when discussing his practice as a physicist. Perhaps the stage of his doctoral studies caused him to reflect on these aspects of academic life a great deal.

David's goals were to pursue a post-doctoral fellowship that would find him stationed in a laboratory out of the province. He knew that this would be necessary to continue a career in physics, but he struggled with how this would affect a relationship he was in at the time. He told me that he had some "big decisions to make" regarding his career (Interview #1). When I followed up with him in the winter of 2009, David had already completed his doctorate and had ended his relationship to take up a post-doctoral position out of province.

Recognition and influence of others. David claimed that when he was in high school, he was more interested in sports than science, and had a negative image of physicists as nerdy. His teachers saw that he was quite talented in science and asked his parents to allow him to participate in a science fair. At first, David said he was hesitant because of the social stigma he feared, but he eventually agreed to it, and participated in science fairs for years afterward, often winning top prizes.

> At first, I was like, hmm I don't know, because I didn't want to look like a, you know, a nerd or that type of thing because I was really into the sports stuff and everything. But [the teacher] said, ‘you don't necessarily have to not play basketball, you can just keep doing that, this could be an interesting project. They meet at lunchtime once a week and you just prepare this little like, an exhibit, poster stuff, and then you present it. And if you don't like it immediately, then you just, you know, stop doing it and do something else.' And I was like, 'yeah, maybe.' But the teacher [running the science fair] was a bit known to be like, he looked strange and he looked like a very hippie-type person, like very ecological. So he would like, recycle and stuff and we would make fun of him all the time. So, I was like, ‘I'm not sure I want to be associated to him' but in the end I said, 'ok, I'll try it.' (David, Interview #1)

David’s hesitance came from an unwillingness to associate himself with that nerdy scientist image, but also with a dichotomous view of science and sports. He said that he didn’t want to give up the basketball, but also that he didn’t want to be associated with nerds because he was really into sports. However, David convinced a friend to enter into a science fair with him, and he began a run of very successful entries, taking him all the way to national science fair levels. As David achieved higher levels in the science fairs, he began to work with university professors, and developed a keen interest in physics. However, it wasn't until he met a teacher at CEGEP[iv] that he decided he would pursue a career in physics.

> When we got the scholarship, there was prize money coming in and there was a ceremony. [Representatives from different CEGEPS] were trying to get us to choose their school. He was there and right away, I was like, 'whoa, that guy seems really cool.' I was really impressed like that. Like, compared to other profs that were not like that. (David, Interview #1)

This particular CEGEP teacher was young, would go to nightclubs and bars with the students, and portrayed an image that was contradictory to the nerdy associations David had previously held about physics. The introduction of this professor to David's academic life allowed him to see being a physicist as a new possibility for himself.

> **David**: He was like 30 years old so he was not like, quite grown up. He really had a big influence on the way that I saw physics.
>
> **AG**: Ok, so what do you mean by that?
>
> **David**: Like the way that he was teaching was not too formal. He would make jokes all the time. The class was really relaxed but the guy was really—you can tell he's got a lot of background in science, not only about physics, but about many many fields. He knew about history and about a lot of things and you can tell when a prof teaches and knows what he's teaching about because he's sort of prepared the course. He was just that kind of guy. He was also organized on lunch times, once a week, or once in a while, a science club. He would go beyond the course material and teach us about relativity and string theory and things like that. (David, Interview #1)

Until he met this influential CEGEP professor, David carried a very specific image of physicists in mind. Interestingly, David's hesitation to enter physics was not a doubt about whether he could do it, or whether it would be a viable career option for him, but rather that the nerdy image of physics would not fit with his more athletic image. This individual showed him that not all physicists are the same, and that he could be a physicist without changing his image or athletic interests.

Once in CEGEP, David took a lot of science courses, with a view to doing a degree in astrophysics. The stories David told of doing science fairs in high school and then doing physics coursework in CEGEP indicated that he recognized his potential in physics from that time:

> I told myself, I am totally going to do a BSc in physics because you can also do, let's say, physics engineering and then do a master's say in astrophysics, if you want. I told myself that it's physics that I want to do. (David, Interview #1)

David appeared to have decided on his career path from the time of CEGEP, and did not express any doubt in this. The successes he had in science fairs provided him with the recognition he needed to keep going, and the positive influence of the CEGEP teacher allowed him to see physics as a viable career option for himself.

Personal contexts. At the time of the interviews, David was nearing the end of his PhD in astrophysics, but unlike Sandra, he was quite conflicted about what he would do next. He knew he would do a post-doctoral position, but he was just not sure where he would go. His concern was about the strain the long-distance would put on his relationship. However, an academic career in astrophysics was a certainty for David, given his publication track-record and innovative research, so it was a matter of which post-doctoral position he should try for.

> Well, yeah. That's my plan but it's, you're taking me on a strange time because I'm looking for post-docs. Over the last couple weeks and months, I've been flipping my life over, asking myself what I want to do in life, is there life after death? Very fundamental questions about my life, it's crazy. So right now, I'm looking for a post-doc because I'm looking to submit my thesis at the end of August probably. Or, maybe a little bit after, during the fall. We'll see. So, yeah, it's very very stressful [. . .] When you put it in perspective, you have to move away, leave your friends behind, your family behind. Relationship-wise it's also very difficult because I have a girlfriend and things are not doing great and we might break up partly because of that, because she doesn't want to move away. I'm like, 'ok, should I move away? Or stay here?' It's a very tough kind of question. (David, Interview #1)

Questions like these led David to wonder if he should also consider a job in industry, which is outside of the trajectory he had constructed for himself since high school. Ultimately, David took a post-doctoral position out of province and ended his relationship. In my last conversation with him, he was very happy with his decision and was having a great deal of success, traveling to conferences overseas, and preparing several publications.

Ruby. At the time of her participation in the study, Ruby was in her mid-twenties and in the fourth year of her PhD. She was hoping to finish in the following year, and was teaching physics part-time at a local CEGEP. Ruby had some trepidation about participating in the study because she felt as though she would have "nothing to give" and that she did not know how useful she would be to this study (Field notes, April 11, 2007). When I inquired why she thought that, she answered that she didn't believe there was a physics culture, and if there was a physics culture, she certainly didn't know anything about it.

Ruby is of Middle Eastern origin and grew up in an Arab country where she was raised by her father. She had left her home country by the second year in high school, but by that time she had already taken several physics courses, so she was well prepared to study physics here. She had an influential teacher in the Middle East that got her interested in studying physics at school, but it was in CEGEP that she was most encouraged to continue in physics. Ruby told about having great success in her undergraduate degree in physics. She described being at the top of her class, and being the person that everyone went to when they had questions. During her undergraduate degree, Ruby recognized herself as a physicist, but, as described below, shortly thereafter her feelings of being competent in the discipline declined. Ruby did her master's degree in the pulsar research group, and carried on with the same supervisor to do her PhD. However, her attendance at group meetings and seminars dropped off dramatically during her doctorate and she felt as though she was beginning to lose grasp of the discipline.

Ruby discussed a great deal about how she no longer felt like a physicist. Her experiences during her doctorate included disillusionment with research, an inability to participate in community practices due to health reasons, and feelings of incompetence. However, despite these, Ruby continued with her research and did ultimately successfully defend her dissertation. During her doctorate, she took up teaching physics at a local CEGEP. She described this as time-consuming and difficult, but claimed that she feels like a physicist during certain teaching moments. Her positive experience with teaching has led her to consider this as a career option. She feels inadequately prepared to pursue a post-doctorate position or a professorship in astrophysics, although she would like to continue research. Ruby's long-term plans for after her defense were uncertain, but she did have the immediate goals of continuing to teach at the CEGEP.

Influence of significant other and personal context. Ruby's early interest in physics really came from an interest in the sky and stories that she had read pertaining to astronomy. She described books she read as a child as her early experiences that stimulated her interest in physics:

> So the very first comic that was ever read to me before I could actually read was, *Tin Tin*. One of the *Tin Tin* is called, *Tin Tin et les etoiles mystérieuses*, in French. *Tin Tin and the shooting star* in English. That was the first comic that was ever read to me by my Dad, who actually didn't have the habit of reading to me. So one day he just sat next to me and opened *Tin Tin et les etoiles mysterious* and he read it to me and I was looking at all the pictures. That was how I sort of got interested in things in the sky I guess. So it wasn't really physics it was really things in the sky. (Ruby, Interview #1)

Ruby connected this experience of first becoming interested in astrophysics with a shared experience with her father. Throughout the interview, Ruby mentioned her father several times, but did not provide details about her home environment growing up. Her father moved Ruby and her sister to Canada from the Middle East when she was in high school, and she discussed the encouragement she received from him.

After her undergraduate degree, Ruby applied to Harvard, the University of Arizona, Princeton. and California Institute of Technology for graduate school. She was accepted to all schools with full scholarships. However, when considering moving to the United States to study, she became quite worried about leaving her father. This is one of the reasons she cited for continuing graduate studies at Eastern University instead of at another school further away:

> I didn't want to leave my dad. I don't know [. . .] I have the dad who worries the most on the planet. Like if he goes two days without seeing me he worries, 'what happened to her, did she get eaten by ogres or something?' So anyway, it was partially because of this. I didn't want him to worry and I mean he is not always going to be there. I mean one day he will die. I mean probably before me and I hope not. But anyway, I like my Dad and I feel like I owe him a lot and so he would have liked had I gone to Harvard, because he would have gone back to his family and said 'oh hey my kid got in to Harvard!' But he also really liked having me around. So it was a toss between the two, yeah. (Ruby, Interview #1)

The tension between wanting to do something for her career, which would please her father, and feeling responsible to stay with her father created a difficult decision for her when choosing a graduate school. Ultimately, Ruby chose to stay, and suggested that her reasons for applying to Ivy League schools were no longer acceptable to her:

> **Ruby**: I just I didn't feel right about it, like the reason why I had applied to these schools had nothing to do with the fact that I wanted to learn more about astrophysics. Yes, I did want to learn more about astrophysics but that is not why I had chosen these schools.
>
> **AG**: Why did you choose these schools?
>
> **Ruby**: I choose these schools because they had good names and when you

> tell someone 'I am Harvard student' they go 'wow!' That's why I did it. And I just think that is a completely wrong reason. That is entirely stupid and entirely vain. I didn't want to be this person. I don't know. (Ruby, Interview #1)

At the time of applying to graduate school, Ruby had been interested in attending a prestigious school. She said that she was interested in studying astrophysics, but that was not why she applied to those schools. But now in retrospect, Ruby regarded those actions as vain. She elected to stay at Eastern primarily so that she could remain close to her father.

Institutional context. Ruby described herself as graduating "at the top of her class" from her physics undergraduate degree at Eastern university (Ruby, Interview #1). She described how during her undergraduate degree she was the person that others would come to with questions right before the exam. She entered graduate school confident that her academic success would continue. However, things began to change for Ruby when she began her master's degree. She began to realize that her expectations were very different from the realities of graduate research and that pulsar research "is one of the fields where astrophysics is the furthest from the romantic idealistic old fashion astronomy" (Ruby, Interview #1). The work she found herself doing was far away from the observational astrophysics she had become fascinated with:

> Yeah, and then I was completely disillusioned when I started grad school cause nobody does the work; nobody like sits in front of a telescope, and all the science that could have been done with a small telescope that you put in your backyard has been done. [This research] is not what Galileo was doing, it is not what Tin Tin and his friends were doing. I don't even do optical astronomy, so the rays that the stars emit that I analyze you

> can't see them with a naked eye, you need an X-ray detector. So I basically just read numbers coming out of an X-ray detector. It is true the detector is pointing at the sky but it is not the same thing. It is, I don't know. I think I had this idealistic romantic, oh I will sit in front of a telescope and look at stars and we can see the satellites and Jupiter. Nobody looks at satellites and Jupiter any more. (Ruby, Interview #1)

Ruby's struggle with her subject was multi-faceted. She struggled with the realities of doing pulsar research, which were different than the expectations she had. She also struggled with the fact the she had a great deal of difficulty retaining information that she learned. A number of times in the interviews she implored me to believe that she used to be at the top of her class in her undergraduate "[P]lease believe me because nobody else believed me. I did graduate at the top of my class in physics but the part where nobody believes, it is I forgot everything, I swear, I forgot everything" (Ruby, Interview #1).

This difficulty she had retaining information affected her participation in group projects. Along with these difficulties, Ruby also dealt with sleep issues that prevented her from attending seminars and group meetings like the astro-tea or the neutron-star coffee. Although her supervisor would encourage her to attend, Ruby claimed that she was unable to be awake in time for these meetings. She saw these as missed opportunities for learning about her field. However, despite her understanding that these were important learning opportunities she was missing out on, Ruby later admitted that she did not make a big enough effort to attend because she found the seminars boring and poorly structured, but also because she is generally bored with physics:

> I get so frustrated five minutes into it and I am already angry at the

> speaker, because I feel like the speaker is not making effort for us to understand. I feel like the speakers are always assuming we know too much, maybe. I feel like even if I knew what I was supposed to know at this level, I am not going to know enough to actually follow what the speaker is doing. Like, they are trying to get in the latest of what they are doing, while that is not just the right thing to do. The right thing to do would be for every talk to give a little introduction and at the very beginning where you like bring people up to speed on what has been going on. Most people don't do this introduction part. I don't know it might be just me. It doesn't seem to bother most other people. But I find physics talk in general, badly unstructured. Maybe it is just an excuse because that I am making it up because I just, I am bored with the field or something. I don't know. I am bored with physics really for sure. (Ruby, Interview #2)

Recognition of self. In our discussion about her goals for the future, Ruby indicated that she thought teaching full time in college might be a path she could pursue. When I asked her about doing a post-doc, she stated that she couldn't really "see herself as a university professor" (Ruby, Interview 1). Her reasoning was that "I wasted my time in grad school. Instead of doing what a grad student should be doing, which is learn about their field, so I didn't do that" (Ruby, Interview 1). Ruby also expressed concern about her ability to supervise students and her confidence in her knowledge of the subject. In the following excerpt she discussed what she saw as her grasp of the literature in her field versus the others in her research group:

> In the pulsar group, they are all like, really motivated, and they read lots of papers, and they certainly know a lot more physics about the stars that we are looking at than me. And besides, I don't feel confident enough that I would be able to be responsible for a student under me. I am to pick their PhD topic and what if the topic is really, really bad. I don't want the

> responsibility on my shoulders. The responsibility of supervising somebody for four or five years, maybe I am not ready to do it. But at the moment, I don't think I could do it. I don't know enough physics. I don't think I am willing to take the responsibility, so I don't think I can become a university professor. I would have to restart grad school all over. Spend another four years going to all the talks that I missed. Maybe then I would be ready but I didn't take the time to do it once, I don't think I would take the time to do it again. (Ruby, Interview #1)

Ruby blamed herself for not doing the work necessary to become well-versed in the literature of her field or attending the talks where she might have learned more about her field. By the winter of 2009, Ruby had finished her doctorate and was teaching full-time at a CEGEP.

Alice. At the time of our interviews, Alice was in her mid-twenties and just in the second year of her PhD. Alice identified as a White woman, and she grew up in a middle-class family in Eastern Canada. When we met, she had already started doing some research, but at the same time was taking courses to catch up on astrophysics after having done a master's degree and a year of PhD study in math before transferring into physics.

Alice met Ruby during her master's studies in mathematics at Eastern. Through Ruby, she became very interested in the research the pulsar group was engaged in and helped out quite a bit with the programming they were using to organize their data. While she was still working on her master's degree, Alice began co-publishing with the pulsar group, and although she decided to enroll in a PhD in math when she finished her MSc, she maintained a working relationship with the group. Eventually, when she realized she could not continue her PhD in math because she was no longer interested in the topic, she switched over to the PhD program in astrophysics. This was a giant disciplinary leap, but given her previous work in pulsar research, she transitioned smoothly.

Alice attributed her interest in astrophysics to the linkages to actual data. For her, this combines her interest in mathematics with something more tangible. She admitted that she saw no practical application to learning about neutron-stars, but that was of no particular concern to her. However, she did find astrophysics more attractive than math because of the possibility to connect numbers to real phenomena like pulsars.

Alice received a great deal of positive recognition from her colleagues in the pulsar group. Since joining the research group, she has co-authored several publications by contributing a new way of coding data to those researchers collecting X-ray data. I have since heard that Alice is presently finishing up her doctorate, but she did not respond to my follow-up communication to confirm this.

Influence of significant others. Alice attributed her interest in science generally to having grown up in a strongly science-oriented household—her father was a professor in microbiology, later moving to an industry position, and her mother was a high-school science teacher:

> Um, science generally, I mean, I think it was kind of inevitable given my family. Well, actually, no because my sister took a very different path, um, but, my father was a university professor for years, then he moved to doing research in industry, um, but, so he was involved in science. My mother used to be a high-school science teacher and um, my father just is always thinking about how things work and really likes explaining things,

> that is not too surprising for a university professor, but he does it all the time. (Alice, Interview #1)

Alice said that she was interested in science from a young age, claiming that, from the influence of her father: “I got the feeling that at least it was possible that you could know how all sorts of fascinating things worked” (Interview #1). She described being thought of as the smart one from a young age as well, claiming that teachers would ask her younger sister if she was as smart as Alice.

Recognition. Alice’s interest in science, and particularly physics, stemmed from a conceptually deep interest in the underpinnings of scientific phenomena. Alice described the feeling she would get from math and physics as a motivating influence for continuing on to graduate school:

> When I was deciding what to do, when I was in university, I never worried much about the applicability of what I was doing, I was just worried about doing something that I was good at and enjoyed. [Math and physics] seemed like it had sufficient interest to me because it had like, um, just because the fact that other people were interested in it and it had this fascinating structure. It was interesting in its own way. I mean, I say this looking back, my motivations I think are not nearly as rational as I thought they were at the time. I think a lot of it was really, this is what I felt was the most difficult, most challenging thing I could do and I liked a challenge. And I liked, and I wanted to feel like I was smart and I wanted to feel like I was, you know, I wanted everyone else around to feel like I am smart too. I like to think I avoided kind of the worst manifestations of that kind. Because I saw a lot of it, a lot of people felt the same way and a lot of people behaved badly because of it. I like, I hope I avoided the worst of those but I mean in a way that is what was driving me too. (Alice, Interview #1)

Alice’s reasons for pursuing an undergraduate degree in math and physics were rather unclear. She suggested that she had sufficient interest in it, or at least that it seemed like it should be interesting because others were interested in it, but the real attraction appeared to be its intellectual elitism. Alice discussed this tension that she felt between wanting to feel smart, but worrying that this was an undesirable goal that leads to bad behaviour. By this, Alice was referring to the sense of inflated ego that she observed among her colleagues in math and physics. Alice worried about developing this kind of social characteristic herself but nonetheless, she described being recognized as smart as a motivation for pursuing a degree first in math and then physics. This form of recognition was one that she had access to since she was young. She described always being referred to as the smart one of her sibling pair, a position she occupied reluctantly because she didn't care for the effect it had on her sister:

> Yeah, well my sister didn't, I mean she went to Nova Scotia College for Art and Design. She is studying fine arts and she is not at all academically oriented. And some of that I think is that, all through school everyone was asking if she would be as smart as I was, which is a horrible thing to do to a kid. (Alice, Interview #1)

She regarded this as one of the reasons why her sister didn't enter into science despite the strong family emphasis on science. On the other hand, Alice described being recognized at an early age as having ability in math and physics, and subsequently enrolling in a gifted program in CEGEP, which led to her pursuit of these disciplines at university.

Since her transfer into a PhD program with the pulsar group, Alice has been very successful in publishing articles on her subject in high-ranking journals like *Nature*. She discussed her view of the future by elaborating on her present focus on networking in order to set up her web of contacts for her future. Alice did not discuss her future plans in great detail, but often made references to the importance of using conferences to persuade her colleagues that her ideas are sound because:

> These people I am talking to about how to do the X-rays, I will be working with these people, maybe want to do a post doc with some of these people. But I am going to try and get [my work] to published, I am going to try and convince them that this is a good thing to do. And if it works and even if it doesn't and they are intrigued and they think I have a good case, they will remember me. (Alice, Interview #1)

As she is still in the early stages of her doctoral work, her goals at the time of the interview were to focus on finding pulsars and publishing her work. Shortly after these interviews took place, Alice made a major discovery that was widely reported on and published in *Nature* magazine.

Understanding Stories

The participant profiles presented here detailed the academic trajectory of each of the participants in the study and the contexts and experiences that may have contributed to the direction of these trajectories into and out of academic physics. These profiles were compiled primarily from interview data that told stories of recognition and gave us a glimpse of the resources participants have acquired through their experiences with physics.

Participant trajectories. Trajectories are not fixed paths or destinations, but rather a set of experiences that have "coherence through time that connects the past, the present, and the future" (Wenger, 1998, p. 154). Thus, there is a temporal and a spatial specificity to these resources that can only be understood through an exploration of the individual trajectories participants are on. Over time and across spaces, individuals' past experiences and contexts recursively shape how they see themselves. These experiences and contexts also shape the stories that they tell themselves and others about who they are and whether they will continue to use the resources they have acquired to maintain the trajectory they are on.

In these stories, I have identified three distinct participant trajectories: inbound, peripheral, and outbound (Wenger, 1998). Here, the inbound trajectory was characterized by the participants' articulation of goals for the future that included either beginning or looking for a post-doctoral position, or discussion of looking forward to a career as a professor. The peripheral career trajectory is one in which the participant discusses a desire not to continue in academics (for reasons directly related to the culture or structure of academic physics), but to use their physics degree in related private or public sector jobs. Finally, the outbound career trajectory can include the completion of the doctorate, but a view of themselves as not suitable for a career in physics either in academia or the private or public sector. Table 4 details the types of trajectories participants are on and the relationship between participants' goals and the experiences and contexts that have shaped their trajectories.

In identifying trajectories, I have understood the expected trajectory leading in and out of doctoral study to entail the following stages: undergraduate degree, master's degree, doctorate, post-doctorate position (or several), faculty position, and primary research investigator. By describing the expected trajectory as a road to a tenure-track position, I do not mean to imply that this trajectory is the most desirable or the ideal. I have identified this trajectory as the inbound trajectory to address the demand in the literature on doctoral attrition that looks to reasons why students do not continue on to faculty positions (Mason, Goulden, & Frasch, 2009), and the under-representation of women in faculty positions in departments of physics demands research that explores reasons why students leave academic physics after the doctorate (CAUT, 2009).

Experiences and contexts. Participants' experiences and contexts that may have contributed to their trajectories were characterized as either stories of recognition, influences of significant others, personal contexts, or institutional contexts.

Stories of recognition emerged as stories participants told that either included recognition of themselves as physicists or potential physicists (e.g., early interests in physics, stories that acknowledged their ability in physics or stories wherein participants described feeling like physicists), and stories of recognition by meaningful others (e.g., teachers who identified the participant as having an ability in physics, stories about being awarded grants or achieving publication). Meaningful others could have been parents, teachers, or professors who recognized a participants' ability or interest in physics and supported this. Endorsement by funding agencies in the form of fellowships or scholarships or through publications was also identified as a form of recognition by others. Recognition may be positive or negative. An example of this was Victor's provincial doctoral grant. His application for a federal grant did not succeed, a loss that may be regarded as negative recognition from a significant scientific other. However, when he found out that his provincial grant application was successful, he regarded this not only with monetary significance, but also as a "validation thing" (Victor, Interview #1).

Influences of significant others were generally told as stories about personal support from parents or teachers, or role models. Role models generally took the form of high-school teachers or university professors who stood out as examples of who or what participants could possibly be in the future. For some participants, these were examples of people with physics degrees who broke the stereotype of the nerdy, male physicist. For others, influential role models were those professors who were particularly inspiring or encouraging to students in their undergraduate degrees. Again, influential others may have taken positive or negative forms. Many participants detailed stories about individuals who encouraged them or acted as role models and were positive influences on their trajectories, and served as sources for positive recognition as well. However, influences of significant others could also be negative, for example, David described a science teacher who he felt was particularly nerdy, a characteristic which was initially a deterrent for him in science.

Personal contexts arose as influential in participant trajectories. These contexts varied but generally took the form of family or relationship responsibilities, health limitations, and expectations for job security. Often the personal contexts participants told of were limitations in their trajectories to becoming academic physicists. However, occasionally (e.g., in the case of

Ruby's sleep issues), these personal contexts were discussed as limitations. Rather, participants tended to regard the personal contexts that influenced their trajectories as expectations they had for their futures (e.g., altruistic career choices, domestic lives) that did not fit with the culture and structure of academic physics.

Institutional contexts included aspects of physics culture that participants identified as either enabling factors or constraints on their trajectories. Saïd and Peter, for example, discussed the limitations their research design posed for their publication record; and Carol identified the paperwork and administrative responsibilities of professors that were unattractive to her as a career possibility. However, Molly and Sandra regarded some aspects of their institutional contexts, in particular, the collaborative and nurturing environment of the research group, as positive influences on their trajectories. Whereas Saïd constructed the opposite description of what he regarded as the North-American model for scientific research that is hierarchical and competitive.

All of these experiences and contexts identified by participants played a role in how they engaged with the Discourses of physics and constructed identities around the subject positions offered through these Discourses. These individual contexts become important when considering how positioning around subject positions takes place through the acceptance, refusal, or negotiation of subject positions (Holland et al., 1998).

Schema and resources. The schema and resources that participants bring to their practice in physics will be discussed in depth in Chapter 7, involving a selection of participants. As schema and resources emerge out of individual contexts and experiences, they are difficult to discuss in generalized terms, as each individual's acquisition of these will have arisen from specific localized contexts. However, here I will foreshadow that discussion by providing a selection of examples of schema, and material and human resources that emerged from these stories.

As discussed in Chapter 3, schema are the internalized codes, beliefs, and understandings about culture that individuals develop through prior experiences (Sewell, 1992). They are virtual and transposable to new situations. Schemas about what are appropriate behaviours for physicists are learned through prior experiences with the Discourses of physics. Schemas about appropriate gender roles are learned throughout life by participating in gendered communities of practice (most often as women or men, or as boys or girls; Paechter, 2003a). For example, Molly described a situation where she and a colleague had conflicting schema about whether or not women are capable of spatial reasoning. Molly's previous experiences with mathematics and physics helped her to develop a schema of gendered participation in physics that included women and men as having equal ability when it comes to mathematical and spatial ability. Her colleague, however, had brought to his practice a physics schema about gendered ability that positioned women as subordinate to men in their reasoning ability. It is not possible to speculate on the experiences of this colleague, but it is reasonable to suggest that the prevailing Discourse about women's achievement in science influenced this schema (Summers, 2005).

Material resources are objects that can be used to enhance or maintain position (Sewell, 1992). Examples of material resources are funding, publications, type of education (e.g., private school), and family background, particularly socioeconomic status. Participants discussed material resources in the form of doctoral grants, post-doctoral positions, and publications. Acquisition of these resources was regarded as beneficial and necessary to continue into an academic career in physics.

Human resources are non-material things possessed by a person, such as knowledge, emotions, physical strength, or skill that can be used to enhance or maintain position (Sewell, 1992). These are discussed at length in Chapter 6, as they are often espoused by participants as elements of various Discourses of competence in physics. Examples of human resources from participants' stories of experiences and contexts also came in the form of recognition and influences. Recognition by significant others provided positive emotive support for participants, allowing them to in turn recognize themselves as physicists. Role models and influential professors who provide encouragement can provide positive human resources for students, and can help them to develop the knowledge, skills, and desire required to persist in physics.

Chapter Summary

This chapter presented profiles of each participant and described the goals they had for themselves and the experiences and contexts of their engagement with physics that have influenced their present academic trajectory. These stories illustrated three different career trajectories of participants: inbound, peripheral, and outbound. They also illustrated four types of contexts and experiences that students bring to their practice as physicists: stories of recognition, influences by meaningful others, stories of personal contexts, and stories of institutional contexts. This chapter highlighted the importance of local context when exploring students' trajectories in physics as it pointed to the temporal and spatial specificity of participant experiences. This bears considerable importance for later chapters that will explore the construction of Discourses and subject positions in physics, and students' use of schema and resources in their positioning around these. Understanding the heterogeneity of experiences that participants bring to their study in doctoral physics and to this research in particular will be important to later chapters, which will explore how students draw on their resources to construct Discourses and position themselves around available subject positions.

Chapter 6

Discourses of Physics

This chapter relied on a cross-case thematic analysis (detailed in Chapter 4) of participant interviews, photo-journals, and field notes to examine the Discourses that constructed the practice of doctoral physics in this context. From this data, I extracted how participants discussed the nature of physics and the physics community, what elements of physics were attractive to participants, and what they understood to be the goals of physics. The goal of this chapter was not to characterize individual participants and their descriptions of physics, but rather, from their descriptions of their practices, to construct a view of the Discourses that construct the physics community. The research question that guided the analysis and presentation of findings in this chapter was

2). How do physics doctoral students describe the practice of physics in their local contexts of research teams in a particular physics department?

Discourses of physics were identified by first locating broad themes in participants' talk about physics, and then breaking these down into sub-themes. Figure 1 depicts the coding scheme that was generated using HyperRESEARCH coding software. Section I of Figure 1 depicts the thematic categories discussed in this chapter, and their relationships. The figure depicts the following broad categories of Discourses that emerged from the data in answering the above question:

- Constructing boundaries of physics

- Expectations vs. realities

These broad categories made up the two sections of this chapter followed by the various sub-themes to these that are identified in the code map by the connecting lines. The reader will notice that certain voices predominated in each thematic category. Sometimes, this was a function of disciplinary subfield, where certain themes were more relevant to certain subfields. In instances where there was counterevidence for a theme, I discussed these contradictions. However, if certain voices were absent in a thematic category, it was because they did not discuss the related topic in interviews or in journals.

As explained in previous chapters, Discourses are patterns of interaction that manifest the values of the community by which they are sanctioned (Lemke, 1995). Discourses also regulate human interactions, and define appropriate behaviours for members of a community (Gee, 2005). Thus, Discourses of physics define the appropriate ways of doing physics in the local context of the physics department.

Two broad categories emerged from the thematic coding: boundaries of physics and non-physics (construction of physics as a discipline that is defined in relation to other disciplines), and realities versus expectations (discussion of physics in abstract terms that appeared at times different from or contradictory to the work they actually did). Two Discourses were identified under each category. Boundaries of physics was subdivided into sub-categories including physics as precise and definitive, and physics requiring understanding. Expectation versus realities was subdivided into the sub-categories romantic and philosophical, foundational, and mundane.

Constructing the boundaries of physics and non-physics

Physics was described by many participants as different from other disciplines. Often physics was characterized as a discipline that was definite, had clear boundaries, and was precise and logical. These characteristics and the fact that physics was viewed as a fundamental discipline upon which others were built meant that those who engage in the study of physics cannot just memorize, but must really understand the subject. Interestingly, these descriptions of physics often were couched in examples that differentiated physics from other disciplines. In other words, physics was often constructed as a discipline by distinguishing clear boundaries between it and other disciplines. The following sections illustrate these common ways of talking about the nature of physics in general, and in the department at Eastern University. The sections correspond to the code map and each includes evidence from a variety of participants to illustrate the prevalence of each perspective.

Physics as definite and precise: "You could get 100%." In discussions about what attracted them to physics, participants often identified the fact that physics is precise and definitive as qualities of the discipline that they enjoyed. Here Carol, Ruby, Victor, and Peter all provided examples of this. These participants represented a cross-section of all the disciplinary subfields, indicating that the desire to work in a discipline that addresses definitive concerns is not specific to a certain subfield of physics.

In our conversation about the features of physics that encouraged her to pursue the discipline, Carol suggested that what drew her to physics was its definitiveness. In the following exchange, there was the sense that Carol values disciplines that are definitive over those considered to be more subjective. Carol also discussed that her favourite subjects in high school were physics and math:

> **Carol**: Because you could get a right answer, you could get 100%, you could, you know, and not in English.
>
> **AG**: There is not that element of subjectivity?
>
> **Carol**: Yeah, so I really liked math for that reason [and] physics used all of that math, which was really exciting […] so you could predict, um, you know, anything. (Carol, Interview #1)

This is an example of a participant constructing physics in relation to another discipline. Carol drew a boundary between physics and English, a common comparison I found in the data. In the following description by Ruby of what attracted her to physics, she also reproduced this disciplinary dichotomy, between physics and other disciplines (again English):

> People tell you [physics] is very complicated, but the truth is, it is so simple. [. . .] In a physics course, it is so simple because every problem has an answer. It is not like taking an English class and they ask you to write a paper and you can write basically anything you want as long as [you meet] certain criteria. Solving a physics problem is much simpler, you know, the physics laws. Somehow using these physics laws you need to get an answer. I just think the problem is a lot better to define than like, you know, writing a paper where you have to come up with arguments, and most people will not agree with you and there is nothing absolute. So, what am I trying to say? […] I like the fact that it is clearly defined, yeah. (Ruby, Interview #1)

Similar to Carol, Ruby suggested that the laws of physics allow you to get an answer, so to do physics one needs to learn the laws of physics, and understand how they are applied to situations. Likewise, Victor also discussed his attraction to physics because of its precise nature. He suggested that he became enraptured in the precision of physics:

> There was a couple of profs who I could name at [University X] who I would go to their class and I would just be pretty much enraptured in it. You know they just had such a precise way of [. . .] I think something I like about it was how every word, every term, has precise meaning and therefore you could make statements about them which are either true or false and that seemed [. . .] that turned me on. That attracted me more than a more nebulous way of thinking about things in other areas. (Victor, Interview #1)

Victor reinforced those statements by Carol and Ruby and described the precise elements of physics that allows one to make true or false statements. The nebulous way of thinking that Victor referred to here was also discussed by Peter who described physics in relation to biology, which he discussed as "squishy":

> Like as a contrast, as a science, biology, how it was teached [sic] in school, everything was so squishy and you had to learn so many things by heart and stuff. But in physics, when you understand something, you can apply it to understand, like other things. (Peter, Interview #1)

Here Peter held on to some common notions of the nature of physics that are foundational (can be used to understand other things), and that are not learned by rote memorization. Drawing on his schema acquired through other disciplines in high school, Peter identified physics as distinct even from other sciences because, to him, physics was a science to be understood.

"Real physics" requires understanding. Participants also described physics as a science that requires more understanding than other disciplines. This notion was again constructed in relation to other disciplines. In the above section, Peter drew a connection between the definitiveness of physics and the requirement for it to be understood rather than memorized, as in other disciplines. Carol and Laura drew similar comparisons to other disciplines, while Saïd constructed real physics in opposition to engineering (Interview #1).

Carol, while valuing physics because of its definitive nature, also described physics as Peter did, as a subject to be understood*,* whereas other disciplines were thought of as subjects where content was memorized. She pointed directly to the rote learning she sees as required by other disciplines like chemistry:

> **Carol**: Sometimes I don't get, I don't really like chemistry too much or biology. Because you have to memorize too much for biology.
>
> **AG**: OK, but chemistry, no?
>
> **Carol**: Um, I don't like chemistry because it was just, I found it a lot of easy math, like too easy, adding and multiplying and I only took it in high school. I never got to take it in university. The one part I did like was you had a shape and you had to rotate it in your mind and like talk about, yeah, I liked that topic. But the others like, you know where you put A plus B arrow C, I didn't like that part. (Carol, Interview 1)

Carol's experiences with other subjects like chemistry and biology were in high school, and her understanding of those disciplines stemmed from her early experiences with them, which entailed a lot of memorization. She referred instead to topics in chemistry like organic chemistry that require geometric positioning of molecules as topics that attracted her because of their requirement for spatial reasoning.

Laura suggested that physics requires more, or perhaps a different kind of thinking than other disciplines. Here, Laura discussed a frustration that she experienced when in conversation with doctoral colleagues from other scientific disciplines (in this case, friends in geography):

> I think there are a lot more things that all of these people I am talking about [friends] have to do during the day that their mind can divorce from a little bit. Whereas I, if I am work working, which is not marking, not you know, I am really concentrating, I can only do a few hours of that a day. So it is different. I don't think they quite get it. (Laura, Interview #1)

In this excerpt, Laura’s last comment pointed to a disciplinary understanding that only comes with an insider status to physics.

On the other side of that frustration, Saïd described dealing with the engineering elements of experimental physics. In my observations, he and Peter spent a great deal of time troubleshooting with their instrument, and on one occasion spent several hours prepping a sample only to have the instrument short circuit when the time came to actually run the experiment. Saïd discussed the his frustration with the engineering-work he had to perform on his instrument: “A lot of engineering, for example, signal processing and things like that is something that I’ve had to quote, unquote, waste a lot of time on recently at the expense of doing ‘real physics.’” (Said, Interview #1). Thus, Saïd made a reference to the kind of activities that Laura previously described, where one is not required to concentrate on solving a problem all day. However, this characterization of real physics as requiring intense thinking narrowly defines what constitutes physics thinking as related only to pen and paper problem solving. As indicated by Saïd, a lot of time is spent problem solving in other ways (on an instrument, for example).

These characteristics of physics, offered by Laura, Saïd, and Carol indicated that, for them, physics requires intense thinking, spatial reasoning, and an ability to understand the way things work. With these characterizations, they positioned physics as an elite subject that is understandable only by those who have the abilities to grasp the fundamentals of the discipline. The effect of this is to cause physics to retain a status as the most fundamental of the scientific disciplines—an attribute of physics Discourses that is more fully discussed in the next section.

In these data we saw that the participants' talk about physics defined the boundaries of physics by what it was not. Peter described biology as "squishy" and by inference, physics as something not squishy; Carol mentioned that biology and chemistry relied on more memorization than physics; Laura discussed the kind of work that she did in relation to others as requiring more thinking. Physics was constructed in ways that defined what was included as physics (a discipline that was fundamental, precise, and requiring understanding). But physics was also in contrast to other disciplines, that is, in terms of what physics was not. In this way, Discourses of physics set the boundaries of what might be considered to be, in Saïd's words, "real physics" in this particular physics community. Not all of the participants in the study, however, constructed physics using boundaries. In some cases, physics was discussed in broader, philosophical terms without reference to other disciplines, as described in the next section.

Expectations versus realities

When discussing what attracted them to the discipline, the participants' expectations of physics invoked images of a romantic, beautiful, and even philosophical discipline. Molly, Alice, and Laura all discussed physics as a quest for what is out there, to acquire knowledge for the sake of knowledge, and to answer the big questions about the universe. Additionally, Sandra and Ruby provided examples of the idea that physics is a foundational discipline, upon which all the other disciplines are constructed. These characterizations of physics were not discussed in relation to other disciplines or subfields however, these participants all do research in theoretical and observational fields. In contrast to these, some students noted that the practices of physics were decidedly less philosophical or romantic than the discipline portrayed. Saïd, a condensed-matter physicist, also imagined physics to be philosophical, and as noted in the above section, described being attracted to the philosophical aspect of "real physics" rather than the engineering of machinery that he found himself doing. Other participants (e.g., Alice and Ruby) also discussed how these romantic characterizations of physics were in contrast to what they actually did in their practice.

Physics as romantic: "It is kind of theological in a way." Notably, participants who described physics as romantic and beautiful were from fields where the kind of science they were doing was regarded as foundational. Pulsar astronomy and field theory (the subjects Alice, Molly, and Laura study) are not subjects that have applicability to technology. This notion of romanticism in physics was connected to the foundational aspect of this science. Molly compared the importance of doing this kind of research to the importance of art: It has no direct applicability, but it is beautiful to imagine.

Participants from the disciplines of astrophysics and theoretical physics discussed being attracted to physics because they regarded it as a science that could solve some of the mysteries of the universe. Alice referred to this quality of physics in a philosophical way:

> I think it is kind of theological in a way, by that I mean, what we do is not religion, there is no direct relation to religion. But I mean a lot of what religion did for people was tell them, where did the world come from? What did, you know, what is it like in those places we can't see? You know those stars that we can see, those points of light, what are they? Why are they arranged the way that they are? Where did the world come from? And that is just the questions that astronomy is trying to answer, so I think that is why it appeals to people so much. (Alice, Interview #1)

Alice's description of physics pointed to the notion that physics, especially astronomy, can answer the most fundamental questions about the universe, and that this is its appeal, both for physicists and the public. Molly also reported this view of her disciplinary subfield as a means for studying fundamental and beautiful questions of the universe. She described this kind of work as a privilege and a quest for beauty:

> **Molly**: I think that [. . .] and this is quite a romantic view of astronomy, actually. I think that basic research is important to do in the same way that art is important. I think that it's important to society to push, to have people who are pushing our humans to the limit, to see what we can do,

> see what we can find out, see what we can produce artistically and scientifically. There's no benefit to society from what I do in terms of creating new drugs or extending someone's life. There's no new technology that's going to come from what I'm doing, no faster computer, even. At least not directly. I think that it's important in sort of a—because it's a beautiful thing to do.
>
> **AG**: Why do you think that society values it?
>
> **Molly**: I like to think for the same reasons, that we like to see [. . .] you know, that there's more to why we're here than just getting up in the morning, going to work, going to bed. We're doing this for a reason, and we like things that are beautiful, and finding things out, and we're curious people. I feel very lucky to be able to be funded by the government to be like, 'we don't have time to all go look for pretty things, we're going to send you off as our designated people to find amazing things that are going to make us all happy to be alive.' (Molly, Interview #2)

Both Alice and Molly suggested that astronomy is an important disciplinary subfield of physics because it seeks to answer fundamental questions about why we are here, questions that border on religion and philosophy. Laura echoed this idea that physics might provide us with answers to help us understand the universe, but added that there is power attached to having this kind of knowledge:

> I think the first thing, that is, why I choose this topic is when we got introduced to quantum mechanics and special relativity in second year, it was a very, it was just a modern physics course and they just gave us a little taste of these things. But the idea that you could take some fundamental principle and follow the mathematical rules of the game and come up with something that was true, but kind of insane from an intuitive point of view, really impressed me. I liked that idea that the universe is weirder than you could make up and that you could have so much power in the abstract realm of equations, so that got me interested. (Laura,

Interview #1)

The association of physics with philosophy, religion or unlocking mysteries of the universe generally was expressed by the participants who were in the astrophysics or theoretical physics fields. These conversations generally occurred in response to questions asked about why it would be important to study the subject the participant was working on.

Concomitant with the Discourse of physics as a precise and definitive science was the parallel Discourse that physics underlies the basic principles that other scientific disciplines are built upon. Sandra directly addressed the foundational nature of physics as a quality critical to the advancement of knowledge, and that was sufficient motivation for spending time and money researching in a field. She connected this to the lack of funding for foundational research in her own country, suggesting an association of elitism with the study of astrophysics. Ruby also made a connection between the foundational nature of physics and elitism. In the following excerpt, Sandra addressed the issue of applicability:

> **Sandra**: The [outcome] of fundamental science is not always applicable to what we do, but a lot of it is [. . .] You never know, even if you are just doing pure science, you never know if you need to alter your technology because you want to look at something that you hadn't looked at before, maybe that technology can be used for something else. You still never know. Most of it probably won't but maybe you will stumble upon something, a new process to detect radio waves from galaxies or something like that. So whatever you do might be used for something else later on.
>
> **AG**: Why do you think it's important to study the universe like that?

> **Sandra**: If you're just doing pure science, there is nothing you will gain from it that will help you to make money. If you really cared about money you'd be in business. You wouldn't be in science. But I think what's a big part of it is just human nature [. . .] You just want to learn about things. (Sandra, Interview #2)

Sandra suggested that one never knows when fundamental research could lead to an important discovery that might have some applicability to advances in technology. However, she acknowledged that her kind of science was not about technology or even money, but rather her motivaton was to learn about things. However, Sandra also was aware that, whether fundamental science is considered important also has to do with issues of socioeconomics. When I asked her about what kinds of influences would encourage youth to pursue scientific careers such as hers, she responded:

> I think your economic background is very important. Coming from a third world country, I mean, a lot of emphasis is placed in science but the truth is the government doesn't have a lot of money to invest in pure research. Even if it is valued that you know astronomy, you're not going to have the opportunities that go into it as a career because, you can't. The government invests money in hospitals and feeding people. I think we live in a specific time where there's a lot of freedom in what you can do. It's been coming for a long time but now people are better off, life expectancy is high, there's all these technological advancements have allowed us to take some time off to do pure science more. (Sandra, Interview #2)

In Chapter 5, Sandra told the story of immigrating to Canada from Central America. In that story, she described coming to Canada as an opportunity that permitted her to study physics. She was quite sure that she would not be able to pursue a career as an astrophysicist had she stayed in Central America. Thus, her view of physics was very much connected to the sense of opportunity and privilege that she had in her ability to study a foundational science at this level, in Canada.

Ruby's discussion about the foundational nature of physics drew a connection between physics and prestige:

> I believe that out of sciences, physics studies the most basic things that other sciences build on, chemistry and biology, and so I think that physics is a prestigious thing to do because you are studying the most basic thing there is. That is the reason why I think it is a prestigious thing to do. Because [. . .] if you choose to study science, in other words, to understand how things work or whatever, or however way you define science. The most basic you can get is physics, and this is why I think, I don't know if the word prestige is right. It is just I think [. . .] I just think that you should be proud of studying the most basic things that can be studied. Now do I think that the average person thinks it is prestigious to go in to physics? I do know what kind of reaction I get when I say I am studying physics. They go, 'you must be so smart'. So they probably think, 'oh, it's prestigious because it is hard' as in difficult. (Ruby, Interview #2)

Ruby regarded the study of basic things to be important, and something to be proud of, but she considered the prestige associated with studying physics to be constructed by others outside of physics. Ruby suggested that the average non-physicist will link the foundational nature of physics to *hardness* or the difficulty of physics. So, Ruby made a claim that the average non-physicist constructs physics as prestigious because it is fundamental, and that fundamentality is linked to hardness, so physics is perceived as difficult and only for "smart" people.

Physics as mundane: "A big disconnect." Some participants in the study expressed frustration with the disconnect between their expectations about romantic notions of physics and the realities of doing physics research. Saïd, Ruby, and Alice all provided evidence that pointed to a disconnect between the abstract subject they study and the means by which they study it. In the case of Saïd and Ruby, this led to some disillusionment about physics research. While I did not find other examples in participant talk, the data presented here identified a tension for some, between the likening of the discipline to philosophy or religion, which can construct a mythologized form of the discipline, and the actual form that research takes on the ground. The motivation to learn about the world, to abstract our understanding of nature to the philosophical realm, was an attractive quality for Saïd when he entered the discipline at the graduate level. However, he described being disappointed by the reality of the research that was conducted in his disciplinary subfield, condensed-matter physics:

> **Saïd**: [In deciding to pursue physics] there was a little bit of, sort of, romantic ideas as well, but it was very limited. It wasn't so much, um, doing physics, but it was more trying to figure out philosophical truths about the world, you know? My last year of high school in France we had these philosophy classes and we had a whole section on philosophy of science and that was my favourite time of the week, when we would do that.
>
> **AG**: Ok. Do you still feel that way about physics?
>
> **Saïd**: Naw, I've been sort of disappointed overall.
>
> **AG**: Yeah? In what?

> **Said**: You spend much less time dealing with the overall big picture ideas than you do with the detailed, sort of, [exhale] I was going to say uninteresting little things, you know?
>
> **AG**: Uh-huh. Like the mundane kind of work.
>
> **Saïd**: Yeah, it wasn't really my idea of physics. That's a big disconnect, I guess. (Said, Interview #1)

Saïd spends a great deal of time in the laboratory troubleshooting his instrument, preparing to scan a sample, or staring at data in the form of images and curves. These are typical activities for an experimental physicist, however, Saïd discussed initially being attracted to the more philosophical qualities of physics. As discussed in Chapter 5, Saïd had great deal of difficulty with his instrument and with generating publishable data. These frustrations provided some context to his disappointment with the kind of work his project entails.

Of the 101 photographs taken by participants in the study, only one photograph actually depicted an image of an object of study. Interestingly, although many of the participants in this study researched celestial objects or subjects pertaining to the universe, or on the nano-level molecules and atoms, only one participant actually presented an image that was outside of the laboratory, or interpersonal activities associated with physics, such as conferences or classes. Alice presented a photograph in her photo-journal of a comet that she and Ruby had photographed from the observatory (see Figure H2). She discussed going up to the observatory and attempting to photograph this comet, and then her disappointment that this kind of thing didn't happen more often during the time she spent at the physics department, "It made me feel kind of, it is a shame that we don't, nothing more happens with that. Like Sandra was the only one who knew how to operate the stuff up there. She is gone" (Alice, Interview #1). In our first interview, I discussed the difficulties of representing physics on camera with Ruby, and we discussed the kinds of photos she was taking versus the romantic ideas she used to have about physics:

> I think for us, in order to take the pictures that you think you might think we would take, we would have to step back from our everyday and everyday things in front of us, and you know, make sure we see the big picture again. Because I spent the day looking at columns and columns of numbers and sometimes I even forget that these numbers are come from a star. And then you know I have to remind myself, look there is this giant sphere somewhere in the universe very far from earth that is rotating, and this is what these numbers mean. They are telling me how fast it is rotating, so you have to step back to see the big picture. Because otherwise we are going to report to you little things like our computer screen. (Ruby, Interview #1)

Here Ruby describes a disconnect between the expectations and realities of physics. In Chapter 5, Ruby suggested that this disparity caused her some disillusionment, the physics that she does in her doctorate is not the same as the physics she grew up fascinated with. She suggested that she has to remind herself of the big picture, and she also suspected that this is the image of physics that I expected to learn about through the photo-journals.

Emerging from the data presented in this section is a disparity between the expectations participants had for physics (revealed in the way participants talk about physics as a "romantic" portrayal of physics or as a discipline that borders on the philosophical or theological), and the reality of the everyday number crunching involved in the actual doing of physics. In this way, physics may be thought of as having a representation problem. A number of the participants in the study, for example, reported to be attracted to physics because of the visual nature of the type of study they would be doing. Molly even referred to being paid to look at beautiful things. However, as Ruby pointed out, it is easy to lose sight of what physicists are actually studying—she had to remind herself that the numbers on the screen actually come from a star, and that is what she is interested in. The contradiction between how physics is thought of and mythologized by participants in the study and how physics is actually done is thus a new finding that emerged from these data.

Chapter Summary

This chapter presented the physics Discourses that emerged from the stories told by the participants. These Discourses of physics were constructed by drawing boundaries between physics and non-physics and then by comparing expectations for physics versus its realities. Physics was constructed relationally by defining it as a fundamental discipline, that it is precise and definitive, and that it requires deeper conceptual understanding than other scientific disciplines. An examination of participant talk about the construction of physics as romantic, philosophical, and foundational revealed a tension between this and the mundaneties of research that is disconnected from these attractive elements of the discipline, yet central to the experience of doing physics.

Chapter 7

Discourses of Physicists

Following from Chapter 6, this chapter provides a continuation of the cross-case thematic analysis (detailed in Chapter 4) of participant interviews, photo-journals, and field notes, to examine the Discourses of physicists emerging from the data. As in Chapter 6, I do not intend to provide characterizations of individual participants nor do I detail the schema and resources that relate to participant talk about physicists. Rather, in this chapter, Discourses of physicists will be identified through thematic coding of the data that looks for examples of talk about what physicists do, who are recognizable physicists, and what skills or behaviours are required to do physics appropriately.

The research question that guided the analysis and presentation of findings in this chapter was:

3). How do physics doctoral students describe what forms of physicist it is possible to be in their local contexts of research teams in a particular physics department?

As in the previous chapter, Discourses of physicists were identified by first locating broad themes in participants' talk about physicists, and then breaking these down into sub-themes. Figure 1 depicts the broad categories that organized the data and findings. Emerging from the thematic analysis were two distinct ways of talking about physicists: Discourses of competence and images of physicists. These are depicted in sections IIa and IIb of Figure 1. These two categories of Discourses emerged through identification of various ways that participants engaged in recognition work (Gee, 2005, p. 88). Here, stories where participants recognized themselves or others as doing physics or being physicists were thematized and coded into images or sub-categories of competence. Discourses of competence identified the different kinds of knowledge and skills required to do physics appropriately, whereas images of physicists were the identification of stereotypical Discourses of performances of physicist and gender.

Again, the term Discourse (with a big D) refers to the combination of language, action, practices, values, beliefs, symbols, objects, tools, and attributes of places that are associated with being a certain kind of person (Gee, 2000). Discourses of physicists regulate appropriate ways of being a physicist, that is, behaviours, ways of communicating and interacting, modes of dress and appearance, and ways of thinking about the discipline. These Discourses define who can be recognized as a physicist.

Discourses of Competence

When participants discussed doing physics and ways of being physicists, it was almost always in relation to some form of competence. Emerging from a broad category of Discourse of competence (see code map, Figure 1 [IIa]), sub-themes of competence have been characterized as Technical Competence, Analytical Competence, and Academic Competence. Each of these forms of competence was derived from the ways participants talked about the skills and habits that they recognized as belonging to good physicists. Generally, these emerged in response to questions about what makes a good physicist, whether they could identify good physicists, or what they would need to do or to be in order to consider themselves recognizable as a good physicist.

Carlone and Johnson (2007) described competence as a feature of scientific identity that can be represented as degrees of achievement measured by grades. However, among doctoral students, grades are not calculated and competence is discussed as highly specialized sets of skills that are sometimes specific to disciplinary subfields and are recognizable through performances (lab work, writing, communication, teaching, calculating, etc.). Therefore, the Discourse of competence describes a stereotype of appropriate ways to do good physics and be a good physicist, and is comprised of various combinations of technical, analytical, and academic competencies.

Excerpts from interview transcripts will be presented here to build the various elements of the Discourse of competence, and the reader will notice that certain voices predominate, and some voices will not figure at all in this part of the analysis. This was either a function of familiarity with a disciplinary subfield (and by extension, the competence that was most associated with that subfield), or a function of the stage of the doctorate in which the participant was. Thus, responses in the interview were very much a function of temporal and disciplinary specificity, where the context of the participants' degree program may have influenced their perceptions of what kinds of competencies were important to becoming a physicist. Where appropriate, I have referred the reader back to Chapter 5 to provide context to participants' responses.

Technical competence. Technical competence arose as a Discourse that emphasized the importance of tinkering, physical skill, and creativity in doing physics. Not surprisingly, the participants who emphasized these skills were experimental physicists, with the exception of Alice and Ruby, who were observationalists. Lily discussed the importance of learning how to fix instruments, but Carol provided a more ambivalent view of this, suggesting that while it is an important part of being a physicist, it is not a desirable activity to engage in. In this section, I will discuss the elements of technical competence that emerged, primarily from interview data with the participants including tinkering, creativity, and physical skills.

Tinkering: "If you really can't fix it, rebuild it". In our interviews, Alice, an astrophysicist, described how she loved working with electronic equipment, building, and taking things apart. She became interested in computer programming as a sidebar to fixing and rebuilding radios—an interest that she shared with her father. She enjoyed amateur-radio building with her father, but found it too expensive to be pursued as a hobby. They had computers at home, so Alice became interested in working with computer programs, specifically creating programs or algorithmic codes. This interest in creating codes satisfied her until she was old enough to purchase her own kits and gadgets that she could tinker with. In a photograph (Figure H3), she showed a work bench and an electronic gadget she was working on in her spare time. Alice explained:

> So, that is, this is sort of a test bench. This is a power supply with a bunch of different voltages, and one of them is variable, and the couple of meters that measure the voltage and the current so you can tell what your circuit

> is drawing. And that is just a bread board, that um, it has just got a bunch of sockets that are connected, some of them are connected with each other without suturing anything. But you can do some interesting things, like I had one where it displayed a message where it scrolled across, a piece of text that scrolled across a screen for example.
>
> **AG:** And so you just do that for fun?
>
> **Alice**: Yeah, yeah, like I said, I am trying to make the hook, trying to connect it to what I am doing because I mean, it is something I wish I actually had more hands-on work but . . .
>
> **AG**: So, when you say that, you maybe wish, like in your, in what you do in astrophysics that you did more?
>
> **Alice**: Yeah, I sort of wish that one day a week I worked down the hall with the CMP [condensed matter physics] guys trying to build a gadget. In a way it makes me feel like I am not a physicist because you know I don't do any of this stuff. I just sit in the lab, typing on a computer. (Alice, Interview #1)

Alice connected being a physicist with building gadgets in a lab. But instead, her daily activities involve writing codes and analyzing X-ray data from large telescopes. While this entails some tinkering around with computer code, it is not the same kind of tinkering that Alice associated with doing real physics, that is, tinkering with actual equipment. As in Chapter 6, Alice drew a connection between doing real physics and working hands-on with an instrument. However, this is contradictory to Saïd's concept of "real physics" (see Chapter 6), which is not about fixing things, but rather about using instruments to make scientific discoveries.

Fixing equipment and knowing how to fix equipment is an essential part of the experimental physicist's job. However, this skill set is not just attributed to experimental physicists. Participants in this study spoke of the importance of knowing how to fix things as an element of technical competence and of being a physicist. Lily's photo-journal depicted the minute details she contends with when working with the scanning tunneling microscope, and she described the importance of an ability to contend with the instrument, and fix it when necessary. In reference to a photograph depicting an instrument she was fixing (see Figure H4), she described having the ability to fix things as particularly important for the experimental physicist:

> **Lily**: The ability to fix things especially, you know. We have a commercial piece of equipment, so it is a little bit easier, but um, building equipment and being able to fix it, you are on your own if it breaks, and you don't know how to fix it, that's it, it's broken. And you are not going to get your degree or your project or whatever done.
>
> **AG**: Really?
>
> **Lily**: Yeah.
>
> **AG**: So what can you do then if it breaks?
>
> **Lily**: If you really can't fix it, rebuild it [laughter]. That is really the only option you have, to fix it, so that is a big part of it. I've been lucky that I haven't had to do any machining for my project but certainly a lot of people are doing that. Yeah, and so I wanted to at least sort of get a bit of that skill because it is important for, you know, at least small-lab science, in house science. [It is important] that you can go to the machine shop and rebuild a part or replace a part or, you know, build a whole instrument in some cases, so designing it and building it, and it is easiest if you can do it yourself. I thought I would enjoy the machine shop, but I really don't, no not that much. It is OK, and I am glad I can do a little bit but anything

> more than drilling a couple of holes or like making something flat is not that exciting for me. I find it a bit frustrating and tedious (Lily, Interview #1).

While Lily described these skills as necessary for her practice, she found that fixing and engineering instruments was not a job that particularly interested her. However, Lily points to the limitations that can arise for students who do not develop these skills; a consequence could potentially be abandoning one's project or even one's degree.

The fix-it element of technical competence was frustrating for Carol. In the following excerpt, Carol discussed her frustration with having to play around with her microscope in order to get her experiment to work. In her description of these troubles, Carol suggested that the frustration she experienced indicated to her that she did not have the disposition to be a physics professor. To illustrate this, she compared her reaction to her problems with the instrument with what she anticipated her boyfriend's reaction might be. Then she also suggested that her supervisor would have dealt with the instrument more patiently than she did:

> **Carol**: Well, I feel like I am a realist and when things break, you know, I am like, yeah that happens. Things break all the time, all the time, get used to it. But him, he'll be like 'oh it is no problem, you just wire this up and it is done.' But, especially because I do low-temperature physics, things break when you cool down. Like, things break a lot. Like, my first, so my master's was two years and the first year I did courses, the second year I had to fix my microscope, and I didn't get results, and I think I really worked on fixing that microscope for eight or nine months and at the end of it, I told Paul [supervisor] that I had to switch projects because I just couldn't take this microscope. But he told me to think about it and wait it out, and in those couple of months, we fixed it and then it worked

> really well, yeah.
>
> **AG**: So you are still working with that microscope?
>
> **Carol**: Yeah and it works really well. But I put a lot of work into it, really a lot and I think that, like I always will tell people and new students that it is very hard, and I think that whereas if you talk to Paul for example, he'll say things are really good and interesting, and he has to do that, to get money, you know get grant money. But I don't feel—I am not like that, so it is hard for me to be that way. (Carol, Interview #1)

Carol identified the kind of attitude that physicists need to portray technical competence. The comparison she made between her own reactions to stressful situations and those of her boyfriend and supervisor indicated that she feels as though they have an easier time adapting to unexpected setbacks than Carol does. Carol seemed to value these behaviours, suggesting that these were more appropriate reactions.

Ruby also referred to hands-on, fix-it work as part and parcel of being a physicist. But most of the time, she explained, she does not recognize herself as a physicist as she is not engaged in this kind of work. However, in one photo she is fixing her toilet, and she showed me the label, "makes me feel like a physicist" (not available in Appendix because Ruby did not permit her photos to be shown publicly).

> **Ruby**: The handle that flushes the toilet, sure. OK, so when you push it down, and then it flushes the toilet, whatever. At my house what happens is it just kept making sound that it keeps dumping water inside and anyhow, somebody had to fix it. Instead of calling somebody, I opened up and looked at what is happening inside, and I don't know, I figured out that the little chain that was there was going around the rubbery thing,

which actually was getting very old, so the two places where it was attached, one of them had been detached, and one of them was a little bit out, and so, anyway I put, I fixed the way you attach the rubbery thing. Um [. . .] and I don't know what I did with the chain, but anyways it worked, but it didn't work for very long. It only worked for two months.

AG: It is probably because you need to replace the rubber thing. But . . .

Ruby: But, I don't know [. . .] probably another person who had opened it to take the time to figure out how it works would have done exactly the same thing that I did. Except I did do it, and I did figure it out. I figured something out. I don't know, even though it is the most simple mechanism in the world, that is a mechanism that I understood something. I am so not practical. I don't know how cars work, I don't know how a plane gets its lift. At least I understood my toilet. (Ruby, Interview #1)

In the excerpt above, Ruby described a number of elements of technical competence. As Lily and Carol did, Ruby mentioned a do-it-yourself element to technical competence. Instead of calling someone else to help her fix her toilet, she described how she opened the tank and figured out what the problem was. Then she fixed it herself. This small achievement made her feel like a physicist. She described herself as "not practical," making a reference to this element of technical competence that she did not recognize in herself, but regarded as an appropriate element of being a physicist.

Creativity versus by-the-book Two participants, Lily and Carol, discussed the creativity, and although both of these women stressed that creativity was an important part of being an experimental physicist, Carol presented a counter-example to this. As a technical competency, creativity was seen by Lily and Carol as a skill that can be honed, but that emerges in opposition to a prescriptive by-the-book way of doing physics that is taught in undergraduate programs, which Carol found to be often necessary. Lily discussed what she sees as a lack of encouragement of creativity in undergraduate programs. Here she described observing this when supervising an undergraduate summer student. In reference to the same previously discussed photograph (see Figure H4) Lily discussed the need for students to develop a creative approach to research:

> **Lily**: It's the hands-on aspect. You end up making things a lot. I think [in the photograph] I was trying to come up with a way to represent creativity. That's so necessary. This is one of the things I have noticed with the summer student—he’s really reluctant to just go ahead and make something, with no reference or anything. Like, to just make something that's the right shape and the right size and that solves the problem.
>
> **AG**: So why do you think that someone would be reluctant to be creative?
>
> **Lily**: I think it has to do with high school and undergrad and in all of your previous science experiences, you have a right answer. And there's a way to do it, and somebody else already knows the way and the answer. Whereas when you're doing research, there isn't a right answer. There might be a thousand different ways to do it; yours might be better than someone else’s or it might not be. Especially when you're starting, it’s a bit hard because you don't know what other people have done, and if there’s some known smart way of doing it, but at some point, you just have to get over that and go ahead and use your ideas and be creative. (Lily, Interview #1)

Lily works on a very large instrument where she has gained expertise through fixing broken parts and optimizing it to fit her experimental needs. She has largely learned how to do this on her own, through trial and error. In Chapter 5, Lily described having a positive high-school experience in physics, but really emphasized the creative influence of her undergraduate professors. In the above passage, she emphasized that doing research is not prescriptive and experiments do not have a right answer like they do in undergraduate labs.

Carol has also spent a great deal of time optimizing her instrument. This largely took precedence over her master’s degree, and her doctorate has benefited from the long hours she spent trying to get her microscope to work properly. However, Carol had a slightly different view of creativity. While she acknowledged that it is beneficial to be creative, in the following excerpt she also suggested that a physicist can achieve technical competence by doing things by the book:

> [I think] being able to think of different ways to do your experiment or being creative is an asset, but I don't think that everybody in physics is creative, and I don't think that you need to be to be a good physicist. Yeah, it helps a lot but uh, I think that you could be not very creative because you could always read. [If textbooks say] you could test this by doing this, this, and this experiment, then you can say, ‘oh OK well I know how to do that.’ So you don’t need to be creative and come up with new ideas for how to do experiments. But, if an idea is presented to you and somewhere in your past you learned how to do something, you should be able to say ‘OK, I know how to do this experiment. You do this, this, and this.’ And uh, I don't know, a lot of people get results out of mistakes or risks as well. I think that is common across science, all science. So there is creativity, risks, and a couple of different things that come in to how they all interplay to make you good at what you do, I guess. (Carol, Interview #1)

The context of this excerpt was a discussion about what it takes to be a good physicist. Carol identified creativity as a component of technical competence, but did not regard it as compulsory as Lily did. Rather, Carol suggested that creativity, a willingness to take risks, and background knowledge of a phenomenon will make a physicist good at what they do. Additionally, Carol suggested that there are different ways to be a physicist, by being creative or having by-the-book technical competence. Carol described a multiplicity to the competencies that physicists are required to develop, suggesting that physicists rely on varying degrees of these related competencies at different times.

Physical skills. An element of technical competence that emerged from my conversation with physicists is the embodied ability to fix and manipulate objects. Only experimental physicists discussed this element of technical competence, likely because they were the only participants in the study who actually manipulated instruments. Physical skill entailed not just knowing how an instrument or object worked, but actually having the physical ability to fix or manipulate it. Saïd and Lily discussed this aspect of technical competence, and it was also something I had written about in my field notes after having spent an afternoon with Saïd and Peter in the scanning tunneling microscope (STM) lab:

> The microscope itself is large and occupies about a third of the space available in the lab. Moving the sample from the ante-chamber to the vacuum chamber requires the manipulation of external levers that are extremely sensitive yet difficult to move as a result of the extreme pressure difference. Moving the lever one millimetre requires the input of an enormous amount of strength and dexterity. It also seemed stressful. Throughout the procedure, Peter encouraged me to move in closely to peer into the chambers to locate the sample and the tips. This required us to be in quite close proximity. As Peter moved the sample around inside the vacuum chamber, I could see the tension in his arm and face mounted. He

> would move the sample, then take a break, check a few things on the monitor, take some photographs of the tip, and get back to manipulating it. While he was working, I was silent, trying not to disturb his concentration. Saïd stayed silent also. In each break, I can recall myself saying 'That looks like it takes a lot of strength,' or 'How difficult is that?' as Peter peeled off layers of clothing. It looked like a procedure that I was sure I would not physically be able to do. (Field notes, December 12, 2007)

This episode recorded in field notes prompted further exploration of this topic in interviews. In interviews with experimental physicists, I asked about the physical requirements for this kind of work, and whether the strength required to manipulate an object in an ultra-high vacuum would be a limiting factor for some people. Lily addressed this question:

> Yeah. Exactly. So we've determined that for this instrument, there are always three people who work on the instrument because it requires just that much care. There needs to be that many people around to make sure that somebody can always do something. So we always need one person with small hands. The flanges are maximum this big [motions with hands] and you might have to stick your hand right in. If you have big hands, you can't physically do it. And the screws are like 1millimeter screws and stuff like that so, and we need someone who is big and strong because it's all stainless steel, and if we ever have to take a piece off the vacuum, it's really heavy, I can't do it, I physically can't. (Lily, Interview #1)

However, Lily has developed the skill to work with very small objects, and has become an expert on this in her research group. So, the physical skill required for the instrumentation is not just strength, there is also a requirement to deal with very small objects and to move them in a very precise manner:

> It's kind of an art and a skill that you have to learn; it's not something that you can read out of a book and just like be able to do it. Everything is

> small, it's really tiny, so you have to develop the skill to not be all shaky and um, and just sort of, we've now passed down through several people. There are some things that we just figured out through trial and error and some things that are just kind of superstitious, we're not sure at all, but we seem to get better samples if we just, if we do this thing as opposed to other things. (Lily, Interview #1)

The physical skill that Lily discussed here is not something one can read in a book, as Carol mentioned previously, or something that can be taught in a class. It is something that is learned on the job and is imbued with the laboratory folk tales of what works and what does not work that are learned through trial and error and are passed down from generation to generation. Lily referred to these folk tales as superstition indicating that in some cases it is unclear why certain procedures work, but they use them anyway. Saïd agreed that this part of technical competence can be learned, but that he initially was unsure if he would be able to do it:

> I think it's something you can develop. I ah [. . .] I was always someone very clumsy, when I realized I was going to have to work with some pretty sensitive things at the manual level, I was wondering if I would be able to do it, you know? (Saïd, Interview #1)

Previously in this section, Carol lamented not knowing the trouble-shooting and refurbishing that would be required to get her instrument into working order. Saïd's comment also indicated some level of unawareness about the kind of manual work that would be required of him when entering into his doctoral program. Additionally, he points out that the physical skill discussed in this section is not a natural ability, but rather one that can be learned on the job.

As has been demonstrated throughout this section, learning technical competence in physics comes from hands-on experience and a sort of do-it-yourself approach to experimentation that is not evident to students who enter the field from undergraduate programs. But technical competence also entails having an ability to tinker or to be creative with equipment, and to have the patience and desire to work with repairing or troubleshooting difficulties with uncooperative instruments. Creativity was found to be an important element of technical competence, but this was contrasted with a by-the-book approach to doing physics that was regarded as equally necessary. All of these elements pointed to a range of skills that are important to being recognized as a technically competent physicist. Based on the data presented here, participants seemingly used these elements interchangeably in their practices.

Analytical competence. The component of the physicist Discourse that identifies analytical competence as a necessary characteristic for physicists is primarily centered around logic. Logical reasoning and identifying logically coherent arguments are discussed as being important qualities associated with being a physicist. In contrast to the emphasis on technical competence espoused by the experimental physicists in the previous section, analytical competence emerged in discussions with theoretical physicists, or in conversation about theoretical physics. In Figure 1, the code map depicts two sub-themes emerging from the parent-code of analytical competence (section IIa). Logical reasoning emerged from interview data as the predominant element that participants' discussed as important to analytical competence. Associated with logical reasoning was a sense that analytical competence was associated with intellectual elitism. Of the different types of competence presented here, analytical competence emerged as a Discourse that most resembled elements of the Discourses of physics. The associations with intellectual elitism particularly resonated with how participants described “real physics,” and the emphasis they placed on understanding.

In the following sections, examples from Laura, Victor, and Saïd constructed the Discourse of analytical competence based on logical reasoning. Laura and Victor are both theoretical physicists, and Saïd, while an experimentalist, previously emphasized the importance of philosophy to physics, and the basis of his interest in physics. Additionally, Lily constructed analytical competence as a sign of being a “smart super physicist,” demonstrating the high intellectual value that this Discourse of competence carries.

Logical reasoning. In the stereotypical descriptions of the more analytically-oriented physics student, the focus is on the application of logic to situations ranging from mathematical problem solving, to troubleshooting with equipment, to dealing with everyday personal problems. Laura espoused logic as an important attribute of analytic competence, and discussed how this is a necessity for physicists:

> Well, you should have learned them [logical reasoning skills] with any mathematical training you had had beforehand, I would say. So it is um, you know, being able to see whether an idea is logically coherent or not, being able to put your ideas in a logical sequence, um being able to work from broader principles [. . .]. When it came to an exam I tried to be as prepared as possible, whereas [other] people would wing it a little bit more. Um, so one of the things I’ve seen when I teach, when I have

> taught maths and physics, is that some people want, like, a recipe for each type of problem and that is a mistake. I mean you need to have realized that that is not the way to attack problems. (Laura, Interview #1)

Laura discussed logical reasoning as a skill that one should bring into the practice of doctoral physics research. She suggested that this skill should be learned prior to beginning physics research, but that it is a skill to be honed rather than a set of rules to be learned. Her claim that logical reasoning does not come from a recipe is in line with aspects of the Discourses of physics that position physics as a science to be understood, rather than memorized. Also, this is in contrast to the aspect of technical competence that can be achieved by following instructions.

Saïd also identified logical thinking as an essential element of analytical competence. However, he extended this beyond physics and suggested that logic is an important skill for any kind of science. In response to a question about what kinds of skills he thought one needed to be a physicist, Saïd pointed to logic as the most fundamental quality:

> Just basic logic, I guess is an important aspect, probably for anything that's scientific. When you're working in a field, basic solving skills, but the key part of it I guess is really just working with logic. When you try to solve a problem, you come up with hypotheses and then you try to figure out if the hypotheses are, you know, confirmed or not confirmed. And we do it by being logical and by being thorough are probably the main qualities, and being patient and persistent I think are probably the qualities you'd need to succeed. (Saïd, Interview #1)

However, Saïd's description of logic was less connected to mathematics and hard sciences, and rather, was connected to his ideas about scientific method. Laura's description of logic adhered directly to the notion that deductive arguments can be evaluated mathematically, whereas Saïd's notion of logic referred more to the ordering of processes. Here we see a theoretical and experimental division on the subject, yet both theoretician and experimentalist described this logical, systematic component of analytical competence to be essential to being a physicist.

Victor discussed the tendency among physicists to try to apply physics reasoning to non-science situations. He discussed logical reasoning as a typically physicist tendency, but argued that reductionist thinking risks losing nuance and complexity:

> I think there's a tendency to apply logical arguments to everything. I think the people in physics have a typical—I try not to be like this—but they have a way of trying to understand causation. If there's something that's not understood in the sociological context they'd like to, I think physicists often have a desire to chalk that thing up to some very simple causes when frequently the situation can be much more complex. I think if they see something they'd like to have a very clear and simple explanation for it—whether that thing deserves it, whether it's a simple explanation or not. I think in a way you can define physics as being a set of problems which have clear and simple explanations. This guy in jail, how did he get to jail? That's a complicated question that you can't answer that in physics, so a physicist chooses not to try to answer that question because that's sociology; and the way atoms behave, that's physics. (Victor, Interview #1)

Victor's description of physicists' desires to reduce everything, even sociological questions, to clear and simple explanations was in line with his construction of the

Discourse of physics as precise and enabling one to make true or false statements about phenomena. Interestingly, Victor himself positioned himself outside of this tendency, suggesting that he tries not to do this, and rather attributes this behaviour to other physicists. This indicated that Victor's schema about appropriate behaviours for physicists is, at least in part, a stereotype that he holds about physicists. Like Laura, Victor suggested that this connection between the Discourses of physics and this aspect of analytical competence manifests as a tendency among physicists to approach all aspects of their lives using logical reasoning.

Lily suggested that the kind of research skills particular to analytical competence (e.g., coding and programming) are necessary for physicists, but that they are competencies that are more developed by theorists than experimentalists. In her photo-journal, Lily valorized these analytical skills, and suggested that when she does accomplish this kind of work, she feels like a smart super-physicist (see Figure H5 for photo):

> **AG**: Ok [reading from photo-journal] right, so this is a picture of your desktop and you've got like a graph and some code and stuff and you said [in your journal]: 'as much as I hate it, programming is an essential part of physics, whether experimental or theoretical, and because of that when I get it to work I feel like a really smart super-physicist.' Can you explain that?
>
> **Lily**: I would find it really, really mundane to do it every day so I am glad that it is not an everyday thing. But I guess the really smart super-physicist thing comes from the feeling that you are just beating your head against the wall. And for me it is not something I really enjoy. The programming part, like the experiments, I can beat my head against the

> wall for months and I won't care because I enjoy doing it anyway. [. . .] Whereas this, so when it works, I feel like 'yeah, I figured it out'.
>
> **AG**: But this is something that a theorist would be doing constantly, right?
>
> **Lily**: Yeah, and I feel like, I think part of the reason I really wouldn't like theoretical physics is that you never have anything to blame but yourself. It is your own brain that is failing you, not some piece of equipment, or something else. You have to figure out how to make something work. Sometimes it is just nice to say that the equipment is being stupid today, it is broken, or whatever, it is not me. (Lily, Interview #1)

While both Lily and Laura agreed that analytical skills are necessary components to physics, they both claimed to enjoy opposite ends of the technical-analytical dualism. Whereas Laura found working with an instrument to be irritating, Lily found the coding that theoreticians do to be mundane. However, Lily also afforded this practice a great deal of prestige, calling herself a smart super-physicist when she completes these calculations.

Academic competence. While the technical and analytical competencies that are often associated with physics were discussed by many of the participants in the study as necessary elements of the Discourses of physicists, some competencies emerged as important that were not directly related to physics. Many participants talked about being a good physicist in ways that were aligned with the expectations of academia, in general. The Discourse of academic competence emphasized skills like communication including teaching and writing, and competitiveness emerged as elements of academic competence—a specific skill set generally associated with physicists in the academy. In the following sections, I provide examples from Carol who constructed communication as an important skill to physicists, but did not regard herself proficient at it. Molly and David discussed argumentation and Sandra connected communication with teaching. Sandra and Alice discussed the prevalence of competition in their disciplinary subfield, and the importance of developing a skill to contend with that. It is notable that those who discussed academic competence were largely astrophysicists. This disciplinary subfield tends to be the most social and the most competitive of the three.

Communication. From the discussions I had with participants, there emerged skill sets associated with communication that went beyond the ability to motivate and engage interlocutors and audiences in physics. Communication for a physicist also entailed understanding and using physics and other jargon appropriate to the audiences and knowing the argumentation discourses for different physics genres.

Carol discussed this at length, and described what she thought was important about communication, and moreover, her difficulties with the conventions of communication in physics. Carol found that learning the technical language of physics—the jargon, as she referred to it—was something that she struggled with, and it interfered with her ability to interact with colleagues, especially at conferences. She saw learning the language of physics as important to gaining recognition from the physicist community:

> I think that you should [learn the jargon] if you want to be seen as really good at what you do. If you want to be an experimental physicist, I think you should really try hard to make sure you know all of those words. At least the ones that are relevant to your own research that is, so I am trying

> all the time to learn all of these words. I do think it is important. It is just something that I find difficult. (Carol, Interview #2)

Carol told stories about being at conferences and finding it intimidating to talk with people who had questions about her poster. She generally deferred questions to a co-author, or described her results in what she called “laymen’s terms” (see Chapter 5).

Molly noted communication as being the most important part about being a physicist, and cited communication as a distinction between the physics that students do in undergraduate programs and in graduate programs. Showing photographs of collaborative environments like the astro-tea and the neturon star coffee, Molly suggested that these are environments were doctoral students learn how to communicate about physics (see Figure H6):

> It’s definitely where you learn how to make arguments about stuff. I don’t know if it’s where you learn what’s good science and what’s bad science, maybe a bit, partly. I think you get a little more of that just from reading a ton of papers and getting a sense for it. Definitely learning how to communicate about physics, which is super, super important and not something that’s a part of the undergrad at all. There are no communication skills [taught in undergraduate programs]. I gave one talk as part of my undergrad and that was part of my honours thesis. [. . .] A lot of people in this department are super, super shy and don’t hang out with a lot of people, so they don’t even talk to a lot of friends in big groups. There are also a lot of people for which English is not their first language so for them too it’s really important to get practice, it’s that much harder for them. So, yes, there are a lot of pictures of this, it is what I look at everyday but certainly it’s not the whole story. (Molly, Interview #1)

As Molly indicated, there are a number of international students in the physics department. I had a difficult time recruiting any to the study, largely because of language difficulties. Molly suggested that this poses a barrier to many students who wish to establish themselves in the physics community through practices that gain recognition like presentations at conferences. Molly's pulsar group schedules weekly neutron-star coffees to bring together students to discuss papers and practice developing critical-analysis skills. The astrophysics subfield also holds weekly astro-teas to give students a chance to present their work or discuss interesting developments in their field. Molly regarded these as crucial learning environments for doctoral students who may not have received this kind of training during their undergraduate.

Some research groups in the physics department work more collaboratively than others. In my fieldwork, I attended a total of 12 collaborative meetings and eight seminars (see Table 2). In all of these meetings, students and supervisors shared their work and worked through problems and questions together. However, in my observations at the astro-teas and the neutron-star coffees, those students who were second-language speakers tended to stay relatively quiet.

David and I discussed the use of jargon in the astrophysics meetings and in particular, some terms that I was having difficulty following. David brought up his language of origin and suggested that coming to do graduate studies in English was a particular challenge:

> Oh yeah, it's crazy. It takes a long time and especially for me because I'm French and I was coming to grad school in English and it was the first

> time I was in an English environment, so speaking for me was very stressful in the beginning. I wasn't so bad at understanding, but there were the accents. (David, Interview #1)

Thus, the group meetings provided an environment for new students, and especially those whose primary language was not English, to learn the communication skills that academic physics demands. Later on in the interview, David described helping newcomers to the group by explaining difficult concepts or jargon. In addition to learning persuasive talk in group meetings, David suggested that persuasion in writing is an important component of academic competence that physicists need to learn. He regarded his supervisor, Veronica, as a mentor who demands high quality work and also demonstrates integrity and rigour, two characteristics that are important in science:

> Whenever we submit something, or even an abstract, if it's been through her, you can be sure that it's going to be a really, really high level. Maybe some people may find it annoying but I'm fine with that. If you send her your paper or your abstract, it's going to come back black, ink all over the page. You have to redo a lot of work. The first paper I wrote took me a year and basically I had to write it over and over. [. . .] If there's one thing I want to get with me when I step out of this research group is really the integrity and rigour that she shows because I think that's really important in science. (David, Interview #1)

David was just moving into the writing stage of his dissertation work, and had also just completed a multi-author article for submission to the journal *Science* on which he was the first author. In this article, he challenged a well-known theory regarding pulsar behaviour. This provided some context for the emphasis that David placed on academic writing in physics. While discussing what constituted doing good physics in his mind, David rarely talked about developing code or troubleshooting software. His emphasis was squarely on writing and rigour in conference papers and articles. This is also an aspect of physics that David claimed to have learned almost entirely during his doctoral training. This is in agreement with Molly's suggestion that critical reading and writing skills are developed in graduate school, and are crucial to being recognized as a physicist in this community.

Sandra connected communication skills with teaching—a role of the academic physicist that she values a great deal. She also regarded communication as important to academics who wish to gain recognition for their research—without communication skills, one would not be able to convey the importance of one's work:

> I think they have to be good communicators because if you have to teach, teaching is a big part [of being an academic]. [Also] the way you keep going is by getting grants from the government or from the university, or wherever they come from. And because physics is not like medicine, it's not like engineering, you have to make an even stronger case than you would in other areas. So you have to be a really good communicator and be able to explain to people why even though this is just pure science, why it's important. I think someone who is a good communicator [. . .] it's very important to have. (Sandra, Interview #2)

Sandra connected back to her view of physics as foundational, and suggested that its lack of applicability often renders it under-funded. She suggested that communication is a necessary component of academic competence for physicists because it requires one to be persuasive for the purpose of obtaining symbolic and economic recognition in the form of grants and publications; and is an important element of teaching, which allows for the reproduction of knowledge.

Competition. Competition emerged as a theme both in my observations and in the interview transcripts. Laura discussed competition for post-doctoral fellowships in string theory, and Saïd discussed the competitive hierarchical structure of condensed-matter physics, but competition emerged most strongly among participants from astrophysics.

Students in astrophysics saw competition as an integral (although conflicting) element of academic competence in astrophysics. To illustrate the integral role of competition in astrophysics research, I have adapted the following story from field notes that I took on two separate occasions:

> Molly explained to me that there are a limited number of telescopes available to research groups and there are limited times that you can book the telescopes to collect data. In order to get observation time on a telescope, a researcher or research group needs to submit a proposal indicating the evidence that they have that there may be a source (i.e., a pulsar, magnetar) that they would be able to collect data from. However, revealing evidence that there is a source is a very tricky game. Other research groups may have similar forms of evidence, or may be surveying the same portion of the sky, and research groups don't want to reveal too much information. At a research group meeting, Veronica told a story about a research group at Princeton where the researchers had rearranged their office so that the computers were turned away from the door. It was a strange arrangement because it meant that all of the researchers would sit facing the door. However, the benefit of this was that it would prevent a passerby from reading the computer screen of one of the researchers and potentially gleaning information about a source. This story was told to the group upon hearing news that a colleague at another university had left a printout of a proposal for observation time at the photocopier and it had

> been picked up by a competing research group. Everyone at the group meeting was perturbed and upset that a potential crack at spotting a source might be compromised. (Adapted from field notes, April 12, 2007, & November 29, 2007)

Competition in astrophysics is the name of the game. All of the participants from astrophysics expressed some discomfort with the level of competition they engaged in, but some, like Sandra just accepted it and argued that one needed to be a specific kind of person to participate in that field:

> **Sandra:** If you're not very confident then I think it can be too much pressure on you. It depends on what group you're in and what supervisor you have, but if you don't have a lot of confidence and you have a supervisor that's pressuring you all the time to get results out and to do it as fast as you can, then I think it would turn people off from the field. And I have seen people that that's happened to them. They can't take the stress. [. . .] I guess it does take a specific kind of people, where you can work in stressful situations and where, if you need to do something in 12 hours, then you will stay there for as long as you can to finish it on time. So it does take a specific kind of person to do that. It's not for everybody.
>
> **AG**: Why do you think the field has evolved to be like that?
>
> **Sandra**: I guess because whoever would do the big discoveries first is the one who gets the money, and the one who gets the recognition, and the one who gets the papers published, and because the way you communicate your results is by publishing them and by announcing them at conferences and things like that. [. . .] So I guess the people who keep their jobs in this field are the people who are aggressive and who do the discoveries first. (Sandra, Interview #2)

Along with being competitive, Sandra suggested that physicists need confidence to compete in the field. The goal in astrophysics is to "do a big discovery" and then to quickly publish those results before another research group writes about the source you are observing. Securing an observation site is competitive, and then publishing data from that site is quick. All of this is done at such a furious pace for the purpose of recognition.

Sandra referred to being aggressive and fast as skills that astrophysicists need to acquire in order to be recognized as having academic competence in the field, or to be regarded as good researchers who make discoveries. However, Alice lamented this requirement for astrophysicists and wished that research did not have to be done so quickly. She argued that the speed at which research is done might render work sloppy:

> I want to be able to take my time and get it right. Um, I don't like rushing work. I want to do it the right way, um, and I mean, I find that sort of speaking more generally when people get really competitive about things, they tend to get less smart. (Alice, Interview #2)

However, while she acknowledged that competition is undesirable in some respects, Alice regarded it as an essential part of academic competence, particularly for astrophysics. She discussed recognition as the "credit in which academics are paid" indicating that publication is paramount and ownership of sources (e.g., of various forms of light in the night sky, indicating the presence of a celestial body such as a pulsar) to be the driving force behind research in astrophysics:

> That, I mean really the credit in which academics are paid is publication and authorship if you want to do a project where you survey the sky and find sources. [. . .] So, the convention is that if you find some strange object in the survey, like, if you're the one who processes it and looks at

> the candidate [object] and sees it, then it is your object. At least in the short term, you know if you find a pulsar circling a black hole, that will be, you would call it the holy grail of pulsar astronomy. If you find that, I mean everybody else in the group would want to be on the paper, it is really yours. You get to do the analysis, you get to do the study, you get to follow it up. (Alice, Interview #2)

Despite Alice's misgivings about competition, she acknowledged that this is how one gains notoriety in astrophysics. Secrecy, working quickly, and publishing data on sources is how astrophysicists claim their territory in the night sky and how they make a name for themselves in the field. While that culture of competitiveness may be undesirable for some students, it is regarded as a necessary part of the discipline and a skill that must be honed in order to gain recognition in the field.

Section summary. This section detailed how expectations and norms around competence are recognized as features of appropriate ways of doing physics and thus contribute to the Discourses of physicist that structure participation in this context. Three forms of competence were identified in this section:

- Technical competence entailed having an aptitude for fixing instruments or understanding the physics behind how things work; demonstrating creativity in problem solving; and having the physical skill to manipulate instruments.
- Analytical competence involved demonstrating logical reasoning solving physics problems, a skill which was most directly associated with theoretical physics. This particular competence was valorized by students

who regarded solving problems and analyzing code as challenging work belonging in the domain of the intellectual elite in physics.

- Academic competence was seen as necessary for physicists and was recognizable through good communication skills including written and spoken communication, teaching, and the ability to engage with other physicists using the sanctioned jargon of the discipline. This form of competence also entailed having an understanding of the competitive nature of the discipline, particularly in the subfield of astrophysics, and being able to participate in that competition.

Forms of competence that are represented in the Discourses of physicist provide subject positions that may be offered to students entering physics or a disciplinary subfield of physics. As students try to take up or negotiate these positions, their bids for recognition as physicist, astrophysicist, academic, or author are successful to varying degrees. For example, skills that are required to be recognized as a competent physicist may delimit the positions that are available to students by restricting recognition to only those who have those skills or the resources that permit learning these skills. Lily discussed the ways that high school and undergraduate physics programs may stifle creativity among young people entering the field, resulting in the loss of this potential resource. Similarly, the physical skill and sometimes strength required to manipulate instruments in the lab may interfere with students learning to use this kind of equipment and being recognized as competent in doing so. In this way, the requirements for recognition outlined in this section may limit the ways in which people can be recognized as appropriately doing physics.

While technical, analytical, and academic competence were espoused by most participants regardless of disciplinary subfield, often these competencies appeared to be more salient in different subfields. For example, technical competence corresponded with the skills demanded of students in experimental physics, whereas the analytical competencies appeared to correspond more closely with the requirements for theoretical physics. Additionally, the competencies that participants regarded as relevant to being recognized as good physicists often related strongly to the temporal context of our conversations. For example, Sandra and David discussed the importance of academic writing and competition. Both were in the end-phases of their doctorates, and were focused on writing dissertations or articles for publication. Whereas Lily focused closely on creativity and technical ability, important elements of competence to her as she was finishing up her data collection for her dissertation. These differences spoke to the heterogeneity of practices within the discipline as a whole and as experienced within a particular locality, thus emphasizing the contextual nuances that must be considered when analyzing interview data.

Discourses of Images of Physicists

Emerging from the thematic coding of participant data were Discourses that I initially themed *images of physicists*. Broadly, these were stories about how physicists behaved, how they looked, and what kinds of gender performances were appropriate for physicists. The code map in Figure 1 depicts two broad Discourses that emerged from stories about images of physicists: the stereotypical physicist and gender neutrality (Section IIb). The Discourse for the stereotypical form for physicist primarily emerged in terms of appearance: always male, sometimes disheveled, and often wearing the physics uniform (which is dependent on disciplinary contexts). However, also emerging from participant talk about images of physics was the Discourse of gender-neutrality: the notion that participants espouse that performances of gender in the physics department are always neutral or androgynous. Counter-examples for the Discourse of the stereotypical physicist and gender neutrality were also identified in the data. These are discussed in further detail in Chapters 8 and 9.

Discourse of stereotypical physicists. Based on my observations at Eastern University, women graduate students in physics tended to dress very casually in jeans and t-shirts, many had long hair, but often wore it back in ponytails or off their faces. Generally, women physicists rarely wore make-up. The men physicists at Eastern wore similar attire: t-shirts and jeans were de rigeur throughout the department. While I observed that men and women in physics tended to dress similarly, these observations were in stark contrast to the Discourse of the stereotypical physicist that many participants in this study described.

I have selected examples from a cross-section of participants to show that this Discourse is pervasive across disciplinary subfields and genders, while also noting some variation between subfields. Laura, Lily, Peter, Victor, and David all described the typical physicist as awkward, sartorially-challenged, and male.

Laura offered this description of what physicists look like:

> I would venture that theoretical physicists are likely to be thinner than the general population, that hunched shoulders are more prevalent among theoretical physicists than in a random sample of people, and that they are more likely to wear glasses. They are also more likely to be male. These may all hold for most of academia, but nothing much more can be said. I can often recognize a physicist, for example, when arriving at an airport for a conference or summer school, but maybe that is just because people who aren't sure where they're going are conspicuous. (Laura, Journal Entry #1)

This image of the physicist as a recognizable person even in non-physics contexts was a recurrent theme that emerged in several interviews, with both men and women participants. The descriptions of physicists tended to place a considerable emphasis on the style of dress, which was directly connected to social skills. For example, Lily described a situation where physicists were recognizable to her in public spaces, because of their dress, but also by the way they held themselves:

> **Lily**: I don't think it is deliberate, I don't think it is something that people think about, like, but, just because it is mostly is male dominated and usually not the most social group of people. A lot of times it is people who have been very intelligent through their schooling, maybe geeks or whatever else growing up and maybe they are not that comfortable in the social situation so it's more, yeah sometimes more awkward I guess, yeah mostly male, mostly wearing striped polo shirts for some reason I can't pinpoint.
>
> **AG**: Striped polo shirts?
>
> **Lily**: Yeah, I don't know. Like we were sitting at this conference that I went to in September, with these two new master's students that went and my husband came as well, cause we are all in the same group, and we

> were sitting at a cafe having breakfast before going to the conference and we were identifying physicists as they walked by going and then we saw them there. It was really surprising.
>
> **AG**: And so you could just tell? This was at a hotel?
>
> **Lily**: No, it was just on the street, just walking by this cafe, you could just sort of tell?
>
> **AG**: So how could you tell?
>
> **Lily**: There is a certain way of holding yourself and mostly with like a little backpack and a little bit of awkwardness and physicists aren't usually stylish so you can kind of make a guess there as well. (Lily, Interview #2)

Lily identified that the physicists they located were all men, and then went on to discuss the uniform of the striped polo shirts. Lily picked up here on all of the usual physicist stereotypes: male, highly-intelligent geeks that are socially awkward and dress in a uniform fashion. She claimed to be able to recognize this typology easily, but did not situate herself in that category, a strategy that will be discussed in Chapter 8 on positioning.

Lily was not the only participant to have a story about physicists at a conference. Peter, too, described seeing physicists in public who were immediately recognizable. He described this cultural form for physicist as a clichéd physicist:

> In the city you can see around this convention centre where it was, you can easily tell who was attending the conference [. . .] Yeah, it's like, it's very cliché, you see so many people who either forgot their badge or who look like, kind of like these physics geeks. With everyone it's always the same thing, with the people you go out with, you always want to pretend not to belong to these geeky people. Because it's like, you don't want to

> be a typical geeky guy, sitting in a windowless room [laughter] [. . .] They have this over-precise haircut, or the t-shirt put in the pants and then something, like at least one awkward thing, doing one awkward thing. (Peter, Interview #1)

Here, the physicist is not just someone who dresses and looks a particular way, but also someone who behaves in an awkward way. Here, physicists who perform stereotypical forms of physicists may be thought of as doing a Discourse in recognizable ways to physicists, both in the community and outside of the community.

In the following excerpt, Victor suggested that the physicist image is even recognizable in foreign contexts. His description of physicists here included a cultural image (looking French) but yet looking like a physicist remains a pervasive feature:

> **Victor**: There's one instance that comes to mind that I can tell you about which is: I was in France one time and I had a friend who said that he wanted to go to a bar with me. He said 'why don't you come and meet some of the people I work with and we'll go and have a beer.' So this is in Paris and I knew that I'd be going to a bar with my friend who is a physics researcher and some other people he works within a Paris laboratory—Paris researchers. I was late, this section of the metro was broken so I had to take some other metro lines and I had to figure out where I was going, in a part of Paris that I didn't know very well. I was feeling bad cause I was a half-hour late and I came out of the metro stairs, up to street level and here's these guys, they were looking down and I said, 'oh, these guys are in physics.' First of all, they were looking very French but despite that I could immediately recognize those people as physicists. They weren't my friend, because my friend was waiting at the other exit of the metro station. These guys, it was clear and I just went up

> to them and introduced myself. I said, 'Hi, I'm Guillaume's friend. Are you guys going to have beer?' And I knew right away.
>
> **AG**: How did you know?
>
> **Victor**: I don't know. It's just a feeling. (Victor, Interview #1)

Victor's interview excerpt indicated that there is an element to the physicist stereotypical form that is implicitly recognizable in ways that other physicists like Victor do not even notice. He claimed not to know how he recognized those physicists in the metro, which speaks to the internalization of this typology of physicist. I asked Victor why he thought physicists have adopted this look, and what the uniform signifies. His response spoke to the disciplining effects of the physics look:

> OK, Einstein had crazy hair because he was so busy thinking about all these problems that he didn't spend any time worrying about his personal upkeep or his day-to-day life because he was busy. I'd say that stereotype is false in some ways. I don't know. I don't know if there's some kind of perceived expectation to be fulfilled. You shouldn't be spending any time on anything but research. Uh, that's a problem. I'm not sure how much that really exists, it just depends on the individual. (Victor, Interview #1)

Victor was not the only participant to express this kind of manifestation of expectations for physicists to be working hard and neglecting their own physical appearance. In her journal, Laura referred to the more complicated relationship that expressions of femininity has with physics:

> On days when I am busy with physics, in the middle of a project or rushing to meet a deadline, I am very likely to leave the house without putting a piece of jewelry or any makeup on, even without combing my hair, because work is more important. I am likely to have dark shadows

> under my eyes. I know a girl who dresses in skirts and heels when at summer schools, but told me she never dresses up around her supervisor, so that he will think she is always working. Hard-working theoretical physicists who get wrapped up in their work often look absent-minded because they don't pay much attention to their appearance—they would never think of a pocket protector (seriously, where would you even buy one?) but are often seen with stains on their clothes or unseen-to tears. I've seen taped together sandals, jeans, and bags, and I've personally worn taped-up glasses. Theoretical physicists are also often covered in chalk. (Laura, Photo-journal, p.3)

Laura made a connection between physical appearance and being recognized as a hard-working theoretical physicist. In this way, if one is to be regarded as a hard-working physicist, one should not pay attention to one's appearance. The Discourse of the focused, intellectual theoretical physicist (related to the Discourse of analytical competence, and the Discourse of physics as requiring concentration and understanding) regulates the amount of time one can invest in their appearance and suggests that excessive care over how one dresses indicates a lack of commitment to their study.

Laura elaborated on this in an interview by describing an experience recounted to her by a female friend in theoretical physics:

> **Laura**: She was my roommate at a summer school and she definitely dressed up the whole duration of the summer school and talked a lot about boys. And then, and told me that when she is at home she just ties her hair back and doesn't wear makeup.
>
> **AG**: Does she do that, do you think to project an image or because she really doesn't have time?
>
> **Laura**: Oh, no, no, she definitely worries what her supervisor thinks of

her.

AG: So that image of the physicist being somewhat disheveled because they don't have time to take care of themselves is something that she was careful to project when she is around her supervisor?

Laura: Well, I think it makes [. . .] yeah. I mean it also does stand to reason that if you are spending half an hour on your hair in the morning, you are not rushing to get to work. Um [. . .] but she was consciously projecting that image. (Laura, Interview #2)

Laura made a distinction between actually not having enough time to care for one's appearance, or attempting to be recognized as the hard-working, disheveled physicist who does not have time to look after their appearance. In the previous journal entry, Laura stated that she often does not have time to look after her appearance. However, in the story about her colleague, she suggested that this woman purposefully would dress down from her usually more feminine appearance in order to be thought of as hard-working.

The default style in physics as described in the Discourse of the stereotypical physicist is the male standard, as evidenced by Laura, Lily, and Peter's statement earlier. The fact that this default style is linked with maleness indicated that the default gender in physics is masculine, and that the Discourses governing expectations for participation in the field are constructed around this default. In Chapter 5, David discussed his concern about stereotypes of physicists, and the barrier that this posed for him as a high-school student. He discussed not being able to see himself as a physicist until he met a young physics teacher who transgressed that stereotype for him. David also discussed feeling that his appearances have changed since he became a graduate student in physics.

This is not something that concerned him immensely, but he did reflect on this in the following excerpt:

> [I feel] that physicists or people in science might be really cool, sometimes they maybe think a little bit differently. I think they're intellectually a bit sort of [. . .] they like to be different from other people. You go to a physicist meeting and what really characterizes a physicist is wearing sandals with white or gray socks with the t-shirt of the last observatory they've been observing at and that's like, so typical. And actually I'm sort of worried that I would let myself do that but I think I would be forced to do it if I landed a faculty job. (David, Interview #1)

David described physicists as "lik[ing] to be different from other people." However, the description he gave of physicists was a uniform socks-and-sandals appearance. In doing so, he constructed a boundary between physicists and other people, and situated himself among the physicists by worrying that he would become one of them as he moved along the academic pipeline. Thus, the regulating effect that the Discourse of the stereotypical physicist has on participants' appearance was not just a concern for women. As David explained above, this is also a pressure that troubles some men in the discipline.

Discourse of gender neutrality. In this study, men and women participants alike described the typical physicist in male terms, most often without using the actual term man or male, sometimes by using male pronouns (see examples from Lily, Laura, Victor, and Peter above). Many participants also described feeling noticed because of their gender, or not having the space to comfortably express femininity (this is discussed further in Chapter 8). However, somewhat contradictorily when participants were asked about gender performances in physics, many participants agreed that while the population of physicists was still dominated by men, they maintained the idea that physicists' gender performances as gender neutral. In this section, I present examples of this Discourse from four women, two in astrophysics and two in condensed-matter physics. It is notable that none of the men who participated in this study described a Discourse of gender neutrality—the subject never arose in our conversations.

Carol discussed communication as an important skill to have as a physicist, and expressed some difficulty with learning the jargon of physics. She described to me occasions of nervousness at conferences, and I asked her if she thought that the ways physicists communicated were at all masculine. Her response eschewed any connection between physicists' ways of communication and masculinity, "no, usually when I am talking to anybody, it is like talking to somebody who doesn't have a sex [laughter], everybody is just unisex it seems" (Carol, Interview #2).

However, in a counter-example to her unisex claim, Carol also described not liking activities traditionally associated with women and femininity. She describes not having the same interests as most women, and feeling as though the sorts of things that interest women are things she doesn't like:

> I find it hard to talk to a lot of other women because their interests are so far from my own, that we don't really have a lot in common. I am not interested, I barely ever watch TV and I [always wear] the same clothes. Like, all the new clothes I get are gifts that people give me, you know. Um, my roommate has been cutting my hair for the last year and before that I got it cut a year before and I might get it cut this year. Like, to me

> there is just not time for these things. But I find that a lot of women make time for these kinds of things and I am more interested in computer games and, like, if I had to choice between getting my hair cut or playing a computer game I going to pick the computer game or any other game, but not getting my hair cut. I don't even like people touching me so much, so and thing, pedicures, nails, I hate all that stuff (Carol, Interview #2).

Carol describes what she deems to be typically feminine activities that she finds no interest in, and attributes these to things most women do. Comparing these activities to the more physicist-oriented activities that she describes, it becomes clear that displays of femininity are not a part of physics for Carol. Thus, at the same time that she constructs physics as gender neutral, Carol positions women in opposition or different to physics. I did not find in the data, however, a similar positioning of masculinity or men in opposition to physics.

Ruby and I discussed expressions of gender in physics at length (to be further expanded upon in Chapter 8), and while she acknowledged that there are a lot of men in physics, she has never viewed that as a deterrent:

> No, no, um [. . .] I mean when I was in undergrad and there weren't that many girls in the class, I kind of liked it. But, I kind of liked it. I just thought, 'hey look it is funny there is very few girls'. I don't know why I liked it. So I did notice that there are less girls but I never associated the field with a guy field kind of thing. (Ruby, Interview #2)

Ruby described liking the fact that she was one of few girls in her physics classes. The absence of other women in the class caused her to stand out, a feature of the gender ratio that she enjoyed (for reasons she could not explain). However, while she did notice her own difference, she did not attribute this difference to physics being a "guy field." Ruby went on to explain that it was never a problem for her to be in a male-dominated field.

> I never felt like, 'oh no, people are going to think I am more masculine because of this field' or 'oh no, I shouldn't be going to this field because I won't be as good as the guys were.' I never felt anything like that. It is a field that I like and just went in to it, there happened to be more guys, fine, kind of thing. No I never felt any kind of pressure of, 'I shouldn't do it because it is a guy field', I never felt any kind of pressure and I don't understand why other people do too. Like, where is the pressure coming from? OK, you are a girl you want to go and do that because you like it, OK, fine, go. What, where is the problem, kind of thing. (Ruby, Interview #2)

Ruby did not regard the under-representation of women in physics as a problem. She argued that if women wanted to do physics, they just should, and she did not see where the barriers or pressures on women were. However, she spoke this from a position of not ever having felt any pressure or difficulty about being a woman in physics.

Lily also articulated a concern about the representation of physics as a masculine field. Although she regarded physics as male-dominated, she suggested that it did not need to be thought of as masculine. Like Ruby, she suggested that perhaps she was not the right person to ask about gender issues in physics because she had not experienced any problems related to gender in her graduate career in physics:

> **AG**: Do you see it as that, as a masculine discipline?
>
> **Lily**: I don't think it needs to be. I mean, it is male dominated now but I don't think there is anything about it that is inherently masculine at all, so, yeah, I think I am not the right person to ask because it never bothered me so that is why I am here. That's the thing, it is something that has always

> sort of puzzled me so I really don't have any good answers [. . .] it is not a problem, you know.
>
> **AG**: Well 'cause ah [. . .] it is not something that has ever . . .
>
> **Lily**: Yeah, definitely, I mean I have had the occasional professor along the way that has sort of been, you know, women don't belong in physics sort of. They are usually old retired guys who for some reason are still hanging around, but yeah, it has never been a problem. (Lily, Interview #2)

In Chapter 5, Lily described her experiences in high school and undergraduate physics as overwhelmingly positive. Here Lily suggested that she had never had a problem as a woman in physics, beyond the occasional professor. However, later, in the same interview, Lily suggested that men in physics often treat her as one of the guys—a position with which she seemed not entirely comfortable. She began by explaining that she thought the men in her department did not even notice that she's a woman—or that she's not actually one of the guys:

> **Lily**: I think, I don't think most people notice so much, so I don't know how [. . .] around sort of my home department, I think it is rare for them to even notice that I am a girl. I've had some very strange conversations take place in my presence that normally they wouldn't have happened in front of a girl except that I work with them so, they don't even really register that I am there as a young woman that doesn't want to hear about dates and other exploits, so yeah, they see me as one of the guys.
>
> **AG**: What do you think about that? How does that make you feel?
>
> **Lily**: Normally it is OK. Sometimes it is really strange.
>
> **AG**: Do you think that the guys there just think of everybody as physicists and there is no men and women physicist?

Lily: Yeah, yeah.

AG: Is the physicist a default male?

Lily: Yeah, I think so. (Lily, Interview #2)

Here Lily shared two important thoughts on her position as a woman in a male-dominated department. One was that she was not sure that the men see her as a woman, rather, they see her as one of the guys. Another was her agreement with the notion that physicists think of each other as physicists first, and that there are no men or women physicists, but that the default physicist is male. At the end of the second interview, she explained that gender in physics had not been a problem for her, so it was not something she thought about.

Alice had given considerable thought to the expression of masculinities and femininities in physics, but despite her desires to express her femininity more in all areas of her life, both personal and professional, she explained that dressing more feminine in her department would make her feel out of place:

> Well, I think I would feel awkward and uncomfortable [dressing more feminine]. Because you know, I mean, well for example, if I look at the other women in our department, people don't wear dresses to their office, they don't wear high heels, they don't wear makeup or at least not obvious makeup. (Alice, Interview #1)

Alice did not refer to the men in her department as creating a situation where she would be uncomfortable expressing her femininity, but rather suggested that women in her department set a standard of what she called in the following excerpt a gender-neutral perspective, "I think of physics from a more gender-neutral perspective so that I don't think of it as a masculine endeavour and working with Veronica and Ruby and Molly helps" (Alice, Interview #2).

She pointed to the women that she works with (Veronica the PI, and doctoral students Ruby and Molly) as people to emulate in the department, and people that she regarded as adopting a similarly gender-neutral perspective. Women discussing the neutrality of gender in this case have described the default gender expression in the physics department as masculine, but rendered it unmarked by claiming it to be gender neutral. As Lily's and Alice's stories made clear, expressions of femininity in this gender-neutral environment would be interpreted as marked, or different. Trying to avoid difference, the women in this study largely adopted this gender-neutral perspective, and thus felt that gender, to them, was "not a problem."

Section summary. Stereotypical notions of the images of physics still abound in the physics community. This section identified the contradiction that physicists are largely discussed as male, geeky, and socially awkward, at the same time that gender performances in the physics department are regarded as gender neutral. When participants discussed recognizing physicists, they rarely referred to images that corresponded with those they themselves portrayed. Physicists were never described as female, as a person of colour, as fashionable, or sociable. Stereotypes about attire constructed disciplinary uniforms for physicists that have slight nuanced differences among the subfields, but were generally recognizable even in non-physics contexts. The Discourse of the stereotypical physicist as disheveled was explained as demonstrating that one is hard at work or immersed in a problem, so much so that one no longer has time (or cares to take the time) to tend to one's appearances. This was discussed as a likely explanation for the unkempt appearances of many physicists, but also as constructed or feigned appearances that students projected for the purposes of relaying messages to supervisors about how hard they were working. Laura relayed a story to this effect that entailed a woman putting on this hard-working appearance for her supervisor, despite the fact that she often dressed in more feminine attire in other social situations.

Regarding masculinities and femininities in physics, most participants acknowledged that physics was a male-dominated field, but none regarded physics as masculine. Despite stories of being the only woman, of the default physicist being male, and not being able to find places to express femininity, many participants described physics as gender neutral.

Chapter Summary

Discourses that construct physicists were generally found to entail stories of recognizable forms of competence: technical, analytical, and academic competence. Several competencies or a combination of many of these competencies were regarded as requisites to be recognized as good physicists, although there were spatial (disciplinary subfield) and temporal (phase of educational trajectory) specificities to these. Finally, this chapter identified various stereotypical forms of physicists. Generally, the physicist was regarded as male and stereotypically geeky or socially awkward. This was regarded as the default image for physicists. This was in contradiction to depictions of physics as a gender-neutral discipline.

Chapter 8

Positional Identities

In the previous chapters, a cross-case thematic analysis of participant data yielded Discourses of physics and physicists that identified ideas about what it meant to do physics and who gets recognized as being a physicist. Discourses of physics were often constructed in stereotypical terms and emphasized precision, definitiveness and the romantic elements of the discipline. Discourses of physicists identified the practices that were recognized as valuable across the discipline and within specific subfields. These valued practices were discussed as forms of competence (analytical, technical, and academic), which then constructed subject positions for doctoral students (e.g., smart super-physicist, technically competent physicist). Discourses of physicists also emerged as stereotypical forms of the geeky, unfashionable, awkward, male physicist. Participants across all of the subfields described these images, indicating the pervasiveness of this stereotype. Of importance to this chapter is that despite the universality of this stereotype very few participants actually performed this Discourse. When discussing whether there was a masculine culture in physics, participants preferred to describe the practices and images of physicists as gender neutral. Thus, emerging from participant talk about Discourses of physics and physicists were a number of stereotypes about masculinity and physics that have become normalized in participants' schemas about physics.

This chapter brings together elements of the findings from previous chapters by exploring how participants' schema and resources (see Chapter 5) are drawn upon when navigating the subject positions offered by Discourses of physics and physicists (see Chapters 6 and 7). Identifying instances of women participants' positioning around the subject positions, made available through these Discourses, provides a broad picture of the diverse implications these Discourses had for women's experiences in physics. I chose to include only women as embedded sub-cases for analysis in this section for two main reasons. First is the exceptional ways that women participants discussed their histories with physics, presented in Chapter 5. The majority of women gave particular emphasis to sharing stories of childhood interests and aptitude for physics. These stories were interpreted as bids for recognition as physicists—a career choice regarded as exceptional for women. Seeing as these women had stories to tell about why they chose physics, it was important to give voice to those experiences in this study. Second, the Discourses of physics and physicists presented in Chapters 5 to 7 presented a limited availability of subject positions for women. As noted in Chapter 7, in physics, the default physicist is male. Therefore, to understand better how gender enables or limits possibilities for women in physics, this chapter focuses on women participants' stories of positioning around these available subject positions. This chapter is constructed differently than the previous three findings chapters. Here, stories of positioning are presented, which require a great deal more interpretation than the previous chapters, which presented data organized by thematic coding. As such, the stories presented in this chapter will be interwoven with theoretical concepts to provide a richer picture of women's positioning in physics.

To explore participants' positioning, I looked back at stories of recognition introduced in Chapter 5 (recognition of self as physicist, recognition by other; see Table 3 for rules of inclusion) and identified moments of accepting, rejecting, or negotiating the subject positions offered through the Discourses of physics and physicists described in Chapters 6 and 7 (Holland et al., 1998). These acts of positioning were mediated by the schema and resources women participants brought to their practices (Sewell, 1992). This analysis was achieved by examining the individual cases (interview transcripts, field notes, photo-journals, and e-mail communication) and constructing stories that told about a critical incident or a particular stance a participant took relative to the subject positions offered. The findings presented in this chapter were guided by the following research question:

4). **How do women doctoral physics students use their schema and resources and the available forms of physicist to participate in their research groups and physics department, and to construct their identities as physicists?**

The intent of this chapter was not to construct a thematic analysis of forms of positioning, but rather to reveal complexities amongst the individuals' participation or non-participation in the Discourse practices of physics. Further, the stories of positioning presented in this chapter were not the only possible stories that could have been told, nor might they be the most salient for the participant. Rather, they were chosen based on the emphasis that the participant placed on discussing a particular Discourse of physics, and therefore they appeared to be the most salient stories that emerged in the context of the study.

Gendered Tools of Physics: Lily

Lily's case presented an example of the naturalization of gendered social relations, and further, the materialization of those social relations in the actual machinery used by physicists. Looking back to her early experiences with physics, in Chapter 5, Lily recounted childhood memories of playing around with models and figuring out how machines worked. These early experiences helped Lily to acquire resources and schema that influenced her trajectory towards experimental physics. In particular, Lily's experience in her undergraduate degree gave her the resources to become skilled in handling and fixing instruments, and thinking creatively to solve problems. In Chapter 6, Lily discussed a Discourse for physicist that relied considerably on technical competence as a valuable characteristic necessary for recognition as a physicist. The schema that she carried with her from her undergraduate experiences about how physics should be done was seen in her espousal of creativity as an important element of technical competence and also her emphasis that physical skill, while often limiting, is a necessary aspect of doing experimental physics.

In her photo-journal, Lily provided a number of images of her manipulating a sample in the STM, indicating that manipulating samples has become the foundation of her work in the lab (e.g. Figures H4 and H8). In Chapter 6, Lily referenced the limitations that requirements for physical skill pose for individuals who are not big or strong enough to manipulate the instrument used in her line of work. To illustrate this, Lily described a trip to a lab in Germany where the STM she had become accustomed to was built differently.

> **Lily**: I actually, I spent a month in Germany with another research team, and they had an instrument by a different company that's based in Germany, and everything was really big. I had to stand on things to be able to see and reach, and I physically couldn't do a lot of the transfers by myself because I just couldn't, I didn't have the arm span to reach.
>
> **AG**: Is it made for bigger people?
>
> **Lily**: Well, this is my theory. It's made by a German company and a lot of German people, especially men, are like, large, and our instrument is made by a Japanese company, and Japanese people are quite small. I didn't clue in until I came back home and everything was easy, and in reach again and I was like 'I wonder' but you know, it could very well be.
>
> **AG**: Is there a reason why it would be made bigger? Or it just was.
>
> **Lily**: No, I think it just was. There was no real necessity for it. It was essentially the same kind of instrument, but in a different country. (Lily, Interview #2)

In this case, the design of the STM became a material resource that was accessible only to certain people, and which delegated gendered roles, actions, and responsibilities to the physicists who used it. As a smaller-framed woman, Lily was limited by her stature in her work with the STM, a material resource that is accessible to able-bodied men of large stature.

This story identified a conflict between human and material resources that Lily had available to her. The machine at Eastern University was very large, and while she could manipulate it herself, it often required help from others to complete a task. However, while Lily was generally able to participate in all of the tasks on this machine, the instrument she used in Germany was an exception, and her ability to use it fully was constrained. Rather than perpetuate the gendered division of labour the machine demanded, Lily gained expertise (and thus, recognition as being technically competent) in the process of sample preparation for this instrument.

Lily explained that the delicate nature of sample preparation benefited from a handler with small hands and steady fingers. As such, Lily indicated that she developed a proficiency at tasks that were “finicky and small” and that dealt with “small things, small tools, and small fragile elements” (Photo-journal, p. 3). In doing this, Lily gained recognition as an expert at manipulating the samples to be viewed in the STM, and mentored new students in doing the same.

To accomplish the delicate work of sample preparation, Lily employed the resources she acquired throughout her undergraduate (physical skill and creativity), coupled with the benefit of having small, steady hands, and meditative patience rather than brute force. In interviews and in her photo-journal, Lily stressed the importance of creativity and craftiness: “Often for us in the lab, a ‘crafty’ side is quite helpful [. . .] shaping a piece of wire into a tool, using thin foils as parts or springs, etc” (Lily, photo-journal, p. 21). However, while this allowed her to be involved in the use of the equipment to some extent, it set up a practice where the division of labour was defined in ways that re-inscribed gendered power. The engineering of an instrument as the one in Germany that was too large for a woman, slight man, or person with a disability relegated the use of the instrument to only large, able-bodied men (or exceptionally tall women). This constructed a subject position for *physically skilled physicist,* however, the notion here of physically skilled is limited to those individuals whose bodies were appropriate to the instrument. This also potentially indicated that the STM architects designed the instrument with a certain gender in mind. As Berg and Lie (1993) described, tools are often manufactured with gender in mind.

Wacjman (1991) suggested that technical competence is a form of masculinity “based on physical toughness and mechanical skills” (p. 143). She also pointed to machine-related skills and physical strength as being measures of masculine status. Lily’s method of subverting this hegemony was to position herself as expert in preparing the sample and accessing the vacuum chamber with her smaller hands. As a woman with a smaller frame and hands, Lily was able to develop an expertise outside of the traditional realm. In this improvisational act, Lily redefined technical competence in a powerful way, by taking up a subject position physically-skilled physicist on an instrument, yet she might have been unable to do so if the machine had been like the one in Germany.

Thus, Lily was able to reconfigure the masculinity associated with technical competence to include a localized meaning that also included working with small and delicate objects. Generally, work that requires the use of “nimble fingers” has been associated with femininity, caring, and docile labour (Elson & Pearson, 1981). However, Lily also reconfigured this definition of femininity and used it to gain recognition as an expert on manipulating objects in the STM.

Negotiation and reconfiguration of subject positions, however, did not appear to transform the culture of masculinity in this case. Finding new ways to develop expertise on an instrument designed for men is subversive, but also maintains the dominant gender order constructed through the gendering of tools, such as the STM. Material resources of this field of experimental physics remain the same, and are built with a specific kind of person in mind. Rather than placing a demand on the industry to design instruments that could be suitable to a broader spectrum of users, this way of developing expertise constructs and reproduces women's roles and men's roles in the laboratory.

Reclaiming Rationality: Laura

Laura grew up in a family of academics, and discussed spending a lot of time experimenting and engaging in educational activities throughout her youth, and it was this that led to her pursuit of science in university. In talking about her undergraduate years, Laura described showing an aptitude for math and physics and developing a fascination with quantum mechanics. Growing up in an academically-oriented home and having a positive undergraduate experience with physics helped Laura acquire the resources that allowed her to envision a career in theoretical physics.

Laura's stories showed the interaction between schema and resources that she acquired throughout her childhood and university education, and the impact these had on her relationships with people outside of physics. Laura told of frustrated interactions with cashiers or difficulty understanding why people carry their bags in certain ways on crowded buses if it does not seem logical to do so (Laura, Journal #1). As illustrated in Chapter 6, Laura positioned herself in opposition to non-physics people by discussing how her understanding of the world appeared to her to be fundamentally different from that of non-physicists.

In her description, she emphasized that this was not a value judgment on her part, but an epistemological schema that stemmed from her years of enculturation in physics:

> **Laura**: [Physics] has affected the way I look at all kinds of questions and it sometimes makes me feel further away from people who are not physicists and who I interact with, that is for sure. All my examples are trivial but there are many of them. [. . .] I feel like I ask more quantitatively answerable questions in lots of daily things that come up.
>
> **AG**: Do you think that you would have, your perspective would have been different had you gone to, into a different field of physics?
>
> **Laura**: Um, I don't know. But no, I don't think so. I think those are, that way of thinking was already necessary by the time I finished my four year degree I'd say.
>
> **AG**: How about the different disciplines in science?
>
> **Laura**: Again, I don't know, but um, let me think. I am not sure. [. . .] I have a friend in geology who I don't think is as analytical as I am. (Laura, Interview #1)

Laura positioned herself as a physicist by constructing a boundary between physicist and non-physicist using the Discourse of analytical competence as an index for recognition. In doing so, she accepted the subject position offered through the Discourse of the analytically competent physicist. In the above excerpt, she explained that she felt distant from others who were not in physics and she delineated herself from a friend in a different discipline who Laura felt did not think as analytically. She argued that this way of perceiving the world was established by the end of her undergraduate degree, and suggested that this kind of thinking was a necessary resource in her degree program.

Wacjman (1991) discussed analytical competence as a type of hegemonic masculinity. She claimed that one type of subject position offered to physicists is the one of "professionalized, calculative rationality" (p. 144). In a subsequent e-mail communication I had with Laura, we discussed the perceived connection between analytical competence and hegemonic masculinity. Despite the repetition of cultural images associating femininity with intuition and compassion, and masculinity with analytical thought and rationality, Laura rejected the notion that rationality was a masculine way of thinking:

> Science has to be objective and rational, practically by definition. Just because men laid claim to science by pretending only people with penises could think rationally does not make this untrue. Any association of rationality with masculinity exclusively is imagined, along with the assumption that only men could understand politics, or money, or music, or poetry, or anything else. It used to be believed (and is still joked about by too many) that only men can drive well, because men are better at focusing on the task at hand, better at spatial reasoning, more alert, etc. This is not true, but that doesn't mean that one doesn't have to be focused and alert and have a sense of the distances around you in order to be a good driver. Similarly, a good scientist must be rational and objective, and this is not me accepting that science is masculine. (Laura, e-mail communication, January 17, 2010)

In the above communication, Laura accepted the association between rationality and physics that is the hallmark of the Discourse of analytical competence. However, while she accepted that association, Laura categorically rejected the parallel connection of rationality with masculinity. She took offense to the notion that rationality might be a male trait, indicating the association she perceived between masculinity and maleness. By accepting a subject position of analytically competent physicist, Laura did not accept the Discourse of masculinity typically associated with logical reasoning. Rather, Laura suggested that analytical competence was not a gendered trait, but rather a necessary skill that she valued as a physicist.

Laura's schema of logical reasoning challenged the norms of physics and by extension, claimed that certain characteristics like analytical competence are masculine (Wajcman, 1991). Laura's challenge to the association of analytical competence with masculinity pointed to the dangers of essentializing certain characteristics, and suggested that this portrayal of the various ways of doing physics runs the risk of reifying gender in physics. On the other hand, Laura's acceptance of the analytically competent subject position also challenged the expectations that women are not capable of logical reasoning or do not find it appealing because of its association with masculinity. Laura did not find this to be a problematic position for her to occupy, however, she did express concern about societal perceptions of women in physics in our interviews:

> Of course women can do physics and mathematics, but what has happened is instead of just accepting the assumptions [that women were incapable of logical reasoning] were wrong, people have redefined that feminine-masculine line so that it encompasses things that could be recast as, for example, healing roles. And I think that is why things like biology and medicine are now so much more acceptable for women then they were before and the line is morphed. [. . .] So I think that physics and mathematics remain outside of that new line and are still perceived like—how do you recast string theory in such a way that it is healing or nurturing or of service? Women always have to be providing some service to other people. They can't just be abstractly interested in their

> own curiosities. That is messed up and I think that is what is going on. You can redefine, you know, you can handle it as long as there is still some barrier. And that barrier is that a woman is always somehow sacrificing herself and not for an abstract goal. (Laura, Interview #2)

In this interview excerpt, Laura explicitly challenged the dominant Discourse that women are attracted to sciences for reasons of altruism or caring. Rather, she viewed this Discourse as limiting and one that forbids women from pursuing interests for the sake of abstract goals (e.g., string theory or astrophysics).

Laura's positioning had the potential to be transformative in cultures of physics. By challenging dominant notions of gender roles in science, she also implicitly questioned research on gender in science that draws on assumptions that women enter the sciences with altruistic goals (Carlone & Johnson, 2007; Johnson, 2007). Laura made herself visible as a woman, who performs a feminine gender identity, in the role of an analytically competent physicist. While she did express altruistic concerns (see Chapter 5), Laura's intent was to continue pursuing a career in string theory—a role contrary to many societal expectations for women in the sciences. Thus, Laura also had the potential to transform societal notions of the goals that women have entering the sciences, and to decouple the expectations that come with essentialist notions of femininity and women.

Communicating Competence: Sandra

Sandra, an astrophysicst at the very end of her doctoral studies, positioned herself as a physicist by accepting the subject position of academically competent physicist. Sandra's early experiences with science in Central America helped her acquire the human and material resources that allowed her the option to follow an academic trajectory into physics. Sandra credited her parents' encouragement and to some extent her parents' medical background with helping her become successful in science. However, the material resources for her in Central America were limited, and she suggested that she would not have had exposure to research had she not moved to Canada to attend university. She discussed being recognized as an expert in her country of origin as a result of her university education, particularly in relation to her peers back in her home country:

> Actually, yeah, a few years ago, or a couple years ago, when you know there was the whole Pluto thing? They called me from [Central American country], a newspaper called me from [Central American country] to ask me what I think about that. Not that many people from [Central American country] who are in pure science and I can say even less in astrophysics. It's because my friend works at that newspaper and so she gave my name to someone else. They called me, they were like, 'we just wanted to know what you thought,' and I was like, 'ok.' In those countries you don't get the opportunities to go into pure sciences. (Sandra, Interview #2)

This phone call was a moment of recognition in which she was positioned by a significant, non-scientific other as a physicist. This can be regarded as an index of her position as a physicist and expert outside of the community of physicists, and this was made possible by access to material resources not available in Central America. Planetary classification is not what Sandra studies or is involved in, but regardless, her expert status afforded her recognition by others who simply wanted to know her opinion.

But Sandra also pointed to symbols of recognition within the community of physics as an index of her position within that community. The Discourse of academic competence included the elements of communication and competition—the importance of both of these can be seen in the race to publish, particularly in astrophysics. Recognition within the community of astrophysicists comes from the ability to publish significant discoveries in a short amount of time. Sandra identified the importance of this when she discussed the first time she recognized herself as a member of the astrophysics community:

> I think it was maybe three years ago, or so, half-way through my master's and PhD when one of the objects we were looking at got [a] very interesting result. It's been a very important piece of the field right now. It's the first one that we found. [. . .] it was a very interesting result. So when that came out, that's when I had published other papers before, but they were just very standard results and these results were different. These results, you could tell they were different and there had to be a reason they were different. It definitely was an advancement and at that point, I felt like, 'Ok, I have contributed something'. (Sandra, Interview #1)

To Sandra, publishing her results situated her in the history of the field. Publication also allowed Sandra to acquire recognition as a valued member of the community of astrophysicists:

> Definitely in the last few years all the papers that I've published, I do feel that they've contributed to it. I do feel like I am part of it now, I definitely do. It is my own thing, too. As it goes along, you start to understand things better. The field has been changing. There has been a lot of progress in the last few years in my area so it's been really cool to see it developing. In even just a few years, I can see the changes and it's really cool. You can really see knowledge advancing and that you're contributing to it. So it is really cool. So I do feel part of it in that way. I do feel like I have been part of that history, that little bit of history.

(Sandra, Interview #1)

When talking about being a physicist, Sandra rarely evoked analytical or practical competence as Discourses that she used to index her position as an astrophysicist. While she did describe "making discoveries" and managing "stressful situations" (Interview #2), she coupled these descriptions of doing physics with the necessity of having good communication skills and competitiveness in order to transmit these results and gain recognition in the field. Sandra emphasized these skills as elements of being an academically competent physicist that allowed her to achieve the professional recognition from the astrophysics community, in the form of publications.

Sandra did not discuss how she learned these skills. She described herself as an outgoing person, but she attributed a great deal of her success to her supervisor and to the subject she studied:

> The thing about group publishing in big names like *Nature* and *Science* is Veronica. Because what she's doing right now is, like, the really interesting field of neutron-stars. And then she's teaching all of us about it. She's the one who started it and this is why we're in this group 'cause what we're working on is new, new things. So we can publish in things like *Nature* and *Science*. Without Veronica, don't know if I'd be publishing in *Nature* and *Science*. (Sandra, Interview #1)

Veronica, the PI for the pulsar group, was regarded by many participants in this study, both within her research group and in other disciplinary subfields, as a role model and a mentor. Sandra viewed her relationship with Veronica as a resource that helped her get to where she was. She described Veronica's supervision style as encouraging and never demeaning or unreasonably demanding. Referring to her supervision style, Sandra described Veronica as comforting:

> She doesn't pressure you, she doesn't be like, 'oh, you really should have done that already,' 'oh, you're so far behind,' or 'I don't know how you're going to get this done.' She's never said—she really gives you the time and space to do it at your own pace. Even though she might give you [a] sad puppy-eyed look when you haven't done something, she's like 'oh you haven't done it? Oh, ok.' She won't stand there and yell at you or anything like that. She's also good at being interested in what you're doing. (Sandra, Interview #1)

Sandra described her relationship with Veronica as one that encouraged confidence through positive reinforcement and displaying genuine interest in students' work. Sandra also discussed confidence as an important characteristic contributing to success in her field. In Chapter 7, Sandra connected building confidence with good supervision. Thus, to gain recognition in the field, Sandra uses the human resources acquired through her relationship with her supervisor. Through a combination of confidence and collegiality, Sandra positioned herself as an academically competent physicist who was competitive in her field.

Competition is often regarded as a hallmark feature of masculinity, and is often regarded as a practice in science that dissuades women and girls, who are said to prefer collaborative environments (Howes, 1998). Sandra accepted the subject position of academically competent physicist, and the emphasis on competition that it entailed, particularly in her discipline. A unique feature of her research group was that it operated collaboratively, while at the same time was highly competitive in its field. Not only was being competitive in her field a practice that Sandra accepted in taking up the subject position for academically competent physicist, Sandra was also positioned as a recognizable member of the community of astrophysics by others, both within and outside of astrophysics.

The pulsar research group at Eastern University regularly attracts attention from the media and positive recognition from the scientific community for its contributions to the field. The group operates collaboratively, but is highly competitive with other research groups at external research institutions. Members within the group collaborate on projects and the entire group assembles at least twice a week for meetings, to share and discuss results and research ideas, and to critically analyze recent publications in the field. One might say that the group operates collaboratively in order to remain competitive. This is an attractive working environment for men and women in the field, and speaks to a localized reconfiguration of attributes (collaboration and competition), the first most often associated with femininity, the second with masculinity. Sandra, and others who found this group structure beneficial, acquired the resources necessary to build confidence as researchers in this environment, and thus learned to value competition and communication as necessary characteristics of doing physics research.

Not Talking the Talk: Carol

Unlike Sandra, Carol did not regard the subject positions offered by Discourses of academic competence to align well with her goals for her future. Carol was the first of her family to attend university, and as such, a strong imperative to get an education that will lead to job security has been a part of Carol's schema since she was young (see Chapter 5). Carol's goals in entering physics were to develop a scientific background that would allow her to get a good job upon graduation. The kind of job that she gets seemed almost irrelevant to her as long as it paid well and was enjoyable:

> Well, as I really like everything [laughter] almost any job I would probably like. But ideally I would like a job um, yeah, all I really want is a job that is, that pays me well and that I enjoy. I would enjoy something in research and I am not sure if I would like teaching. (Carol, Interview #1)

Carol's goals of having a lifestyle that involved a family, a house, and two dogs in the Maritimes did not seem to fit with an academic lifestyle. However, she also discussed that her partner plans on continuing on in academic physics and hopefully getting a professorship. Carol's goals could be interpreted as stemming from schema around gender roles, family, and the academy, however, when I asked Carol why she thought she might not take this career path, she indicated that her reasons for not pursuing a post-doctorate position were that the academic lifestyle did not appeal to her:

> Because I don't like the idea of combining research and um, teaching. I don't like, like when I look at people who are professors at [Eastern], I don't like their jobs. They do a lot of paperwork and I have no interest in that at all. I want to be doing something that I consider fun, and teaching is alright, and research is fun, those things, but I never want to do a lot of paperwork if I can help it. (Carol, Interview #1)

The subject position presented to Carol by the Discourse for academic competence included aspects of a job that she was not interested in. Her disinterest stemmed from the kind of work that she regarded as administrative and having to deal with paperwork, such as applying for grants, doing departmental committee work, going to conferences, and working with students, or people in general and not equipment. It seemed that while Carol enjoyed parts of the job of the academic researcher, it was the sum of the parts, plus administrative work that did not appeal to her. Carol pointed to this when she discussed the difference between herself and her boyfriend, also a doctoral student in the physics department. Carol suggested that her boyfriend (who plans on pursuing an academic career) is good with people, where she does not feel that she has the "personality" to pull it off:

> It is just your personality, and he is very good with people and I don't know, he can talk to anybody and get them really excited. Whereas I find that if they are interested, then I can talk to them but if they are not interested, then I don't know how to make them suddenly become interested. But I am better at some things, like I am better at explaining things in a laymen terms whereas he uses the language of the—whatever—so that is harder to understand him. But that goes the reverse way when we are with other academics, he speaks the language and I don't, you know. (Carol, Interview #1)

Carol discussed the human resources that one needs to be recognized as being academically competent. She discussed characteristics of personality often associated with charisma (e.g., being good with people, keeping people's attention, and getting people excited) as necessary elements of academic competence (Holmes, 2006). Carol saw this kind of charisma as a resource that she did not have. Carol's schema about the academic skills required to engage others in conversation about her research included being able to excite people and "get them really interested". Carol identified her boyfriend as occupying this subject position, and suggested that she is only able to take up this subject position when in conversation with non-physicists.

Her attention also moves towards oral use of academic language—an additional skill that she suggested that her boyfriend possesses, but she did not. Carol found that she could more easily explain physics concepts in "laymen's terms," whereas her boyfriend used the sanctioned language of the discipline. In the following excerpt, Carol discussed how she did not use the accepted language of her field, but rather made up her own terms:

> **Carol**: Cause I never memorize the terms. I just usually make up my own. Like, I am, like, that tank [points to a tank in the room], I mean, you know it is not called a tank; it has a very scientific name.
>
> **AG**: But then, when you are in a group of other academics, how do you feel in terms of the language that you've been using?
>
> **Carol**: Well, when I first started it was very very difficult because I had so much trouble remembering all of the words and I didn't know a lot of the questions. Because I just didn't know the meaning of, now I understand what they are saying and I think that when I speak to them it might not come across as sounding as intelligent. But they know what I am saying too, so on the other hand it works out fine.
>
> **AG**: How do you think they interpret it?
>
> **Carol**: I am sure that they know that I didn't use the right word so [. . .] in some way I should have used that right word to them. But maybe not, maybe they don't care which word they use, but I just find that everybody else just tends to use the word that everybody else uses. (Carol, Interview #1)

Carol described the shortcomings of her enculturation into the language of physics, and her difficulty acquiring the resources to adopt the vernacular used by physicists in her field. Carol attempted to improvise by replacing the jargon of the field with what she previously called laymen's terms. However, she expressed concern that this may result in others failing to recognize Carol as "sounding intelligent", but she claimed to be able to make herself understood just the same.

Carol's negotiation spoke to the limitations of this Discourse. Carol was, in fact, a very successful student in her subfield, and was generally regarded by her colleagues as a diligent worker with a strong project who produced a great deal of publishable data (Field notes, December 10, 2007). Carol's work has since gained media attention and journal publications. Her research proposals have been recognized by federal funding agencies and she has received the largest doctoral grants one is able to receive in Canada. She has also obtained top grades in all of her course work and comprehensive exams, but when it comes to using the oral language of the disciplinary subfield, Carol feels she does not participate, and that this may limit how she is recognized by her peers in physics. While others position her as having academic communicative competence, since she is well published and with a strong grant record, she does not position herself in the same way. This is a puzzling contradiction that begs us to look more closely at the schema and resources she brings into her practice in physics.

The oral language practices of physics require students to learn a disciplinary code that may be alienating to those who either have limited resources (e.g., English as a second or third language), or to those whose English-language practices do not fit with those generally recognized in the academy. Carol's struggle with this was two-fold: she struggled to learn the oral jargon of the field, but outside of her practice, she also described choosing not to share elements of her work-life with family and friends:

> I avoid talking about what I do, because they are not going to understand and I really don't like to—a lot of people get frustrated because they don't understand, and it is never a good reception. In the end, you can't tell them enough for them to be interested. Or, if they might be interested and they start asking questions, the more questions they ask, the more they are going to realize they are not understanding. It is very rare you come across somebody who can understand what you are talking about, unless it is another physicist. So, uh, I don't, I never have had a good experience trying to tell somebody what I do, not 'cause I feel I can't explain it, but because eventually at some point, even if they are at first interested, they are going to start asking questions and the more questions they ask, the more they are going to realize they don't know. So I just try to say, ah, you know 'are you sure you really want to know?' And even then they still get mad sometimes at the end when they know and they say something snarky [laughter] like, 'well I could never do that' or something, you know. (Carol, Interview #1)

Here, Carol constructed a boundary between physicist and non-physicist that appeared to be language-dependent. This could reflect her own struggle with the oral communication practices in the discipline and her reticence to pursue a career in academic physics. A career in academic physics did not fit with her career and family goals for herself, nor did it fit with the schema she acquired from her family background. Thus, Carol appears reluctant to participate in the language practices of the disciplinary subfield, but also unable to share her work with other non-physicist friends and family members.

Carol's identity construction as a physicist was context-dependent, and her ability to be recognized as an academically competent physicist, through the use of oral language depended on with whom she was interacting. As a result, Carol struggled with feeling disconnected from the community of experimental physics (by her non-participation in the language practices of the disciplinary subfield), and disconnected with those outside of the community, as well.

Constructing Difference: Ruby

On many occasions in our interviews and during the time I spent observing in the pulsar group, Ruby made reference to the difficulties she had participating in the practices of astrophysics. In particular, she found attending seminars and group meetings like the astro-tea and the neutron-star coffee to be difficult. She attributed this difficulty to her health problems, but also to the structure of those meetings, which she found to be painfully boring (see Chapter 5 for details of Ruby's struggle with attending group meetings).

As discussed in Chapter 5, Ruby had difficulty with sleep issues that limited her access to the resources that other doctoral students in astrophysics acquired (e.g., group meetings, the neutron-star coffee and astro tea, and other departmental seminars). Thus her participation in her doctoral program was also limited. In many ways, Ruby did not recognize herself as an astrophysicist, and felt as though she was not recognized as such by members of her group. Looking at a photograph[v] of the seminar room, Ruby said:

> Yeah, like I feel so out of place when I sit in a place where you know, the other people from the group are. They all know so much more than me. I feel out of place, but it is all my fault. I am the one who did it, so that they know more than me. So yeah, that room makes me feel guilty. (Ruby,

Interview #1)

Ruby's experience of doctoral physics—in particular, the personal contexts that shaped that experience—resulted in Ruby's non-participation in the Discourses of academic, technical, and analytical competence. In the excerpt above, Ruby discussed the feelings of marginalization that she got when she looked at an image of the seminar room where her team meetings took place. Earlier, in the same interview, she pointed to an image of the physics building and said, "I am just sick of it" (Ruby, Interview #1). In Chapter 5, Ruby discussed the institutional contexts that led up to her feelings of alienation from her physics research group and her feelings of inadequacy as a physicist. These included meetings that she felt were boring, and her attention to detail that was not a valued characteristic in her research group. Although Ruby ultimately finished her doctoral dissertation and defended it successfully, she did not recognize herself as a physicist by using the indices of the Discourses of competence.

However, Ruby did recognize herself as a physicist on occasion through other means. One way that Ruby was able to position herself as physicist was to accept the subject position offered by Discourses that constructed stereotypical images of physicists, and simultaneously asserted her difference to other women. My discussions with Ruby often turned to descriptions of acceptable gender performances within the context of the community of physics. During our interviews, Ruby positioned herself as a physicist by suggesting that she looked like a recognizable physicist:

> In general, I don't care what I wear, and lots of physicists don't care what they wear—or some of them, anyway. Girly girls are something else, I

> can't stand girly girls, I don't think you are a girly girl, don't worry [laughter]. (Ruby, Interview #2)

In taking up the subject position of stereotypical physicist, who shouldn't care what she wears, Ruby positioned herself against the so-called girly-girls who perform stereotypical femininity (Wajcman, 1991). I asked Ruby to explain further what she meant by a girly girl:

> **Ruby**: You know when, this might offend you, because you might be wearing high heels, but wearing high heels makes . . .
>
> **AG**: I don't.
>
> **Ruby**: I know you are not now, but wearing high heels makes no sense. If you think about it, it completely ruins your posture, it, it, it just, when I see someone walk with high heels, I don't get the message that it's attractive. I get the message, so awkward, you know you hear like, you hear them, like it is not a normal sound when they walk, it is like a 'chu chu chu' as though they are falling with every single step. What is the point? If you are a logic person, why, why, I don't know. Maybe there is a logic behind it and I just, it escapes me or something, I don't know. (Ruby, Interview #2)

Ruby's schema about gender roles positioned stereotypical femininity in contrast to logical reasoning. Thus, from this perspective, girly girls (performing stereotypical forms of femininity, as indicated by attire) would be deemed incompetent according to the Discourse of analytical competence. By positioning herself in opposition to girly girls, Ruby asserted her difference to what she saw as a gender performance incompatible with physics, thus aligning herself with what she determined was an appropriate way to be a physicist. Later in the same interview, Ruby reasserted the incompatibility of femininity and physics by drawing on the Discourses of logic and rationality to explain how there was a contradiction between physics and girly girls:

> **Ruby**: I just find that physics and girly girl—there is a contradiction somewhere.
>
> **AG**: OK, I want to explore that somewhat though, like what, why is there a contradiction between girliness and physics?
>
> **Ruby**: Well there is a contradiction, like, the wearing high heels thing. If you are [a] logical person who is able to do string theory, then you should realize that you are hurting yourself by wearing high heels. Um, what else is the contradiction? It is all the scale of priorities where people have different priorities and I suppose they are allowed to have their appearance as high a priority as their research, so why is that bothering me? I don't know but it is bothering me for sure. (Ruby, Interview #2)

For Ruby, women who dressed more feminine were allowed to have femininity as a priority as well as their research, but Ruby had a hard time seeing how this could be the case.

Ruby's positioning of girly girls as non-physicists, however, did not mean that she saw herself as constructing an association of girly girls with femininity. During the interviews, when I tried to reframe Ruby's construction of girly girls as representations of stereotypical femininity, Ruby challenged my own notions of femininity:

> **AG**: Do you think that—could we also think of it as a, as a scale? That if there are degrees of masculinity and femininity, the girly girls you are talking about would probably fall under the hyper-feminine end of the scale?
>
> **Ruby**: But why are you associating girly girls with more feminine? Maybe more feminine doesn't mean being more girly? (Ruby, Interview

#2)

To Ruby, the incompatibility of girly girls with physics had nothing to do with femininity. Rather, she suggested that there may be multiple forms of femininity. Ruby's challenge to my notions of femininity might be interpreted as a challenge to my construction of femininity as a White, Western formulation of gender expressions. Ruby refused the subject positions offered by stereotypical femininity, but this did not mean that she rejected femininity outright. Rather, she challenged me to rethink my own formulations of gender, and to interrogate their Western underpinnings. What I think of when I discuss stereotypical or hyper-femininity has meaning only when we situate that concept in a White, Western Discourse of gender. Ruby easily rejected this formulation of femininity, associating it directly with an incompatibility with physics, and instead accepted a subject position for the stereotypical physicist, which she did not regard as incompatible with her construction of femininity:

> **AG**: Do you feel like you are one of those people who are—
>
> **Ruby**: Yeah, I don't mind whistling in the corridors, sometimes when the corridors are empty in the physics building, I try to do cartwheels. And I wear sandals, and I don't exactly mind that. I am wearing a slightly older t-shirt, so appearance eccentricity and sometimes behaviour eccentricities, I sometimes do horde them, so yeah, so I sort of am part of those people, so yeah. (Ruby, Interview #2)

Ruby did not recognize herself by any of the indices of competence that constructed Discourses for physicist. However, Ruby did recognize herself as a physicist (and was recognizable to others) by her attire and behaviours. By taking up a subject position as a stereotypical physicist in her appearance, Ruby found a way to achieve recognition even though she did not recognize her abilities otherwise. Rather than dichotomizing masculinity and femininity, she argued for a plurality of femininities, and took up a subject position otherwise reserved for the default male physicist.

Gender Neutrality: Alice

While participants (women and men) described stereotypic forms of physicists as geeky, awkward, and wearing identifiable clothing, many did not appear to occupy that subject position, nor did they recognize themselves as doing so. While the default physicist was always described as male, in contrast to this, Alice and other participants discussed the neutralizing of gender in the physics department (as described in Chapter 6). Alice in particular, regarded the physics department as a place where extreme forms of both femininity and masculinity were discouraged, resulting in what she called a gender-neutral environment. However, Alice was interested in performing a more traditional form of femininity through her attire, and this Discourse of gender neutrality made it difficult for her to find spaces in which she could enact expressions of femininity:

> **Alice**: I could try and dress in a more feminine fashion but, at least as it stands now, I think my choices are between choosing something that is kind of androgynous but which looks reasonable, and choosing something which makes an unambiguous statement but looks really awkward and uncomfortable and I'd rather . . .
>
> **AG**: Awkward to somebody else or to you?
>
> **Alice**: Well, I think I would feel awkward and uncomfortable. Because you know, I mean, well, for example, if I look at the other women in our department, people don't wear dresses to their office, they don't wear high

> heels, they don't wear makeup, or at least not obvious makeup. And if I did those things, I would be making a definite statement but also look quite out of place. (Alice, Interview #1)

Alice felt a conflict in taking up an androgynous or gender-neutral subject position because she was unable to express femininity. However, at the same time, she did not feel comfortable dressing, for example, in ways that signified traditional forms of femininity. In another example, Alice continued to explain her struggle with gender expressions in physics:

> I mean, that is something that I am actually fighting with. I sometimes feel like I don't have enough, get enough chances to express femininity in my field. And I am still figuring out how to do that in a reasonable way. Even, I mean, even apart from the issue of physics, just you know figuring out, finding opportunities when—I think I have learned to get by with a very small amount of femininity. [. . .] Um, there aren't many places where I am comfortable wearing a skirt and finding more places and times where that is appropriate is actually something I am fighting with. (Alice, Interview #2)

Alice suggested that in order to participate in physics, she cannot subvert the entrenched gender order in physics and must conform to the stereotypical subject position for physicists made available through the Discourse of gender neutrality in the department. However, neutral or androgynous here must be read as masculine, as the default gender in physics is not in fact, neutral, but rather male, as indicated in descriptions of the Discourses of the stereotypical form of physicist. This posed a problem of authenticity for Alice who wished to perform her femininity, but felt as though this would make her uncomfortable, because she would stand out from a group of individuals who she regarded as performing androgynous gender identities. Rather than redefining the subject position constructed by the Discourse of gender neutrality, Alice's acceptance of this subject position might be interpreted as a submission to the policing of the boundaries of gender in the department of physics (Butler, 1999).

When she entered the pulsar group at the beginning of her doctorate, Alice brought along intellectual resources acquired through a youth where science and scientific exploration were emphasized. Alice also transferred into the group from the math department after she collaborated with a few members of the group, and it was determined that her code-writing skills would be a considerable resource. Thus, Alice occupied a subject position of analytical and technical competence that was recognized both by the members of the physics department and those in the broader scientific community (as discussed in Chapter 5). Alice received grants for her work and her work was published in prestigious scientific journals like *Science*, and had even received media attention. Thus, her reasons for accepting the stereotypical subject position for physicists might be different from Ruby's. She seemed to do this not out of choice, but rather in an example of what Keller (1985) labeled *inauthenticity*, because by dressing "more feminine" she might be regarded as displaying an inappropriate, non-gender conforming performance.

Constructing a New Subject Position: Molly

As Alice's story depicted, the Discourse of gender neutrality was so pervasive, that performances of masculinity were not recognized as such—they were seen as androgynous. As a corollary to this, expressions of femininity were seen as not permitted in the physics community, or even (as Laura discussed in Chapter 7), potentially punitive. My interviews with Molly revealed a new perspective on the neutralization of gender in the physics community in light of her new identity as a pregnant woman (now mother). As discussed in Chapter 5, Molly previously positioned herself against the subject position offered by the Discourses of stereotypical physicist—describing herself as being more visible because of her ways of dressing and non-traditional choices for hair colour. However, she described suddenly being recognized as a woman (and not just different) when she became pregnant:

> I feel more like people don't really pay much attention to [whether] you're a man or a woman in the department and that's almost why the pregnancy has thrown people off. You really can't ignore how much of a woman I am now that I'm about to give birth, really obviously. Suddenly they really see me as a woman whereas before I was just another grad student. (Molly, Interview #2)

As described in Chapter 5, Molly's experience of motherhood in the physics department had been one of Othering by virtue of making her gender obvious where previously it was neutralized. The responses of her colleagues in physics at times were varied and, in one incident, rendered her invisible, whereas before she had been a recognized member of the community:

> **AG**: Do you feel that people treat you differently now that you're pregnant?
>
> **Molly**: Oh yeah. Huge. There's people who, it's very weird. I was actually really surprised. I think part of it is sort of a societal thing where people feel uncomfortable asking somebody if they're pregnant. I announced my pregnancy, but I did not go around to every person in the

> department and say, 'hey, I'm pregnant.' I told a bunch of people and I just figured, I mean, it's a very gossipy place, I figured word would spread like wildfire. There was a bunch of profs that I know well enough to say hi to and chat with, one in particular that I had spoken with many times, both about research stuff and more socially. He stopped saying hi to me completely. He still hasn't said hello to me since I've been pregnant. He doesn't make eye contact with me anymore. (Molly, Interview #2)

Molly's experience with pregnancy in the department presented a radical re-description of the kind of person it is possible to be in the community of physicists. How people reacted to her pregnancy ranged from acceptance, to ignoring the pregnancy, to ignoring her. Molly attributed some of this awkwardness and not knowing how to act around a young, pregnant, unmarried woman to the general awkwardness of physicists. In her words, "these are awkward boys" (Field notes, October 17, 2007).

However, while Molly recognized the awkward, and even negative, reaction of some in the department, she had the resource of support from her supervisor and research team. The impact of having a supervisor who was successful and a mother of three appears to have been very important to Molly. She described feeling nurtured by her environment and told about receiving hand-me-down clothes and a baby carrier from her supervisor, Veronica. As a role model, Veronica helped Molly acquire the schema and resources necessary to see herself as continuing on in physics, as a mother. Thus, Molly did not seem to regard her pregnancy as a barrier to finishing her degree and a career in physics in the future.

Molly's pregnancy forced others to recognize her simultaneously as a woman and as a physicist—breaking down the mutual exclusivity of these two subject categories. In doing so, Molly constructed a new subject position for women in physics: a pregnant physicist (and soon-to-be physicist mother). While Molly constructed an identity for herself that included women, mother, and physicist, she advocated for recognition as a physicist and woman by asserting her new identity and demanding institutional recognition from the university. Her pregnancy—the first of any graduate student in the department—required the department to examine the regulations around maternity leave for graduate students who are new parents. This was not only precedent-setting administratively, but it also constructed a new subject position for graduate students in physics—one that broke down the dichotomy between women and physicist, at least for one individual. However, as far as I am aware this was the only structural change that had been made to accommodate pregnancy and parenthood in the department.

Chapter Summary

The stories of positioning in this chapter built on the participant trajectories presented in Chapter 5 in that the trajectories provided an empirical context for understanding how each female student positioned herself around the subject positions presented in Chapters 6 and 7. In this way, the ideas expressed in this chapter built on those in the previous chapters. Whereas the previous two chapters focused on Discourses that I identified through a thematic analysis, here I looked at how individuals responded to the Discourses discussed previously. The stories I presented here were a perspective of how women in the physics department employed resources and schema acquired through previous experiences to position themselves in relation to the subject positions offered through the Discourses that defined appropriate ways of being physicists. These schema and resources were not always immediately obvious (either to the researcher, or, presumably to the participant). Nevertheless, the different ways that participants accepted or negotiated subject positions were reflections of their differential access to schemas and their use of human and material resources.

I identified two distinct forms of positioning that participants engaged in around subject positions: accepting and negotiating (Holland et al., 1998). A third form, refusing subject positions arose in part during negotiation. Some participants negotiated subject positions by accepting some of the Discourses related to that position and refusing others. Accepting a subject position entailed taking up the position and adopting the Discourses of that subject position. However, this did not always occur uncritically.

Laura and Alice demonstrated how it was necessary (and in Laura’s case desirable) to accept a subject position offered to them that had associations with masculinity, even though they fundamentally disagreed with the masculine connotations of the position. In Laura’s case, accepting a subject position as an analytically competent physicist was seen as separate from engaging in a Discourse of masculinity. However, Alice’s acceptance of a subject position of gender neutrality seemed incongruent with her desires to express femininity in her work, and so she did so reluctantly. Ruby, on the other hand, took up a subject position of stereotypical physicist as a way to be recognized as having membership in the community, and saw this as fitting her schema around the incongruency between femininity and physics. Sandra appeared to unproblematically take up the subject position for academic competence. Her story was an example of a situation where the resources acquired from her institutional context enabled Sandra's recognition of herself as academically competent, and recognition by others.

Carol's negotiation of a subject position that required her to communicate using a language sanctioned by the discipline caused her to often feel as though her peers did not recognize her intelligence. Carol's negotiation was unique because it might in part be interpreted to be a refusal of the subject position for academic competence, however this refusal was only related to one aspect of the Discourse of academic competence—oral communication. Carol positioned herself as competent in other ways, and earned the kind of symbolic recognition (funding, publications) usually reserved for successful and acknowledged members of the community. Her resistance to adopting the language of the discipline was perhaps a function of the resources she brought into the field (coming from a family that did not emphasize academics), and was also related to her schema about what kinds of people communicate well in her discipline, for example, those with charisma. Carol's schema about doing academic physics, and the work this entailed, also came into conflict with her desires to raise a family, have a relaxed job that provides security, a good pay cheque, and would provide her with the kind of lifestyle she sought. Additionally, this positioning spoke to schema about gendered roles, both in relation to what kind of person gets recognized as being a good communicator in physics, and what kind of person gets recognized as appropriate for an academic career in physics.

Lily and Molly also provided examples of negotiation of subject positions offered by the Discourses of technical competence and stereotypical physicists. Lily used resources she acquired through her undergraduate training and her own physical skill to negotiate the limited subject positions offered in her line of research. By developing expertise on a specialized area of an instrument designed for a person of much larger stature and greater strength, Lily demonstrated improvisational negotiation that constructed a new subject position for expert on this instrument. Molly, by necessity, made use of the resources available to her by a role model in her community, and constructed a new subject position for women in physics, that required that she be recognized not only as a physicist, but also as a woman.

These stories of positioning showed a multitude of ways of navigating the Discourses of physics and physicists and the subject positions made available through these Discourses. I attempted to make connections to schema and resources that participants acquired through previous experiences and contexts that were significant to their trajectories. These schema and resources became important tools in participants' positioning around available subject positions.

Each of these examples of positioning were identified by examining individual participant's narratives, and were presented here as exemplars of the most significant episodes emerging from these narratives. These stories were not meant to be interpreted as deterministic—it is not possible to know what effect these stories had on participants' persistence in physics. However, these stories did give us a glimpse into the heterogeneity of practices in the physics community and the variety of ways that women negotiated dominant Discourses of physics, and some of the subject positions available in the community. The following chapter will critically examine the construction of Discourses of physics and physicists, and will situate this research in a larger body of literature examining the co-construction of gender and physics.

Chapter 9

Discussion

In this chapter, I will present an analysis and discussion of the findings presented in Chapters 5, 6, 7, and 8. This chapter is organized into sections that respond to the specific research questions guiding each of the analysis chapters. Here, I will draw on sociocultural theory and previous research on the topic of gender and science to contextualize the findings in each of these chapters.

Trajectories

Research Question 1: What experiences and contexts have contributed to participants' trajectories into and through physics?

Participants' trajectories into and through doctoral physics took on various forms that were influenced by schema and resources acquired through their individual experiences and contexts with physics (Sewell, 1992). Emerging from participant profiles were three distinct trajectories that demonstrated inbound, peripheral, and outbound participation in physics (Wenger, 1998). While participants could be grouped into various trajectories based on common elements related to experiences and contexts, these remain individual trajectories bounded by time and space. Mishler (1999) emphasized the "situatedness of 'tellings' which argues against any conception of one 'true' life story" (p. 151). Thus, the situated tellings that I provided here are only one perspective on the trajectories that emerged from participants' stories. Gee (2000) discussed individual trajectories as unique movements through Discursive space. Like Mishler, he emphasized the temporality and situatedness of these trajectories, but also stressed the importance that past experiences has on an individual's direction:

> [H]e or she has, through time, in a certain order, had specific experiences within specific discourses (i.e., been recognized, at a time and place, one way and not another), some recurring and others not. This trajectory and the person's own narrativization (Mishler, 2000) [sic] of it are what constitute his or her (never fully formed or always potentially changing) 'core identity.' (p. 111)

Mishler (1999) and Gee's (2000) notions of trajectory as a salient feature of identity were important concepts to help organize and understand the contexts and experiences that participants had on their road to and through academia, and the schema and resources they acquired along the way. However, attending to trajectories meant finding a conceptual tool that could also highlight the various formations these trajectories took. Thus, Wenger's (1998) work on trajectories and modes of belonging emerged as a helpful analytic concept.

Like Gee (2000) and Mishler, (1999), Wenger (1998) also suggested that identities are fundamentally temporal, ongoing, constructed in social contexts, and composed of multiple, intersecting trajectories. However, additionally, Wenger proposed that trajectories are influenced by modes of belonging—indicators for membership in a community. Wenger identified three modes of belonging including engagement, imagination, and alignment, and these will be discussed later in this section. The nature of these trajectories may vary depending on the stage of the participant's doctoral career, and events in his or her personal lives, and are subject to change depending on contextual events. The trajectories that I discussed here are but one of the multitude of various trajectories of membership that participants may follow. However, at the time of the study, they emerged as indicators of the motivations and goals of participants. Trajectories have no predictive value and cannot be used to determine persistence. Rather, they chart "a continuous motion—one that has momentum of its own in addition to a field of influences. [They have] a coherence through time that connects the past, present, and the future" (Wenger, 1998, p. 154).

Wenger (1998) described four different forms of trajectories, three of which were relevant to the trajectories identified in the participant data described herein. The descriptions of inbound, peripheral, and outbound trajectories were in relation to a traditional trajectory into academic physics. Inbound trajectories described the individual's investment in their future as full members of a specific community. Peripheral trajectories described circumstances wherein by choice or by necessity an individual's goal was not full participation in a community, but their access and contribution was still significant enough to contribute to their identity. Outbound trajectories entailed moving on from the community (possibly into a new community), but that new trajectory was shaped by practices of the old community. Outbound trajectories also involved "developing new relationships, finding a different position with respect to a community, and seeing the world and oneself in new ways" (p. 155).

Table 4 provides a comparison of the goals, experiences, and contexts that emerged in participants' stories detailing inbound, peripheral, or outbound trajectories. As I will discuss in the following paragraphs, a number of similarities among the participants' influences and early experiences with physics emerged from the stories presented in Chapter 5. Most notable was the connection between stories of recognition by others and an inbound trajectory into academic physics, and the connection between recognition of self and gender (e.g., the gendering of stories of early experiences). Also notable is the relationship between institutional contexts and academic trajectories. For example, Saïd, Peter, and Ruby told stories that detailed frustrations with the realities of their research contexts versus the expectations they had for doctoral studies. However, these experiences were also influenced by personal contexts participants brought into doctoral physics; for example, Carol came to the program not anticipating a career in academics.

Inbound. Participants identified as taking an inbound trajectory to academic physics were Laura, Victor, Lily, Sandra, David, Alice, and Molly. For many of these participants, recognition of oneself or by a meaningful other (scientific or otherwise) was an important factor contributing to an inbound trajectory. All of the participants on an inbound trajectory described either recognizing their own abilities in science, or being recognized by a significant other as having ability in physics or having achieved success in physics. Carlone and Johnson (2007) also identified being recognized as a science person or a scientist as key elements of gaining membership to a community of scientists. For participants on an inbound trajectory, recognition often began early and was often expressed as having had a childhood interest in science or physics, or by being identified in high school as a student with potential to succeed in physics, and then continued on throughout their academic trajectory. Recognition of themselves included identifying a childhood interest or ability, or feeling like a physicist in relation to other non-physicist people. Examples of recognition from significant scientific others were being selected for programs like science fairs, or being recruited into gifted high school and CEGEP programs. Recognition was also symbolic: Most of the participants in the inbound category received funding in the form of summer internships, graduating scholarships, or doctoral fellowships. For those on an inbound trajectory, positive recognition from meaningful others began early and seemed to be continuous throughout their academic careers.

Participants on an inbound trajectory also demonstrated positive interactions between recognition and significant influences in their academic lives. For example, supportive parents and encouraging teachers often provided recognition by acknowledging participants' potential to be physicists or by recognizing ability. Additionally, significant influences like role models demonstrated available subject positions that allowed participants the possibility to see themselves as physicists (e.g., a cool physicist rather than a geeky one).

Personal and institutional contexts were generally undisruptive and positive for participants on an inbound trajectory. Some participants described uncertainties, such as David's questions about the sustainability of a long-distance relationship and the time away from work that Molly would take when she gave birth, but generally those participants on an inbound trajectory did not discuss personal contexts. While it was possible that participants did not at the time have personal contexts that could disrupt their trajectories, it was also likely that they did not see these personal contexts as necessary to mention in the context of an interview or in other interactions. Alternatively, it could be that participants' commitment to their trajectory was so strong that there was little recognition that these personal contexts might derail their trajectories. Institutional contexts varied for those on inbound trajectories, but were generally positive.

Peripheral. Those participants on peripheral trajectories (Carol, Peter, and Saïd) did not discuss recognition as physicists by self or by others as much as those who were on an inbound trajectory. Constructing a peripheral trajectory meant engaging with the practices of physics and contributing to the community enough to acquire the resources necessary to be physicists, but not necessarily seeking to achieve recognition of themselves as physicists. Often, this was due to alternative career goals. Those participants on a peripheral trajectory instead demonstrated an interaction between influences, personal contexts, and institutional contexts that led to seeking career opportunities outside of academic physics, while still retaining the competencies of physicists. Wenger (1998) suggested that peripheral trajectories are out of choice or by necessity. Stories emerging from the profiles of participants on peripheral trajectories pointed to the interaction between personal and institutional (physics) contexts that influenced these trajectories.

Saïd cited altruistic purposes as a motivator for his decision to study physics. He described physics as giving him the fundamental tools to then pursue a career that would address “greater goals for humanity” and cited an interest in sustainable development that arose later in his academic career. Peter was also strongly influenced by his father who also did a doctorate in condensed matter physics, and entered into the private sector. Carol regarded her physics degree as a means to an end, and she particularly emphasized her desire for job security.

These personal contexts and influences pointed to the choice to take a peripheral trajectory, but the profiles of participants also showed institutional (physics) contexts that led to frustrations and uncertainty about continuing along an academic trajectory. Frustrations with a project that did not generate publishable results plagued Peter and Saïd, while Carol expressed her frustrations with academic language, and her doubts about administrative work in academia. These institutional contexts also contributed to these participants’ decisions to take a peripheral trajectory where they would use the resources they had acquired through doctoral studies in new contexts.

The interaction between personal and institutional contexts provided information about the direction participants’ trajectories took. However, individual motivations for entering doctoral physics were not always congruent with traditional assumptions that the degree was designed to enable entry into academia. Similarly, individual motivations for completing a doctorate change across time, thus shaping trajectories on an ongoing basis.

Outbound. The only other participant who did not intend to pursue a postdoctoral position or an academic job was Ruby. Ruby thought that she might continue teaching, but was not sure, and her future seemed also to be contingent on her partner's plans. Ruby was disillusioned with physics, and did not want to pursue a career in physics at all, for that reason. Ruby's trajectory demonstrated an interaction of recognition and personal and institutional contexts that constrained her continuation in physics and led her to look at other career options related to physics, not including academic research. Ruby's stories of recognition hinged on being identified as a stereotypical physicist based on attire and behaviour, but she did not recognize herself (or tell stories of being recognized) as taking up a subject position related to analytical, technical, or academic competence. Personal contexts such as health issues and institutional contexts such as program structure were strong influences on her participation in the physics community.

Modes of belonging in academic trajectories. Academic trajectories demonstrated different ways of becoming physicists, some that led to full membership in the participants' disciplinary subfields and some which led to peripheral membership or non-participation. Wenger (1998) discussed three modes of belonging that were indicators for membership in communities:

1. Engagement—active involvement in mutual processes of negotiation of meaning.
2. Imagination—creating images of the world and seeing connections through time and space by extrapolating from our own experiences.
3. Alignment—coordinating our energy and activities in order to fit within broader structures and contribute to broader enterprises (p. 171-174).

The trajectories presented above detailed distinct modes of belonging for participants. Those on an inbound trajectory showed evidence of all three modes of belonging. Engagement was demonstrated through the sustained practices of physics research and particularly through publication, which acted as moments of recognition in which participants could share in the history of the discipline (as detailed, for example, by Sandra in Chapter 7). Inbound trajectories were also characterized by imagining oneself fitting into the community and often recognizing oneself as a physicist both in physics and non-physics situations. Finally, those on an inbound trajectory were seen as aligning their actions with a continuing career in academic physics—this meant completing requirements for the doctoral program, publishing articles, and applying for postdoctoral fellowships.

While participants on peripheral trajectories demonstrated an engagement in the practices of academic physics and in some cases, recognized themselves as research-oriented physicists or imagined a trajectory that included physics research, they did not do the work of alignment to carry on through an academic path. This was neither by choice nor by circumstance, but rather these participants sought out other modes of belonging by looking towards other physics communities to continue along their trajectories (e.g., private sector).

Finally, an outbound trajectory was characterized by limited modes of belonging. Often, for reasons of circumstance, this meant limited engagement in the practices of the community, which resulted in limited recognition as a member of the community from colleagues. This reduced the opportunity for the participant to be recognized as a physicist, and to envision herself as a physicist in or out of the research community. Finally, Ruby did not take the means necessary to align her energy and activities with the academic physics trajectory. Rather, she sought out teaching opportunities and pursued membership in another community of practice.

Gendering choice: Telling trajectories. The most salient gender difference emerging from the participant stories of becoming physicists were not the reasons participants gave for choosing physics, but rather the stories of recognition that explained their choice. As discussed in Chapter 6, participants' reasons for being attracted to physics tended to be fairly uniform across genders. Participants discussed enjoying physics because it was precise and definitive. Participants also discussed their attraction to the philosophical side of physics, and the connection physics had to big questions about the universe including, "what is out there?" and "why are we here?" Participants discussed doing "real physics," and had different explanations for what that meant, often invoking technical or analytical competencies to explain this. Many described enjoying tinkering with equipment or solving mathematical problems.

Despite these common interests, the way participants told stories about their choices to enter physics differed considerably. All of the women participants described early experiences of expressing an interest in physics or being recognized as having ability in physics while very young. But the men in the study did not tell similar stories. While women sought to establish their connection with physics as authentic by describing an early interest or ability in the discipline beginning in their youth, the men in the study did not. Faulkner

(2007) discussed the notion that hard sciences including physics or engineering are more gender-authentic options for men than for women. To explore this, she coined the term *gender in/authenticity* to capture normative pressures of schemas about masculinity and femininity that lead people to expect the gender norm (e.g., a man physicist). Thus, as physics is regarded as an unremarkable career choice for men, the men who participated in this study gave scant justification for their choices. In fact, many of them shared stories of being interested in other subjects and then falling into physics. However, the women in this study all had stories or explanations about why they were interested in physics as children, emphasizing how their families felt about their choices, which can be interpreted as bids for recognition as authentic physicists.

Discourses of Physics

Research Question #2: How do physics doctoral students describe the practice of physics in their local contexts of research teams in a particular physics department?

Discourses with a big-D represent the combination of languages with other practices (Gee, 2005). In this section, Discourses of physics are discussed and are regarded as the combination of language with the beliefs and practices of the discipline that construct a way of viewing the world (from this local standpoint). Discourses of physics emerged from the organization of participant data into two categories: construction of boundaries between physics and non-physics, and realities versus expectations. Within those two categories, two predominant findings emerged including the so-called hardness of physics as a factor that delineates it from other disciplines and is strongly associated with masculinity, and the fundamentality of physics that gives it a romantic quality that is not experienced in participants' day-to-day engagement with their subject.

Boundaries and the hierarchy of the sciences. The Discourses of physics as presented from participant data in Chapter 6, depended on the construction of boundaries between physics and other scientific disciplines. Thomas (1990) discussed similar findings in the way physics is constructed by students relative to the humanities. She noted that physics was seen as a discipline that required understanding rather than rote learning. This narrative enshrined physics in its position in the epistemological hierarchy among the disciplines, wherein physics was awarded higher status than the other sciences. This depiction of physics was consistent with sociological research around the construction of epistemological hierarchies in science (Bucholtz, Barnwell, Jung-Eun, & Skapoulli, 2009; Knorr-Cetina, 1999; Traweek, 1998; Whitten, 1996). These constructions of physics set up a hierarchy of "hardness" among the disciplinary fields of science. Schiebinger (1999) addressed the hierarchical construction of the disciplinary subfields of physics by suggesting that they reify a Cartesian hard/soft separation of the disciplines. "[H]ardness is determined by the degree to which the science is thought to be built on fundamental laws that describe reality—[according to this paradigm], [p]hysics ranks first" (p. 162).

Part of what sustained physics as a high-status discipline was the emphasis participants placed on its foundational nature, and as an extension to this, the requirement for understanding rather than rote learning. Walkerdine (1988) discussed the production of masculinities in math through a dichotomous construction of success in math/science as dependent on either real understanding or hard work. In her work with elementary-aged girls and boys in mathematics, Walkerdine (1989) showed that a high performance in math by girls was perceived by teachers, parents, and even educational researchers as evidence of their hard work and diligence or rule-following behaviour, whereas similar performances by boys were regarded as evidence for a natural aptitude in math. Girls' hard work was praised as it was seen to make up for the fact that they needed to learn by rote, whereas boys were not praised for diligent work, but rather for their rationality. As discussed previously, the women participants in this study all provided stories about their childhoods that positioned them as authentic physicists by implying a natural aptitude or early interest in the subject.

This impulse to tell the story of how they became woman physicists pointed to the perceived unnaturalness of this choice, one that marked women in physics as unusual. The bid to be recognized as having a natural aptitude for physics is tied, therefore, to the Discourse of physics as a science for understanding.

Expectations versus realities. Participants constructed Discourses of physics as a romantic discipline. Often they made reference to exploring the mysteries of the universe, to understanding beautiful objects, and even to theology when explaining physics. Wertheim (1995) reported that physicists often describe their work as a "quest for quasi-divine knowledge" (p. 145). Rolin (2008) suggested that this quest is often understood by physicists or used as "rhetoric to advertise their research programs" (p. 1117). Indeed, information on the Eastern University website pointed to similar quests (precise citation not provided here to preserve anonymity). However, many participants reported a mismatch between the philosophical, theological, or beautiful goals of the research that was conducted in their disciplinary subfields, and the day-to-day mundane activities that they engaged in to achieve those goals. In fact, some participants reported that their activities were so abstracted from the big picture that they often had to remind themselves that what they were working on was more than numbers on a screen.

Participants' notions of real physics were grounded in abstract images of physics that were often contradictory and disconnected from the actual practices of physics. Alice talked about wishing she could go to the condensed matter lab to do some real physics on an instrument (Interview #1), and Saïd discussed the time spent troubleshooting on his instrument as time away from doing real physics (Interview #1). Ruby discussed feeling disillusioned with the way physics was done in her discipline, and felt disconnected from her actual topic, thus she actually changed her trajectory to an outbound one. The realities for these students did not match their expectations coming into physics.

Discourses of Physicists

Research Question #3. How do physics doctoral students describe what forms of physicist it is possible to be in their local contexts of research teams in a particular physics department?

Recognition was important to participants' trajectories, in particular, thinking of themselves or being thought of as physicists. Additionally, competence emerged as the measure by which physicists were deemed to be doing physics appropriately. In their study of identity construction of women doctoral students in sciences, Carlone and Johnson (2007) discussed competence as a critical element of science-identity construction, along with recognition and performance. They described these three elements of science identities as interrelated in the following way:

> For example, a scientist presenting her work at a conference must use language according to prescribed norms, dress and interact in certain ways, and demonstrate that she thinks in certain ways for others to recognize her performance as appropriately 'science-like' if she wants to be considered a scientist (Carlone & Johnson, 2007, p. 1190).

While Carlone and Johnson suggested that competence could only be ascertained through grades and/or publication record, in this study, competence emerged as an identifiable theme in participant data. Participants discussed competence as the *currency* by which individuals become recognized as physicists (Wood, 2004). In her research on the identity construction of doctoral women engineers, Wood used the term currency to denote the value of being recognized as a competent engineer. Her research found that students engaged in *posturing*, where one asserted competence in an area of engineering in order to deflect attention away from other weaker knowledge areas.

In this study, I found that participants espoused different forms of competence when they described the Discourses that made up the community of physicists. Here, Discourses with a big-D referred to the combination of language, behaviour, actions, interactions, attire, ways of thinking, and using tools that made one recognizable as a physicist (Gee, 2005). Depending on participants' disciplinary subfield and stage in their doctoral studies, he or she discussed the importance of performing three distinct kinds of competence: technical, analytical, and academic. The technical form of competence emphasized physical skills, knowing how things worked, and a proficiency at tinkering or creatively problem-solving with instruments. Analytical competence highlighted the importance of logical reasoning and intellectualism, whereas academic competence pointed both to people skills including communication, and the ability to be competitive through the disciplinary conventions of publication, procuring grant money, and conference presentations.

Technical competence. The Discourse of technical competence represented a set of behaviours or norms recognizable and valued in the physics department. Most particularly, technical competence was espoused as a necessary recognizable feature of being an experimental physicist, and thus had some disciplinary specificity. Technical competence was associated with the handling of machinery, with an ability to fix machines or understand how they work, creativity, and physical skill. Parsons (1995) described different kinds of tinkering valued among science students in laboratory work. Tinkering, according to Parsons, is valued most when it is regarded as intuitive, creative, and connected to scientific reasoning. I saw these kinds of descriptions of tinkering in participants' constitution of the Discourse of technical competence. For example, Ruby valued

Alice's ability to instinctively know why a machine hums and how it works. Lily valued the ability to be creative when troubleshooting with an instrument—whether this involved fixing the instrument or modifying it to suit the needs of an experiment.

Wajcman (1991) suggested that the control of technology is involved with archetypal hegemonic masculinity. She described this form of masculinity as based on physical toughness and mechanical skills, and further suggested "all the things that are associated with manual labour and machinery . . . are suffused with masculine qualities" (p. 142). Technical competence and practical ability actually comprised fundamental components in the cultural construction of masculinity. Wacjman argued that central to the construction of masculinity and technical competence was the absence of stereotyped femininity. However, Cockburn (1985) demonstrated that women use technologies just as much as men do, and are just as skilled as men. Yet, as seen in Lily's description of her experiences with the scanning tunneling microscope, becoming recognized as technically competent in her field could be achieved by redirecting the focus of technical competence, in instances where technologies are still not designed with women users in mind.

Over the years, research in feminist technology studies has shown how technological artifacts embody elements that were designed with implicit assumptions about the gender of the individual using the tool (Berg & Lie, 1993; Cockburn & Ormond, 1993). The gendering of technological artifacts can have the effect of maintaining power relations in a physics community. Oudshoorn, Saetnan, and Lie (2002) argued that objects can become gendered because engineers anticipate the "preferences, motives, tastes, and skills of the potential users, and the cultural norms in society at large" (p. 473), and these then become materialized into the design of the artifact. Indeed, Lily's experience with the German STM demonstrated how assumptions about who would be using the microscope pervaded the design of the instrument.

This pointed to the cultural construction of the association between masculinity and technology. Cockburn (1983) described the "construction of men as strong, manually able and technologically endowed, and women as physically and technically incompetent" (p. 203). This cultural construction of the differences between genders relied on essentialist ideas of men and women that are unproblematically connected to masculinity and femininity. As such, this Discourse resulted in limited subject positions for women as technically-competent physicists. In the case of Lily, a negotiation of this subject position was required to cast her as an expert in her field of study.

Analytical competence. The Discourse of analytical competence was centred around logical reasoning, and had strong connections to notions of intellectual elitism. Stereotypical descriptions of analytical competence included problem solving skills and the desire and ability to apply logical arguments to everything, including non-physics situations. Analytical competence was highly valued and associated with high intelligence, and was used as a strong indictor for delineating between physicists and non-physicists.

Lily described achieving a feeling of being a "smart super-physicist" when she solved a problem that required analytical competence. This type of characterization of analytical competence—as an element of doing physics that was very difficult, required a great deal of intelligence and was an elite practice—is common to cultural understandings of theoretical physics as a *hard* science, and to theoretical physicists as highly intelligent people. Schiebinger (1999) discussed physics as a hard science. She suggested that the correlation of physics with hardness of science—defined by what it studies, how it is studied and who studies it is—correlated positively with prestige and funding, and negatively with the number of women in the field. Schiebinger suggested that the question of whether physics was considered hard because of the low numbers of women in the field or whether there were so few women in the field because it was hard, was to some extent circular. “Which came first, the few women in physics, or the notion that it is hard and not welcoming to women? That physics is more difficult than other fields of study is part of its cultural image” (p. 163).

Analytical competence has a strong association with rationality. Harding (2006) argued that “objectivity and rationality . . . are persistently linked to certain models of [dominant Western] masculinity” (p. 83). Part of the problem with labeling rationality as masculine, is that it enshrines masculinity in normal science, and causes the institution of science to take up masculine practices attributed to males (Keller, 1985). However, women participants did not cite this as being either detrimental or a deterrent to their progress in physics—rather, they offered several counter examples. Laura argued that analytical competence was the cornerstone of doing good physics and rejected the association it had with masculinity, and Lily associated a positive emotion to successfully solving an analytic problem and feeling like a "smart super-physicist."

Academic competence. Perhaps the most surprising finding emerging from the descriptions of these three different Discourses of competence was the strong association between academic competence and social skills. Cultural stereotypes of physicists described them as socially inept, independent workers, and reclusive (Danielsson, 2009; Rahm & Charbonneau, 1997; Traweek, 1988). However, all of the participants in this study had to interact with others, often in large collaborations, and thus, the ability to communicate using the language of the discipline was of utmost importance. The participants who espoused the importance of academic competence largely came from astrophysics. This was not surprising given the high degree of collaboration and competition that constructed the social structure of that subfield. However, most participants discussed communication as a Discourse of competence—whether it was the ability to teach others, to share findings in social environments such as conferences, or to share findings through written documents such as article publications.

Physics generally falls at the technical end of a technical-social dualism that constructs fields like physics and engineering as focused on problem-solving and building, with little emphasis on social skills (Faulkner, 2007). However, as Faulkner showed, this technical-social dichotomy is a false one that is based largely on gendered interpretations of the field, given the strong associations between femininity and the social, and masculinity and the technical. The data collected in this study supported the challenge to this dichotomy that Faulkner posed, and went further by suggesting that not only are physicists actually engaged in institutionalized social activities, they also value the acquisition of social skills and see this as a competence that is necessary to the academic physicist. In addition to the importance of these activities noted in the participant data, my observational field notes chronicled numerous institutionalized opportunities for social interaction including weekly seminars, research group or lab meetings, teas and coffees, and visiting lecturers.

Social skills including communication were particularly valued among those on inbound trajectories. This emerged as a counter example to reports that physicists tend to be individualistic and asocial (Traweek, 1988). Many participants, both men and women, described valuing social skills, and there were examples of women who saw themselves as lacking the social skills of the academic competence Discourse, despite the strong marking of sociality as feminine (Faulkner, 2000).

However, though communication was an important element of the Discourse of academic competence, the style of communication that was most valued had gendered connotations. Carol discussed the difficulty of learning the language of physics, but more particularly, she struggled with the style of presentation of information that was valued socially in her physics community. She discussed not having the personality to interest people in her work, making reference to her boyfriend who could engage others more easily. Carol constructed a gendered notion of charisma as a valued form of communication in physics. Charisma as a personal communication style is one that is typically associated with masculinity (Holmes, 2006). Moreover, her suggestion that other physicists would be more engaged by her boyfriend's explanations of physics phenomena than by her own resonated with reports that scientists who display more prototypically masculine characteristics are often listened to more closely and taken more seriously than women in scientific venues (Conefrey, 1997; Hasse, 2002). In an ethnographic study of a physics classroom, Hasse (2002) found that the language that men used to communicate in physics was jocular, entertaining, steeped in references to science fiction, and often excluded women. Conefrey (1997) demonstrated through conversational analysis of laboratory interactions the many ways that the men in the lab used jocular comments and jovial conversation style, not only to hold the attention of other members of the lab, but also to undermine the credibility of women interlocutors or speakers in lab meetings and presentations. I did not observe this kind of behaviour in laboratory meetings with Carol, however, those meetings were small and consisted of a supervisor and a post-doctoral fellow. Even if Carol had not experienced the kinds of interruptions and discrediting that Conefrey described, her schema about what kinds of communication styles are acceptable in physics appeared to be underpinned by notions of masculinity.

I also observed counter examples to the common perception that men prefer competitive learning environments and women prefer collaborative ones (Hasse, 2002; Lorenzo, Crouch & Mazur, 2006). The disciplinary subfield that emphasized competition the most was astrophysics. This was also the subfield in this study that attracted the most women, and had the only woman primary investigator. However, the kind of competition that I observed was not the competitive individualism that Traweek (1988) described in her ethnographic study of high-energy physicists. Rather, the environments that I observed emphasized competition between research groups, and thus demanded collaboration within each group. Both women and men in this study emphasized that competition was an important part of his or her discipline, but both women and men participants also described preferring to work in collaborative environments. Saïd in particular was disappointed with the competition and hierarchical structure of North American physics departments, and claimed to prefer a more collaborative environment.

Stereotypical physicists. In participants' talk about recognizing physicists, they almost uniformly constructed Discourses that portrayed images of physicists that relied heavily on the stereotypic nerdy male who was socially inept and sartorially challenged. The images that participants constructed were consistent with those found in the literature. Tonso (2006) identified numerous categories for engineers that were associated with geekiness or nerdiness, all of which bore localized nuances around what defined nerds and geeks, but were related to broader Discourses of social ineptitude and awkwardness, and all of which were categories almost exclusively for men. Traweek (1988) described a disciplinary uniform for theoretical physicists that transgressed cultural boundaries. She described seeing images of trans-national research teams, wherein all of the physicists dressed similarly, indicating that there were no cultural issues among them, and signifying that culture was not an issue that influenced their activities as physicists. Wood (2004) similarly described a culture of sameness among engineers wherein doctoral women felt that there was a dress code with which they had to comply.

The image of the disheveled, unkempt physicist had significance, as it allowed one to be recognized as a committed doctoral student. Laura discussed often not having time to take care of her appearance, and even told a story of a friend who would dress down for her supervisor. Wood (2004) discussed the notion among women doctoral engineers that "the level of difficulty of the engineering workload left little time to be spent on appearance" (p. 244). Similarly, Dryburgh (1999) discussed the conformity in appearance among engineers as a symbol of membership or solidarity.

The images of physicists that participants provided were seemingly universal, however, very few of the participants involved in this study actually performed this stereotype, and there were many more counter examples of women and men who resisted this stereotype, both in how they dressed and behaved, and in how they talked about their own resistance to or modification of the stereotype. Thus, there was a contradiction between the Discourses participants constructed about physicists and the ways that participants performed images of physicists. This contradiction was a significant one: All of the descriptions of physicists were male. This indicated that while participants may have performed a diversity of physicist types, they still recognized the archetypal physicist as male. Yet, and in an even greater paradox, when asked about gender performances in physics, they suggested that they regarded the gender performances of physicists as gender neutral.

Neutralizing gender. There is a contradiction between how women participants described physicists doing gender and how they described themselves doing gender. Although many women discussed feeling their gender was visible or invisible, or wished to have more space to express femininity, they predominantly identified the Discourse for appropriate gender performances in physics as gender neutral. In the physics community, gender became invisible, androgynous, or as Carol phrased it, unisex. However, counter-examples abounded and it became clear that gender neutral, in the case of the physics department, meant not-feminine.

The Discourse of gender neutrality in performances of physicist seemed to reflect how physics is constructed as a science that produces universal, value-neutral, and objective knowledge, independent of societal factors (Schiebinger 1999). Harding (1998) discussed how physics and physicists are understood to be void of culture due to formality and abstractness. For example, Traweek (1988) provided examples of artifacts that enshrined the Discourse of gender neutrality in physics communities. She reported on photographs lining the hallways of research groups, the members of which were all dressed in the same physicist uniform, indicating no cultural or gendered variation. Traweek suggested this was representative of “a culture of no culture,” a phrase she used to explain how objectivity was understood to be a distinctive cultural feature of physics (p. 144). Physics, in this way, was associated with rationality, objectivity, and logic—

features that have been historically also associated with masculinity (Harding, 1991; Keller, 1992; Kelly, 1985). The unproblematic association between masculinity and maleness constructs a similarly unproblematic association between physics and maleness. However, when rendered within a culture that sees itself as objective or a culture of no culture, the cultural associations with masculinity and maleness are erased. The trouble this poses to the production of gender and identity in physics is that the scientific mind is then regarded to be simultaneously and contradictorily disembodied and male (Keller, 1992).

The paradox of the Discourse of gender neutrality is that while participants described gender performances in physics as gender neutral, they discussed the stereotypical physicist in masculine terms. Masculinity, then, became neutralized, or unmarked (Salzinger, 2004; Tannen, 1993). The default physicist then, was described as a man, but was also not regarded as having gender. In this way, the physics community can effectively police the boundaries of gender, as any non-gender conforming performance (read: expressions of femininity) may be regarded as different or Other. As Keller (1985) pointed out, this poses a conundrum for any scientist who is not a man, or who does not conform to the default or gender-neutral ideal of masculinity in the physics community.

Available Subject Positions for Women in Physics

Research Question #4. How do women doctoral physics students use their schema and resources and the available forms of physicist to participate in their research groups and physics department, and to construct their identities as physicists?"

Subject positions are made available to persons through Discourses. Individuals may position themselves around these by drawing on their schema and resources from previous experiences and the Discourses that define who it is possible to be in the physics community. Individuals also accept or negotiate subject positions in order to be recognized, either fully or in part, as being a certain kind of person (Gee, 2000). Positioning around a subject position implies a tension between the structuring elements of that subject position (and the Discourses that limit or make available subject positions) and the choice that an individual has to accept, refuse, or negotiate that position. Examples of positioning were found to take on the forms of accepting or negotiating participation in the subject positions for physicist (Holland et al., 1998). However, accepting and negotiating subject positions in physics did not always involve a simple matter of participation in the practices associated with that subject position (Wenger, 1998). In some cases (e.g., Carol), negotiation meant refusing participation in some of the Discourse practices associated with a subject position, while participating in others. Here I will discuss the complex ways in which women negotiated subject positions, and the issues of gender, ethnicity, socioeconomic status, and language practices that emerged from these stories.

Accepting subject positions for physicist. The stories that emerged from the data showed that accepting a subject position as a certain kind of physicist did not always mean accepting the gendered connotations associated with that subject position. For example, Laura accepted the subject position for analytical competent physicist, but rejected the Discourse of masculinity that was associated with that position. Alice accepted the subject position offered by the Discourse of gendered neutrality of physics by presenting her gender in what she termed an “androgynous” performance. However, she did so reluctantly, feeling as though she compromised the expression of femininity that she wished to perform otherwise. This was interpreted to be an example of what Butler (1993) termed *passing* across gendered boundaries of acceptable performance in physics. Here, passing is understood as the act of pulling off a Discourse that positions oneself in a false subject position. On the other hand, Ruby’s acceptance of the subject position defined by the Discourse for stereotypical physicist involved the simultaneous rejection of stereotypical femininity, thus constructing difference between women who did physics and other women.

Sandra’s story was the one exception to these complicated examples of positioning. Sandra’s acceptance of the subject position offered through the Discourse of academic competence appeared seamless. This was discussed with respect to the schema and resources Sandra had access to, and demonstrated how resources like confidence and good supervision articulated with the Discourses of academic competence in ways that allowed her to accept the subject position offered through this Discourse relatively unproblematically.

These stories demonstrated that accepting a subject position for physicist was not a simple matter, and gaining recognition as a physicist required the acquisition and use of schema and resources necessary to take up these positions. Sometimes accepting subject positions also involved passing in order to be recognized as an authentic physicist. Gendered passing and gender authenticity in physics relies on the reification of the masculine/feminine binary persistent in cultures of physics (Danielsson, 2009; Keller, 1985; Traweek, 1988). The following two subsections describe ways that women participants in this study constructed their difference from other women and from men, thus calling into question the existence of subject positions for women physicists, and raising the issue of authentic gender performances for women in physics.

Constructing difference. Ruby described being the kind of person that exhibits eccentric behaviour consistent with the subject position for stereotypical physicist. In taking up the subject position for stereotypical physicist, she also positioned herself as different from women who were not physicists. A combination of both of these subject positions (stereotypical physicist and not-stereotypical femininity) helped Ruby to gain recognition as a physicist. Ruby did this by relying on the persistent dichotomy between masculinity and femininity, and physics and non-physics to construct “girly girls” as incompatible with physics. Keller (1985) and Schiebinger (1999) suggested that the foundation of modern Western science associated masculinity with the qualities of rationality, objectivity, and rigorous intellectual inquiry, at the same time that femininity was associated with emotion and subjectivity. Ethnographic studies of science research units demonstrated that the masculine and feminine dichotomy persisted through the assumed superiority of the appearance of the White, middle-class male, and the valuing of the characteristics of the competitive individualistic scientist (Margolis & Fisher 2002; Traweek 1988).

Further evidence for the persistence of this dichotomy was seen in the construction of subject positions for physicists and non-physicist women explored in this study. The subject positions for physicists relied on cultural stereotypes about physicists that drew on the Discourses for physics and physicists discussed in Chapters 6 and 7, and tended to be constructed for men. Subject positions for women in physics relied on two forms of difference including difference from the *physicist* and difference from the non-physicist woman. I have placed physicist in italics because the Discourse of the stereotypical physicist was always constructed as male with the various characteristics associated with masculinity. Thus, subject positions for woman physicist that do not rely on some form of difference (from men or from other women) did not seem to exist.

In Chapters 7 and 8, I provided examples of women who suggested that they were not interested in or comfortable with activities and performances typically associated with women. For example, in Chapter 8, Ruby rejected stereotypical subject positions for women that were defined by femininity (e.g., girly girls), positioning them as incompatible with physics. Similarly, in Chapter 7, Carol discussed her disconnect with other women who performed stereotypical femininity. At the same time, there were examples of women including Molly and Lily who regarded themselves as different from the stereotypical male physicist (discussed in Chapter 7).

These stories of positioning revealed instances of women rejecting stereotypical subject positions for physicist and simultaneously rejecting Discourses of stereotypical femininity. By positioning femininity outside of physics, these women simultaneously positioned themselves as different from what Ong (2005) called *ordinary women* (who perform stereotypical femininity). Henwood (1998) and Walker (2001) also observed that women position themselves as tomboys, taking up subject positions as different from other women "who remain, by definition, weak and unable to cope in a man's world" (Henwood, 1998, p. 41). Henwood argued that this positioning challenged the dominant Discourse that women were weaker than men, but the result was an Othering of more gender-conforming women, which in fact operated to reinforce that Discourse.

In/authenticity. Keller (1985) used the term *gender inauthenticity* to describe the passing women must perform in physics in order to take up a physicist subject position or to be recognized as physicists rather than women. Faulkner (2000) used this term to "capture a sense that a woman who chooses to go into a male-dominated occupation is in some way putting aside or undermining her feminine gender identity" (p. 787). Later, Faulkner (2007) adapted the term inauthenticity to in/authenticity to "capture the normative pressures of 'the way things are'—pressures that lead people to expect the gender norm (in this case, the man engineer) and to notice when they see something different (the woman engineer)" (p. 333).

Passing, or pulling off a Discourse related to a false subject position, is achieved through "corporeal self-presentation, performance, and management of social interactions" (Ong, 2005, p. 603). Passing enables an individual to avoid the marginalization associated with their original social group, and instead enjoy the benefits of fitting into the dominant group. Ong (2005) argued that this is a fragmenting process, because passing requires one to maintain the Discourses of the subject position one is taking up in order to maintain an appearance of ordinariness, by downplaying other cultural or gendered parts of themselves. In Chapter 7, I presented the cases of Laura and Alice and I suggests that they do the gendered work of passing in order to be recognized as authentic physicists.

Bids to be recognized as doing an authentic performance of a physicist Discourse also appeared to be spatially located, resulting in individuals taking up multiple gendered subject positions in and out of physics. Laura discussed performing the Discourse of an authentic stereotypical physicist by indicating that she too had donned portions of the uniform that go along with it. However, to meet Laura in person painted a very different picture. Outside of the department, and on occasions when I met her socially, her self-presentation fit with stereotypical femininity. She also told stories about colleagues who dressed down for meetings with their supervisors, but dressed up for events where there were opportunities to flirt with men. These spatially-located performances of gender might be seen as a form of gendered code-switching, and were evidence for localized femininities and masculinities.

Similarly, Chapter 8 presented the story of Alice, who described wishing that she were more comfortable expressing femininity in her physics environment. Instead, Alice suggested that she experimented with finding spaces to perform femininity outside of physics. This kind of public/private conundrum that Alice was faced with fit with both Keller (1985) and Faulkner's (2009) notion of gender in/authenticity. Alice suggested that she cannot subvert the gender order in physics for fear of feeling awkward or out of place and therefore must conform to the gender-neutral Discourse in the department. Thus, Alice presented us with another example of the strategy of gendered passing. Using Ong's (2005) term, Alice experienced this passing as fragmenting, as she described the difficulty in finding public spaces where she felt comfortable expressing her femininity, and was always aware of feeling awkward or standing out.

Another example of passing can be told from Ruby's experience as a woman of colour in the physics department. Ruby's story of positioning told us much about the intersection between the notion of stereotyped femininity employed in this study and a White, Western construction of femininity. Morse (1997) suggested that this type of femininity, what Wajcman, (1991) called *stereotypical femininity,* was generally constructed in opposition to technology and was "culturally circumscribed: it is Western, and probably heterosexual, as well as racially inflicted with 'whiteness'" (p. 25).

Ruby's association with the subject position offered through the Discourse of the stereotypical physicist was in some ways a bid to be recognized as an authentic physicist—an identity she was unable to obtain for herself by other means. However, in positioning herself as a stereotypical physicist, she was not just rejecting femininity; instead, Ruby dissociated herself from dominant Western femininities. Ruby was of Middle-Eastern origin and thus could easily distance herself from the girly girls that she saw, performing a type of Western femininity that Ruby did not associate with. In doing so, Ruby asserted a contradiction between girly girls and physics, thus reifying the discontinuity between Western femininity and science.

Hughes (2001) has identified similar forms of positioning around Discourses of science and femininity by girls of colour who seek to position themselves against "conformist, white, middle-class subject positions" defined by femininity (p. 284). Hughes describes girls of colour taking up science subjectivities, despite demonstrating less than exceptional achievement in science, by not adhering to gender binaries and rather redefining new gender and science subjectivities for themselves. Ruby's positioning against the white, Western femininity of the girly girl may be seen as an attempt to pass as a recognizable physicist. Thus, her positioning constructed a new subject position for her, or as she put it, "a different kind of femininity" as a woman of colour in physics (Interview #2).

Negotiating subject positions for physicist. Chapter 8 revealed instances of women negotiating subject positions for physicist. Lily used resources acquired in her undergraduate program to negotiate the limited subject positions offered through the Discourse of technical competence as it was locally constructed in her laboratory environment. Lily's negotiation resulted in the construction of a new form of expertise that afforded her recognition as a technically competent physicist. However, Lily's negotiation was not optional, it was required because the gendering of the instrument she worked on rendered it otherwise prohibitive for her. In a community that valued gender neutrality, the gendering of this instrument pointed to the underlying assumption of maleness associated with the gender neutrality. Lily's negotiation of this instrument might be seen as a visible gender performance.

Molly's story was also an example of negotiation of subject positions available to women in physics. Pregnancy for Molly meant making her gender very visible by necessity. To receive the institutional support she needed (e.g., maternity leave), she had to assert this difference. Pregnancy itself was not a gender performance, but rather a biological phenomenon that signified Molly's sex. However, in the physics community, Molly's pregnancy came as a disruption to the perceived gender-neutrality of identity performances in the community. Thus, as a pregnant woman, Molly received mixed reactions from her colleagues, including reactions that rendered her invisible as a physics colleague.

Carol's story demonstrated a unique example of negotiating the subject position offered by the Discourse of academic competence. In this case, Carol did not script a new subject position for herself in physics. Rather, Carol's example showed a rejection of a certain component of that Discourse for academic competence (e.g., oral communication). Emerging from this story were the importance of schema and resources (e.g., job security, language practices) Carol acquired through a family history of non-participation in academic cultures and a concomitant peripheral trajectory leading away from an academic position in physics, while still retaining aspects of a physicist identity.

In/visibility. Stories of negotiating subject positions revealed evidence of what Faulkner (2009) termed the "in/visibility paradox" (p.181), where performances and negotiating subject positions makes the actor both visible and invisible. There were several examples in the data of women who, despite asserting their femininity elsewhere, adopted a performance of supposed gender neutrality in order to fit in to the community of physicists. Chapter 7 revealed instances of women who described the culture of physicists as “unisex” (Carol, Interview #1), or described dressing androgynously (Alice, Interview #2). However, as described previously, although a Discourse of gender neutrality was professed by participants, the stereotypical physicist was constructed as male by default, or at least non-feminine. Faulkner (2009) described fitting into a masculine culture like engineering or physics as an extra layer of work that women must do to be seen to belong to the community. However, when it comes to gender performances, fitting in is not always seamless.

For example, as discussed above, Lily’s gender presentation was made clearly visible by the negotiation she performed to be recognized as technically competent on her instrument. However, in Chapter 7, evidence was presented pointing to the invisibility of her gender among male colleagues. Lily described wondering if her male colleagues “notice that [she’s] a girl,” when they had discussions about dating other women in front of her, a situation that left her feeling strange (Lily, Interview #2). In this case, rather than her gender being made visible, she was treated as “one of the guys” (Wood, 2004, p. 243). In this sense, Lily’s gender was simultaneously visible and invisible.

Whereas Lily felt as though her gender was at times invisible, Molly’s was anything but. Becoming pregnant in the middle of her doctoral program meant that Molly’s identity within the department shifted. Where she may have been visible before, because she subverted the dominant stereotype for physicist by dying her hair different colours or listening to different music, now she stood out for being a woman, and a sexual woman—signified by her pregnancy. Kvande (1999) contended that "by being pregnant, the women erase the idea of gender neutrality in the workplace" (p. 307). However, the result of this might have been that Molly was not recognized as a physicist by some of her colleagues. Reaction to Molly's pregnancy ranged from those who ignored the pregnancy to those who ignored her. The interpretation that followed from this was that if her pregnancy was ignored (if people failed to mention it), she was not recognized as woman, but she was still recognized as a physicist by these colleagues. However, in cases where she was ignored entirely, she may not have been recognized at all, either as a woman or as a physicist.

Thus, while Molly asserted her gender identity as a woman and mother (in follow-up conversations with Molly I learned that she sometimes brought her daughter to work, especially during times when she was breast feeding), there were others who ignored these obvious performances of gender, rendering her invisible as a physicist. Etzkowitz et al. (2000) discussed the messages that pregnancy in graduate school sends to colleagues. They argued that a pregnant student is often interpreted as unreliable, not serious about their studies, and will not have time to devote to their studies or research. Along with the dissonance that Molly's pregnancy caused, this perception about pregnant women may be related to her in/visibility.

Intersection of academic language and socioeconomic status. Carol's story highlighted the barriers to membership posed by the conventions of scientific *d*iscourse on student participation in communities of physicists, even at the doctoral level. Studies at the doctoral level examining the intersection of social class, language, and culture in scientific discourse in physics are scant (Danielsson, 2009). Lemke (1995) discussed the various ways that scientific talk restricts available subject positions for students by limiting the ways of talking science that are acceptable or recognizable in the science community. Carol's story of negotiating the subject positions made available in the Discourse of academic competence revealed an intersection of family history including socioeconomic status, and language as influential to Carol's modes of belonging.

Carol described being the first member of her family to attend university, and discussed the difficulty that this posed for her when she tried to explain her work to her friends and family who were not in physics. This experience caused her to feel Othered from her community at home, but also set up a situation of a double bind, wherein the language and behaviours of academic life in physics were also alienating to Carol.

Carol rejected the oral communication practices valued in the Discourses of academic competence. As such, she seemed unable to recognize herself (or in her opinion, be recognized by others) as a physicist in academic terms because she had difficulty communicating orally using the jargon of the field. However, Carol got a significant amount of recognition by others through her grant proposals and publications. Thus, this part of the Discourse of academic competence Carol seemed to accept. Her experiences and contexts discussed in

Chapter 5 revealed much about the schema and resources Carol brought to her practice. Her family goals and the importance of job security seemed to direct her trajectory, and were also perhaps a reflection of her family history. Thus, Carol did not align her trajectory to an academic one, but rather sought out a career trajectory that was more in line with her personal goals.

Interrogating Gender

In this final sub-section, I address heteronormative construction of femininity and masculinity employed in this study. Throughout much of this analysis, I pointed to instances where participants positioned themselves in opposition to what Wajcman (1991) referred to as stereotypical femininity. This notion of femininity is constructed in what Butler (1990) termed the *heterosexual matrix*. Within the heterosexual matrix, certain gendered behaviours are assumed in order for gender to be intelligible. That is, bodies and gender performances must cohere in a way that is consistent and knowable: "There must be a stable sex expressed through a stable gender (masculine expresses male, feminine expresses female) that is oppositionally and hierarchically defined through the compulsory practice of heterosexuality" (Butler, 1990, p. 151). Thus, stereotypical femininity takes the form of a heteronormative femininity—the boundaries of which are policed by communities that determine what kinds of behaviours are admissible for women and for men (Butler, 1990). In this research, the Discourse of stereotypical femininity was pervasive in the way participants (mostly women) talked about being a women, and as a stereotype, femininity became essentialized in participant talk. These normative conceptions of femininity are not exclusive to physicists. They are reflective of wider gender norms in which stereotypical femininity represents a recognizable standard of gender intelligibility (Butler, 1990). According to Butler, people only become knowable once they are gendered. Society's dependence on this dualistic, heterosexual notion of gender (through the recognition of masculinity and femininity) may underlie physics' resistance to gender normative pressures for change, as documented in the literature (e.g., Bug, 2003; Danielsson, 2009; Danielsson & Linder, 2008; Rolin, 2006; Tsai, 2004).

Chapter Summary

This chapter offered an analysis and discussion of the findings presented in Chapters 5, 6, 7, and 8. Participants' contexts and experiences identified in Chapter 5 were discussed using Wenger's (1998) concept of trajectories and modes of belonging as organizing concepts. Analyzing the stories of contexts and experiences that led to participants' pursuit of doctoral degrees in physics using Wenger's concepts was useful in important ways:

1. It permitted an examination of the similarities and differences in the participants' experiences and contexts, and allowed for a comparison of these with the various goals and trajectories of participants.
2. It allowed an analysis of the ways participants engaged with the physics community, and helped to determine how contexts and experiences provide resources that enable or restrict that engagement.

Emerging from this analysis was the salience of competence as the currency by which participants get recognized as physicists (Wood, 2004). However, the different forms of competence discussed (technical, analytical and academic) were demonstrated to be imbued with the gender ideologies of the discipline. The link between analytical competence and Discourses of physics in particular, demonstrated a link between masculinity and the perceived hardness of physics (Shiebinger, 1999). Additionally, the analysis of academic competence revealed a challenge to the technical and social dualism typically associated with the field (Faulkner 2007).

Finally, an analysis of the various subject positions that emerged from these Discourses was presented and discussed *vis-à-vis* the constructs of gender in/authenticity (Keller, 1985; Faulkner, 2007) and in/visibility (Faulkner, 2009). These concepts helped to demonstrate the complicated ways that women accept, reject, or negotiate subject positions in physics, and the implications these actions had for their recognition as women and as physicists. Emerging from these discussions were the issues of class and race as intersecting constructs that bore influence on experiences in physics. The issue of intersectionality will be discussed further in the next chapter.

Chapter 10

Conclusion

This dissertation began with a vignette that shared my experiences as a visitor in a physics laboratory. I shared that story to give a sense of the kinds of gendered boundaries that are constructed around physicists and their practice, and that give the impression that only certain kinds of people can be physicists. Deemed to be a hard science, physics is often regarded as a practice reserved for the intellectually elite and the stereotypical male physicists that come along with these associations (Schiebinger, 1999; Traweek, 1988). The findings shared in this dissertation helped to reveal that while those stereotypical ideas still abound, the actual people and practices that make up this local community are a heterogeneous group, and the practices of physics are as varied as its participants.

The goals of this dissertation were to explore, theoretically and empirically, how doctoral students constitute Discourses of their field and how they position themselves around these Discourses. In particular, I sought to identify ways in which Discourses offer limited and/or gendered subject positions, and to explore how participants negotiate these positions. Understanding Discourses and positioning, of course, also meant learning something about the participants themselves and the academic trajectories they took. This helped to elucidate the temporal and spatial location of Discourses and to understand the schema and resources participants acquired along these trajectories that then played a role in positioning them around subject positions.

The overarching research plan was guided by the following four questions:

1. What are the experiences and contexts that have contributed to doctoral physics students' academic trajectories?
2. How do doctoral physics students describe the practice of physics in their local contexts of research teams in a particular physics department?
3. How do physics doctoral students describe what forms of physicist it is possible to be in their local contexts of research teams in a particular physics department?
4. How do women doctoral physics students use their schema and resources and the available forms of physicist to participate in their research groups and physics department and to construct their identities as physicists?

To conclude the dissertation, this chapter presents a summary of the findings, guided by these four research questions. I then discuss insights gained from the study, limitations, and future directions for research in the field. Finally, implications for researchers and teachers in the field are presented.

Summary of Findings

Trajectories. The experiences and contexts that participants narrated in interviews and through photo-journals revealed four elements that were influential to their academic trajectories: recognition (by self and others), influences from significant others, and personal and institutional contexts. Consistent with previous research, recognition as a competent physicist emerged as an important element to participants' inbound trajectories into academic physics (Carlone & Johnson, 2007). Recognition by others often came in the form of encouragement from significant scientific or non-scientific others (e.g., professors, teachers, or parents), or as symbolic recognition in the form of grants, awards, or publications. Recognition of self as a physicist emerged as an important element influencing trajectories, particularly of interest were stories of early recognition, indicating a lifelong interest or aptitude in physics. Influences from significant others were also important for participants' trajectories. Often these were parents or family members, some of whom had science backgrounds. Significant others also often included role models—individuals who did not fit the physics stereotype and who allowed participants' to see themselves doing similar work.

Personal and institutional contexts also seemed to be related to participants' trajectories. Those participants who described positive experiences with physics, and who seemed to have lifestyles that supported academic careers, were characterized as being on an inbound trajectory. Participants who struggled with their research, or who did not develop a liking or a proficiency for academic language and the academic lifestyle where characterized as leaning towards peripheral career trajectories.

Finally, there was one participant whose institutional and personal contexts led her to become bored and disillusioned with physics. Related to these contexts was the fact that she was not recognized by significant others as a physicist. These experiences were characterized as related to this participants' outbound trajectory.

Emerging from these stories was the notable distinction between the way that women and men described their early interests in physics. Women participants tended to emphasize their early interests or experiences with physics, often detailing childhood experiments and obsessions with scientific matters particularly related to physics. No man in the study revealed the same kind of early interest or aptitude for physics. This was interpreted as the women's bids to be recognized as naturally suited for a discipline with which they are typically not affiliated. The lack of these bids by men was interpreted to reflect the naturalness associated with men's participation in physics due to the gendering of physics as masculine by society in general.

Discourses of physics. Overwhelmingly, participants in this study described physics as precise, definitive, and a science that required understanding, not just rote learning. This was achieved by constructing boundaries between physics and other disciplines, often describing physics as requiring more concentration or understanding. The effect of this was to enshrine physics in the hierarchy of the sciences as the most foundational discipline, and concurrently, the hardest. This Discourse of physics was related to another Discourse of physics that participants described as linked to philosophy, romance, and even theology. Participants, particularly those from astrophysics, discussed physics as a discipline that holds the potential to understand big questions about the universe and our place in it—questions that are not answerable by the other scientific disciplines. Many participants described this and the precision of physics as the reasons that attracted them to the discipline. However, participants' experiences of physics in graduate school contrasted with this Discourse of physics. Some participants described being disillusioned with the number crunching or machine repair work that was the daily work of physics, and described these as distractions from what they interpreted as "real physics." The Discourses of physics, like the Discourse of physicists discussed below, were often constructed in stereotypical terms that did not quite fit with the actual practices that participants engaged in. As such, there seemed to be a misfit between the ideas about physics that attracted participants to the discipline and the participants' actual work of doing the physics.

Discourses of physicists. Participants' descriptions of the recognizable qualities of physicists revealed two types of Discourses: Discourses of competence for physicists (technical, analytical and academic) and Discourses of stereotypical images of physicists. Discourses of competence yielded three different types of competence recognized as associated with doing physics appropriately. From the analysis of Discourses of images of physicists emerged two types of physicist: the stereotypical physicist and the gender-neutral physicist.

Discourses of competence. Participants discussed technical competence as necessary for experimental physics and desirable in other subfields like astrophysics. Technical competence was closely associated with the ability to understand how machines and instruments work, and having the creative and physical skill to operate or fix them. However, performances of technical competence can be limited by instruments that are not designed with different kinds of operators in mind.

Analytical competence was most closely associated with the physics Discourse—particularly the connection between logical reasoning and intellectual elitism. This type of competence was deemed most necessary for theoretical physics, and was associated with intellectual elitism in the field. Analytical competence was often invoked as an idealistic portrayal of physicists, associated with the idealism of the physics Discourse.

As discussed in Chapter 7, participants who, at the time were concerned with procuring postdoctoral positions or jobs discussed academic competence most predominantly. This indicated the temporal and disciplinary specificity of these Discourses, and related them to the kinds of trajectories participants were on, in addition to their stage of degree completion. The Discourses of academic competence were largely social ones and involved being able to be communicative and competitive in one's subfield. This type of competence emerged in contrast to stereotypical perceptions of physicists as an asocial group (Traweek, 1988). Rather, participants described physicists who can make social connections, demonstrated communication skills and had the ability to work collaboratively and competitively.

Discourses of images of physicists. Despite recognizing the importance of being social people who do not present themselves in stereotypically sartorially-challenged ways, participants in this study still invoked Discourses of physicists that relied on cultural stereotypes. Many participants discussed typical physicists as easily recognizable because of their geeky awkwardness and poor fashion sense. Additionally, in all of the descriptions of physicists that participants gave, the default gender was male. This description was in contradiction to both their own personal presentations and their descriptions of gender performances by others in the field. Despite identifying the average physicist as a male, participants described physicists as largely gender neutral, and some described the appropriate style of dress in physics as androgynous or unisex.

Positioning. Subject positions offered by the prevalent Discourses of physics and physicists were defined by various forms of competence, by stereotypical images of physicists that tended to be male, or emphasized androgyny. Participants were found to accept or negotiate these subject positions, sometimes in improvised and innovative ways, and sometimes in ways that constructed new, previously unavailable subject positions (e.g., pregnant physics student).

Emerging from the stories of positioning told in Chapter 8 were a number of themes related to gender that have been supported by previous research on physics and engineering fields (Faulkner, 2007, 2009; Tsai, 2004; Walker, 2001, Wood, 2004). In positioning stories, evidence emerged that women often made attempts to neutralize their gender expressions or pass in order to be recognized as a hard-working dedicated physicist (Ong, 2005). For some participants, this resulted in in/authentic presentations of gender that left one participant concerned about finding locations to express her femininity. Positioning also stories told of how subject positions for women in physics were constructed as different from men, but also different to other women. Additionally, technologies designed for men require women to reconfigure subject positions that render them visible in their difference. Issues of gender in/authenticity emerged in relation to the construction of physicist Discourses as either stereotypically male or gender neutral (Faulkner, 2007). Conversely, evidence also showed that gender neutrality and the subject position of the stereotypical physicist could be occupied comfortably by women in their attempts to be recognized as a physicist.

Finally, Chapter 8 also revealed how socioeconomic status and ethnicity interacted with gender in participants' positioning around subject positions for physicists. These issues were concerned with typically masculine and middle-class expectations for forms of communication and drew attention to the particular type of White heteronormative Western femininity that was constructed both in the study and in the physics community.

Contributions

This research provided insight into the experiences and contexts that shape doctoral physics students on their trajectories to becoming physicists. Previous studies have focused on individual's doctoral experiences (Wood, 2004), Discourses of physics (Tsai, 2004), and positioning within Discourses and subject positions (Danielsson, 2009). A particular contribution of this study was the salience of the interweaving of participants' schema and resources acquired from past experiences, and contexts with the Discourses of physics and physicists and the subject positions made available by these. Each of these analytic foci revealed new information about doing physics that contributed to our understanding of the doctoral student experience in physics. For example:

- The identification of student trajectories gave insight into the influences of the past experiences and contexts on participants' modes of belonging in academic physics.

- The identification of Discourses of physics and physicists demonstrated how students constructed boundaries around what constituted physics and non-physics, and how they used these boundaries as mechanisms to achieve recognition; Discourses also revealed discrepancies between student expectations for their experiences in doctoral physics and the realities of doing physics.
- Discourses of physicists revealed the types of competencies that were valued in physics; and also demonstrated the persistence of a stereotypical male image of physicists, despite an insistence that physicists were gender neutral. These Discourses shed light on the ways that difference was constructed in the practices of physics.
- Stories of positioning demonstrated a confluence of schema and resources with the subject positions available to participants through Discourses, and thus gave insight into how women doctoral students negotiated issues of in/visibility and gender in/authenticity in physics.

The findings in this study also highlighted some of the institutional and personal contexts that may act as barriers to doctoral students' transformation into academics including oral communication practices that limit participation to those with certain language resources, limitations posed by equipment in constructing do-able research projects, and the negative effects that health issues pose to participation in community practices. This research also gave attention to forms of recognition and influences that may also relate to students' persistence in the field, particularly positive recognition by meaningful scientific others in the form of mentorship or symbolic recognition including grants and awards and the importance of participants' recognition of self as physicist.

Some of the findings herein demonstrated that widespread stereotypes of physics and physicists persist even among doctoral students, despite the fact that their activities and performances do not reflect these stereotypes. This finding pointed to the entrenchment and naturalization of ideologies such as masculinity and elitism in the constitution of Discourses of physics and physicists. However, the good news is that participants in this study, men and women alike, sometimes found innovative ways to negotiate these Discourses. This study also highlighted the importance of the social in physics, an element of physics education that is often ignored or underplayed (Faulkner, 2007).

Methodological considerations and limitations of the study

Looking back on the research presented in this dissertation, there are a number of methodological and analytical issues that are necessary to reflect upon and discuss, as well as suggestions for future research. In this section, I provide reflections on ethical considerations, participant verification, participant recruitment, methodological considerations pertaining to the study of structure and agency, and the importance of attending to intersectionality in research design.

Ethical considerations. A number of methodological constraints arose as I conducted this study, many of them influenced by an ethic of care for the participants as well as participants' concerns to preserve anonymity and privacy.

Working in a local environment of a physics department presented a number of challenges for anonymity. In many cases, important attributes about participants' ability, sexuality, and gender identity were concealed to protect individuals' anonymity and privacy. This limited a richer, intersectional analysis that might have been possible with this information available. At the same time, I endeavoured to retain the voices of individuals to show the complexity and variation of identity construction in such a setting (Luttrell, 2000).

Participant verification. This dissertation is the end result of research that took place in the third year of my doctorate. Reflecting back on the process allowed me to consider some different possibilities I might have taken when designing the methodology. First, my decision to collect narrative data, mostly from interviews, restricted the possibilities for participant involvement in the research design and implementation. To circumvent this, I used photo-elicitation as a means to allow the participants to share their voice in the interview process. However, while the analysis was shared with participants, as I reflected back I could see the advantages of involving participants more in the analytic process. This might have entailed holding focus groups to discuss the outcomes of the analysis—a method that would have strengthened participant verification and would have allowed for an analysis of participant trajectories and Discourses over time.

Participant recruitment. Because of the small size of the participant sample involved in this study, it was not possible to generalize results to other physics departments or to other populations. However, the goal of this study was to identify Discourses of local practices and to explore how individuals negotiated these Discourses, so the small sample size and the detailed data collection and analysis it allowed was not viewed as a limitation, but rather an affordance. Additionally, while there were a few participants from minority backgrounds involved in the study, the participants who elected to participate were by no means a representative population of physicists. For example, there was a large population of Chinese students enrolled in doctoral studies in the physics department but none of these students showed interest in participating in the study. With the inclusion of a broader representation of the diverse members of the physics department, the analytic lens of the study might have changed to reflect issues of race, class, and ability, although it is likely that participant concerns about anonymity and privacy would have still occurred.

Methodological reflections on structure and agency. Further research into the co-construction of gender and physics could benefit from an exploration of the interplay between structure and agency in students' identity constructions through their practice in physics (Sewell, 1992). This could be achieved by using methods that allowed for the identification of the use of resources in enactments of agency at the micro-level in moment-to-moment interactions (Seiler & Elmesky, 2003). Although I did partake in observation, I was unable to obtain permission to video or audiotape meetings and symposia, so an analysis of positioning and discourse at the micro-level of interaction was impossible. This was an important methodological limitation, but not one of my own making. Future research in this area could benefit from developing a method that circumvents anonymity concerns yet still manages a closer look at research group dynamics—in particular, the situated meanings Discourses take on in the local environments of the disciplinary subfields. A longer ethnographic study of one particular research group might reveal further localized meanings and provide more insight into students' negotiations of these meanings. For example, the usefulness of the concept of *improvisation* might be explored as an analytical tool for understanding how students enact agency when they come into contact with structuring Discourses of gender (Holland et al., 1998).

A longer time in the field with multimodal data collection methods (e.g., video or audiotaping, interviewing, focus groups, participant observation) would also possibly yield data that could allow for claims about the intersections and differences within disciplinary subfields of physics as practiced in the different research groups. This initial analysis of physics culture provided only a surface-level glimpse into the cultural differences of these subfields. An examination of interactions in these different subfields might yield even more information about the local contexts in which gender was produced, and perhaps could shed light on the relative success of the field of astrophysics in the recruitment and retention of women to their doctoral programs compared to other subfields.

Intersectionality. The ways that gender was constructed through Discourses of physics in turn influenced forms of positioning and modes of belonging that participants experienced in physics. However, intersecting with gender are numerous other factors including race, class, ethnicity, and sexuality that regulate how we think about gender expressions such as masculinity and femininity in localized circumstances. Thus, it was important to highlight the multiple intersections of the experiences of race, ethnicity, ability, socioeconomic status, and age that also provided or limited resources for students engaging in the Discourses of physics. Reflecting back on the process of constructing this study, I recognize that the difficulties of using gender as an analytic lens foreclosed my opportunities to reveal issues of intersectionality (Collins, 1990; Crenshaw, 1991). Butler (1999) warned of this, and encouraged us to regard what counts as masculinity and femininity as highly contextual and variable across social contexts and over time (also for one person over the contexts of their lives). Moreover, she cautions that to foreground gender categories with already limited ideas of the feminine and of women precludes an analysis of the ways gender "intersects with racial, class, ethnic, sexual, and regional modalities of discursively constituted identities" (Butler, 1999, p. 4). As an exclusive category of analysis, therefore, gender is limiting, as it becomes impossible to separate gender from the cultural intersections in which it is produced and maintained.

However, my interest was to focus on the local construction of Discourses and subject positions as a way to highlight the temporal and spatial specificity of gender expressions and identity constructions. Future analyses of the data collected here could benefit from the use of multiple theoretical lenses and analytical approaches through which to regard the production of these gender manifestations. For example, Carlone and Johnson (2007) found that women of colour in university science degree programs experienced difficulties on their science career trajectories, in part because their bids for recognition were disrupted by an interaction of gender, race, and class factors. Thus, Carlone and Johnson constructed a model for science identity that foregrounded recognition as a salient factor in constructing a science identity. Using this model as an analytic tool allowed them to demonstrate how women of colour redefined who counted as a meaningful other in the interaction of recognition, and what it meant to be recognized as a scientist in the local environment of a specific university context. Thus, they were able to show the multiple ways that race, gender, and class intersected with women's successful or disrupted bids for recognition. Where possible, in the discussion presented in Chapter 9, I paid attention to the ways that ethnicity and class intersected with conceptions of femininity and with the gendering of academic language, particularly as these related to the stories of Ruby and Carol.

Recommendations for policy and pedagogy.

This research has important implications for research and policy initiatives into the recruitment and retention of students in doctoral physics. First, this research alerted us to the dangers of associating women with femininity when constructing program initiatives to make science more female friendly (Phipps, 2007). Much of the research on gender and science, particularly pertaining to the under-representation of women in science, assumes that the so-called problem arises out of the unproblematic association of masculinity with boys and men and with science—an association that presumably makes science unattractive to women and girls (Thomas, 1990). The response to this association was a reformist approach to science education to make it more appealing to girls and women (Howes, 1998; Rosser, 1990, 1997). As demonstrated here, while participants may have reinscribed the masculine construction of Discourses of physics and physicists, many of the examples described in this dissertation showed that these depictions of physics were often also appealing, a finding supported by others (Henwood, 1998; Walker, 2001).

Thus, a recommendation emerging from this research is that policy makers and researchers designing initiatives to recruit and retain women and girls in physics avoid appealing to stereotypes of gender, particularly with respect to femininity. Faulkner (2007) suggested that promoting heterogenous images of science would create space for a diverse range of people to become scientists. Emerging from her study on engineering identities, Faulkner identified a key question: "Why do engineers so often foreground a technicist engineering identity in spite of the lived heterogeneity of their actual work?" (p. 349). A similar question arose in this study, particularly in relation to how physics doctoral students themselves identified stereotypical forms of physics and physicists, but engaged in practices that did not resemble these stereotypes. This research showed that the actual practices of physicists were diverse and highlighting these differences may serve to subvert the dominant gender order.

Also emerging from this research was the finding that women participants needed to explain their early attraction and ability in physics, indicating that there is an assumption that this is not normally the case. Efforts to recruit and retain women into physics should make attempts to mitigate the Otherness women feel in their careers as physicists by normalizing physics as a career choice for both men and women.

Pedagogical implications. Emerging from this study were a number of concerns about institutional contexts that physics departments might consider as ways to support their undergraduate and doctoral students, and to educate students, faculty, and staff on issues pertaining to equity.

Do-ability of research projects. One particular issue that arose was the constraints that doctoral students experienced when using instruments for experiments that may require repairs or modifications. Peter and Saïd's story was an example of this constraint, one that seriously limited their possibilities for publication and hence elongated their time to completion. At Eastern University, students may take up to eight years to complete a doctorate, but this is not desirable, and a student is considered to be in extra sessions after four years of study. One of the benefits of taking more than four years to complete a degree is the leeway this provides for students like Peter and Said who experienced technical difficulties throughout their study. However, the construction of research problems that might be achievable is of concern for graduate students. Delamont, Atkinson and Parry (2000) discussed the importance of a supervisor's role in the construction of realistic research goals for students to achieve results from their instruments and their research projects. The construction of feasible problems and the creation of conditions to make this reality possible—what Fujimura (1987) termed the construction of *doable projects*—needs to be taken into consideration when graduate students begin research on instruments that have been shown to be problematic. Additionally, attempts should be made to mitigate circumstances where instruments may pose physical limitations to diverse range of users.

Gaps in undergraduate and graduate education. Findings discussed in this study pointed to a gap between representations of physics in undergraduate programs and the realities of graduate studies in physics. Several participants described being enthralled by physics at the undergraduate level, yet feeling disappointed or disillusioned by the realities of graduate study. This disconnect might be related to the lack of authentic experiences that students have in undergraduate physics courses. The differences between the expectations participants had when entering doctoral physics, and the realities, therein suggest that a more realistic view of the field is necessary at an earlier level. For example, Lily described the limitations to creative thinking that undergraduate physics lab activities posed. Rather than allowing students to experiment in an open-ended fashion, students still conduct physics labs in a recipe-style fashion that has a precise and known end. There are numerous limitations to designing labs that provide open-ended authentic experiences for students (e.g., Handelsman et al., 2004), but this option might mitigate some of the disconnect participants described in this study.

Furthermore, evidence from this study pointed to a need to hone undergraduate students' critical research skills before they enter graduate programs. Participants in the astrophysics program had the benefit of attending the astro-tea or the neutron-star coffee as venues to test out critical reading skills and argument development. However, as Molly emphasized, this was often the first time a doctoral student was required to work on developing these communication skills. Faulkner's (2007) research identified a false dichotomy between the technical and the social that abounds in engineering. Similarly, in physics it seems that students entering graduate school are not prepared in their undergraduate programs for the social elements of doing physics. The emphasis on oral and written communication in physics programs begs a reconsideration of this dualism. One way to tend to this might be to add required communications courses or to provide effective mentoring to teach doctoral students how to write and critically construct arguments in physics. This recommendation seems important, as communication was regarded as salient to being recognized as a physicist in the field.

Addressing equity issues. To address issues of identity and difference in physics, there is a need in physics education to continue efforts to educate students about cultures of science. Feminist science studies challenge the epistemology of science, its relationship to cultures of science, and subsequently, who gets to be recognized as contributors to science (Haraway, 1989; Harding, 1991; Keller, 1985; Longino, 1990; Schiebinger, 1999). Yet, history of science, sociology, and anthropology of science courses are generally not required for university physics students, either at the graduate or the undergraduate level. Nor are there usually workshops available to faculty and students that might promote a deeper analysis of physics cultures. Optional courses or workshops could increase awareness of the gender norm in physics and the in/authenticity and in/visibility issues that some non-gender conforming individuals face. One of the recommendations of this study is for physics programs to consider efforts to promote an awareness of gender and diversity issues through workshops and/or required science studies courses that emphasize issues of culture in physics.

Gilbert (2001) suggested that science is represented in science education programs in ways that are meant to reflect the ”internal logic of the discipline” (p. 300). In many ways, as demonstrated in this dissertation, the Discourses of physicists reflected the internal logic posed by the Discourses of physics, rendering physics separate from gender and other social and political concerns. The implications of this are the very real in/visibility concerns that non-gender conforming individuals face in physics. To mitigate these effects, Gilbert suggested that science education programs should not just train students to become scientists, but also educate them about the culture of science. In physics, a discipline that has been constructed as one without culture, this advice seems particularly pertinent. Thus, a hope for this dissertation is that it will engage science educators and students in a critical examination of physics as a cultural practice as well as a subject.

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Footnotes

[i] http://www.nserc-crsng.gc.ca/Professors-Professeurs/CFS-PCP/CWSE-CFSG_eng.asp

[ii] A pseudonym

[iii] A summary of interview questions can be found in Appendix G.

[iv] (Collège d'Enseignement Général et Professionnel). This is a post-secondary collegiate institution in Quebec that offers 2-year diploma programs for students out of high school (Grade 11). Quebec students attend CEGEP for vocational programs or before attending university.

[v] Photograph not included in appendix because Ruby did not give permission for photos to be publicly displayed.

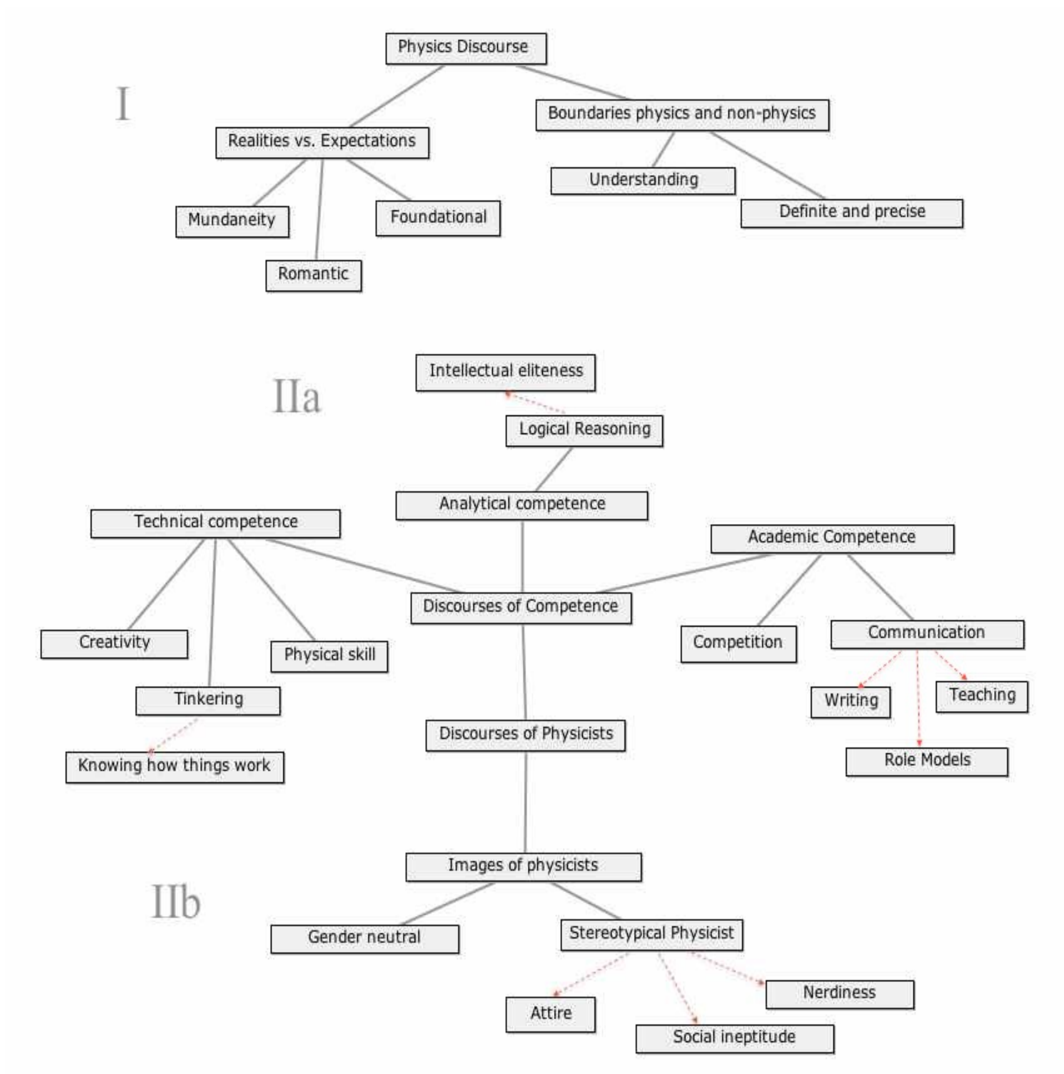

Figure 1. Code Map indicating themes used in analysis

I - indicates the code tree used to organize themes pertaining to the Discourse of physics (Chapter 6);
II - indicates the code tree used to organize themes pertaining to the Discourse of physicists (Chapter 7).

> IIa represents Discourses of competence; IIb represents Discourses of images of physicists. The connecting lines represent the relationship of the sub-themes to the parent themes. The dotted arrows represent the relationship between sub-themes and sub-sub-themes.

Each box represents a section or sub-section in each chapter with the exception of those boxes at the end of a dotted arrow. These are discussed within the context of the parent theme.

Table 1. Participants in the Study

Name	Year	Gender	Disciplinary subfield	Types of data contributed
Laura	PhD 3	Woman	Theoretical high energy physics (string theory)	Journal[a] Observational Field notes Interview
Victor	PhD 2	Man	Theoretical high energy physics (cosmology)	Photo-journal Observational Field notes Interview
Lily	PhD 4	Woman	Condensed matter physics (nanophysics)	Photo-journal Observational Field notes Interview
Peter	PhD 3	Man	Condensed matter physics (nanophysics)	Photo-journal Observational Field notes Interview
Saïd	PhD 4	Man	Condensed matter physics (nanophysics)	Photo-journal Observational Field notes Interview
Carol	PhD 3	Woman	Condensed matter physics (nanophysics)	Photo-journal Observational Field notes Interview
Molly	PhD 3	Woman	Observational astrophysics	Photo-journal Observational Field notes Interview
Sandra	PhD 4	Woman	Observational astrophysics	Photo-journal[b] Observational Field notes Interview
David	PhD 4	Man	Observational astrophysics	Photo-journal Observational Field notes Interview
Ruby	PhD 4	Woman	Observational astrophysics	Photo-journal[b] Observational Field notes Interview
Alice	PhD 2	Woman	Observational astrophysics	Photo-journal Observational Field notes Interview

[a] Participant declined to take photographs. [b]Photos not to be displayed in any research documents at the participants' request

Table 2. Meetings and Seminars Attended

Meeting	Astro-tea	Neutron-star Coffee	Astro research meetings	CM weekly lunch seminar	Theoretical seminars	CM supervisor meetings
Times attended	3	4	5	6	2	6

Table 3. Rules of Inclusion for Stories of Recognition

Recognition of self as physicist	Positive recognition by meaningful others	Positive recognition by non-scientific others	Recognition of other as physicist
Proclaims a natural affinity for physics: • provides examples from childhood • early interest • describes being able to fix things or to understand abstract concepts	Received awards or scholarships	Parents or teachers recognized ability in physics at a young age	Identifies in others what it means to do "good physics" • Describes ideal physicist • Points to others as examples
Enjoys research Describes being good at physics (demonstrated through achievement measurable by grades)	Publications or conferences: • receives positive feedback from members of the field	Others regard individual as smart due to physicist background	Describes appearances of other physicists
Individual describes feeling different from non-scientific or non-physicist others OR Describes fitting in with physicists	Collaboration: • describes fruitful collaborations with colleagues either within the research group or in the field generally	Others look to participant as an expert in the field	Stories of role models or childhood influences

*Note: F*or each of the positive forms of recognition here, there are possibilities for negative or neutral forms to exist (e.g. not receiving awards, publications, not collaborating, not being regarded as "smart" relative to other physicists or non-physicists).

Table 4. Analysis Comparing Goals with Experiences and Context

Name	Goals	Experiences and contexts[a]			
		Recognition	Influence of Significant Other	Personal contexts	Physics contexts
Inbound trajectory					
Laura	Post-doc	Self (early interest)	Supportive parents University professor		
Victor	Post-doc	By others (teachers) Symbolic other (funding)	Supportive mother Teachers	Unsure about career plans	Preliminary exam
Lily	Professor	Self (early interest)	Supportive parents High school teachers University professor		
Molly	Professor	Self (interest in physics) Collaborators	Scientist father Teacher role model	Pregnancy	Difference Nurturing research environment
Sandra	Professor	Self (early interest) By others (symbolic—publications)	Parents in medicine Research environment		Nurturing research environment
David	Post-doc	By others (teachers)	Teachers CEGEP Professor role model	Relationship	
Alice	Post-doc	Self (early interest and ability) By others (teachers)	Father is a science professor		

Peripheral trajectory					
Saïd	Industry			Commitment to student government Altruism	Expectation for more collaboration Problems with instrument/research design
Peter	Industry		Father in industry		Cultural adjustment Coursework expectations Problems with instrument/research design
Carol	Non-academic job	Self (early interest and ability in physics)	Supportive parents Mother as role model	Job security Prioritizes domestic life	Not interested in administrative life of academic
Outbound trajectory					
Ruby	CEGEP teaching	Self (early interest)	Supportive father	Health issues Family responsibilities	Program structure

(Table 4 continued)

[a] Experiences and contexts included forms of recognition (by self and others), types of significant influential others, influential personal contexts, and physics contexts that may have contributed to career trajectory.

Appendix A: Piloted Methods

Pilot studies are often used informally in qualitative research—generally to determine if a research site is really appropriate and if the methods the researcher intends on using are feasible. For this study, I conducted a pilot study as a way for me to familiarize myself with the research environment, and to determine if the methods I intended to use would be appropriate for the field. In piloting the methods, I spent two weeks in the physics department shadowing one participant, Molly, attending meetings, and conducting interviews. I asked Molly to keep a photo-journal, which was used in the interviews. After the pilot study, Molly continued participation in the study.

Shadowing

The shadowing activity that I conducted during the pilot gave me a taste of what it might be like to spend eight hours a day in the physics department following students, and how much of an intrusion that would be for them. My intent in shadowing each student was based on a study by Fletcher (1999), who conducted structured observation with six women engineers in their workplaces. Structured observation initially appealed to me to answer the question—what do physics doctoral students do? This had the intent of identifying practices of doctoral physics through the recording of micro-interactions in the workplace, which would subsequently be subjected to discourse analysis. I was, of course, concerned that my presence would influence the participants' day—a worry that was elevated on my first day of observations with Molly, when she immediately began by explaining to me what she does and what her day looks like.

Photographs

At our initial meeting, I asked Molly to take photos of things that represented being a physicist. While these directions seemed vague, my intent was to be as non-directive as possible to allow Molly to take the lead in defining points of interest for research topics. Molly took 20 photographs, and recorded details about each photograph in a log book that I had given her. Although I had discussed with her the goals of the photo-taking (to get an idea of how she saw physics, and to provide a starting-off point for interviews), the unstructured nature of this project seemed a bit bewildering to Molly and, ultimately, to me, as it was hard to imagine what value some of the photographs she took could have. During the pilot study, I de-emphasized the importance of journaling about the photographs she took—something I tried to place more emphasis on later in the larger study.

Interviews

I conducted two interviews with Molly, and both of them occurred in my office at the university. This was my suggestion because there were no private spaces in the physics department. As I was interested in student experiences, the interviews for the pilot study derived inspiration from Seidman's (1991) protocols, which sought to elicit life histories, describe details of experiences, and then reflect on the meaning of experiences. The first interview focused on Molly's history with science and in particular physics, and what events led her to her present position as a graduate student of physics. In the first interview, I also conducted the photo-elicitation, during which her photos were discussed for the purpose of detailing further experiences in her present location of work. The second interview attempted to elicit stories of Molly's experiences with physics but also allowed for a free-form discussion about what it was like to do physics, how to find joy in physics, and what doing physics meant for Molly.

Lessons Learned

The pilot study revealed a misfit between the actual setting and activity I was studying, and the methods I had envisioned to study that activity. The method of observation I used in the pilot study was intrusive to the students in the labs. The observations I set out to do required extensive writing of field notes. I did not receive permission from the majority of my participants to conduct video recordings of their work spaces. Besides being intrusive, my presence was also conspicuous and certainly affected people's interactions to have me there taking copious amounts of notes. Additionally, the interactions that I observed Molly engaged in were largely with her computer. Long stretches of the day involved sitting in front of the computer and coding data, which was not only extremely boring for me to observe, but involved very little interaction with much other than the computer. There were a few conversations with colleagues, but generally students were immersed in coding their data. I realized, by conducting the pilot, that structured observation involving shadowing for the entire day would not be a useful research method in this particular environment. I inquired about weekly meetings that occurred within the research groups, and I decided that I would limit my observations to seminars, group meetings, advisory meetings, and informal sessions like brown-bag seminars and journal clubs. This decision permitted me to more easily schedule my observations around the meetings and seminars of several different research groups at once, which meant that I could interact with all of my participants during the week at various times, rather than fragmenting the study and shadowing individuals over a longer period of time.

Another one of the limitations from this perspective was the fact that I had not properly thought out how to arrange it so that the participants could take photographs of other people. In my ethics renewal, I included a clause that the photograph project could include the photography of people not included in the study with the expressed and informed consent of the individual. This opened up new possibilities for photography, and circumvented the awkwardness of having to photograph only hands or feet.

I also learned from this pilot that a journal, which encouraged the participants to think reflectively about what they were representing by the image and why they chose that image, was going to be necessary in order to make the photo-taking a meaningful project. In discussion with Molly about the usefulness of the photos, it arose that the images themselves were not as useful as the potential they had for reflection about why people choose to represent themselves in certain ways and what that means about who they are.

Appendix B: Ethics Forms

McGill

FACULTY OF EDUCATION – RESEARCH ETHICS BOARD
APPLICATION FOR ETHICS APPROVAL FOR HUMAN SUBJECT RESEARCH
(please refer to the Application Guidelines at www.mcgill.ca/rgo/ethics/human before completing this form)

Project Title: Becoming a physicist: Learning and identity in doctoral physics programs.

Type of Review: Expedited Review _X____ Full Review ____

Principal Investigator: Allison Gonsalves **Dept:** Integrated Studies in Education

Phone #: 514-398-1510 **Fax #:**__________________ **Email:** allison.gonsalves@mail.mcgill.ca

Mailing Address (if different than Dept.): ______________________ AS/PS

Status: Faculty ____ Postdoctoral Fellow ___ Other (specify) ________
Ph.D. Student _x__ Master's Student ___ Undergraduate _____

Type of Research: **Faculty Research** ____ **PhD Thesis** _x___
MA Thesis ____ Independent Study Project ___
Other (specify)____________ Master's Project _____
Course Assignment (specify course name and #) __________________

Faculty Supervisor (for student PIs): Dr. Anthony Paré and Dr. Lynn McAlpine
Email: anthony.pare@mcgill.ca; lynn.mcalpine@mcgill.ca

Office Use Only REB #: #778-0307 Approval Period: Apr 12, 2007 to Apr 12, 2008

List all funding sources for this project and project titles (if different from the above). Indicate the Principal Investigator of the award if not yourself.

Awarded: SSHRC Doctoral Award (2006-2008); T-PULSE Doctoral Award (2006-2007)

Principal Investigator Statement: I will ensure that this project is conducted in accordance with the policies and procedures governing the ethical conduct of research involving human subjects at McGill University.

Principal Investigator Signature: [signature] **Date:** March 19, 2007

Student's Faculty Supervisor Statement: I have read and approved this project and affirm that it has received the appropriate academic approval. I will ensure that the student investigator is aware of the applicable policies and procedures governing the ethical conduct of human subject research at McGill University and I agree to provide all necessary supervision to the student.

Faculty Supervisor Signature: [signature] **Date:** March 19, 2007

Checklist for Application for a Certificate of Ethical Acceptability
This checklist is designed to help you make sure your application materials for a Certificate of Ethical Acceptability include all of the required materials:

- ☑ Completed application form with the signature of the principal investigator, and for students, the faculty supervisor.
- ☑ Recruitment ads or letters of invitation
- ☑ Consent forms (for all participants or their guardians and for all research procedures) and assent forms or scripts (if research participants are children)
- ☑ Letters requesting access to a research site (e.g. a school)
- ☐ Research tools (questionnaires, interview guides, tests, etc.)

Please provide **3 copies** of the complete application materials for an expedited review, and **8 copies** for a full review.

3/19/07

McGill University

ETHICS REVIEW
RENEWAL REQUEST/FINAL REPORT

Continuing review of human subject research requires, at a minimum, the submission of an annual status report to the REB. This form must be completed to request renewal of ethics approval. If a renewal is not received before the expiry date, the project is considered no longer approved and no further research activity may be conducted. When a project has been completed, this form can also be used as a Final Report, which is required to properly close a file. To avoid expired approvals and, in the case of funded projects, the freezing of funds, this form should be returned 3-4 weeks before the current approval expires.

REB File #: 778-0307
Project Title:
Principal Investigator: Allison Gonsalves
Department/Phone/Email: DISE / x1510 / allison.gonsalves@mcgill.ca
Faculty Supervisor (for student PI): ANTHONY PARE

1. Were there any significant changes made to this research project that have any ethical implications? ___Yes ✓ No
   If yes, describe these changes and append any relevant documents that have been revised.

2. Are there any ethical concerns that arose during the course of this research? ___ Yes ✓ No. If yes, please describe.

3. Have any subjects experienced any adverse events in connection with this research project? ___ Yes ✓ No
   If yes, please describe.

4. ✓ This is a request for renewal of ethics approval.

5. ____ This project is no longer active and ethics approval is no longer required.

6. List all current funding sources for this project and the corresponding project titles **if not exactly the same** as the project title above. Indicate the Principal Investigator of the award if not yourself.
   SSHRC Doctoral Award.

Principal Investigator Signature: [signature] Date: Feb. 16. 2008.

Faculty Supervisor Signature: [signature] Date: Feb. 18, 2008
(for student PI)

For Administrative Use **REB:** ____REB-I ✓ REB-II ____REB-III

____ The closing report of this terminated project has been reviewed and accepted

✓ The continuing review for this project has been reviewed and approved

✓ Expedited Review ____ Full Review

Signature of REB Chair or designate: [signature] Date: March 28 2008

Approval Period: April 13, 2008 to April 12, 2009

******NOTE NEW MAILING ADDRESS******
Submit to Lynda McNeil, Research Ethics Officer, 1555 Peel Street, 11th floor, fax: 398-4644 tel:398-6831

(version 12/07)

Appendix C: Informed Consent Forms

SSHRC-Study on Graduate Experience in Physics

INFORMED CONSENT FORM

I am a doctoral student in Integrated Studies in Education conducting a study to help us understand the experiences of doctoral physics students as they engage in the day-to-day practices of laboratory life, and how these experiences influence student learning and shape student identities. I will be offering the summarized results of this inquiry to your department/Faculty so they can open a dialogue among departmental/Faculty members to enhance the doctoral experience and more effectively prepare students for their future careers. To accomplish these goals, I will:

a) observe the daily practices you participate in as part of your doctoral studies for a period of several weeks (this will be restricted to mainly group activities or additional events that you wish me to attend, or think might be informative);
b) ask you to represent your daily activities through photography using a reflective process known as photo-voice and journaling (either in a booklet that I will provide or on a private online discussion blog that I have set up);
c) use the photographs as starting points for two interviews during which I will ask you to describe your experiences as a doctoral physics student and respond to my observations of activity in the research groups;
d) document the perspectives of the laboratory supervisors;
e) provide information and perspectives gathered in a), b) and c) above to students, faculty and Program Directors in the Faculty so that you can generate recommendations;

If you agree to be part of this study you will have <u>the choice of participating in one or more</u> of the following:

a) participant observation in the form of non-intrusive/disruptive shadowing for several weeks
AND/OR
b) photographic recording of your places, events, things, people and practices that you feel best represents you as a physicist, and your understanding of what physicists do.
AND/OR
c) participate in an online discussion about the representation of physics and physicists and how your experiences meet or have not met your expectations
AND/OR

d) Individual audiotaped interviews (2, each 60-90 min) following the auto-photography, using an unstructured format;
AND/OR
e) Participating in video-taped interviews, or having your daily activities video-taped

I do not foresee any potential risks or discomfort to you as a result of participating, and participation is entirely voluntary. I will take the following steps to guarantee your rights as a participant in this study:

a) You have the right to review all of your data at any time.
b) Names will not appear in the database. You will be asked to choose an alias.
c) The results will be reported in an aggregated fashion and any particular findings will not be attributed to you without seeking your permission.
d) If data from this study is used in future studies, I will seek consent from you.
e) The documents, audiotapes, photographs and/or videotapes will be safeguarded for the period of time after the research ends, and will then be erased or destroyed.
f) You always have the right to withdraw at any time without any penalty or prejudice.
g) This study is in no way a part of the courses you are taking, and there are no consequences for refusal to participate in this project or any part of it.

I will be happy to share my findings with you. Results of this study will be presented at professional conferences and submitted for peer review and publication in professional journals and/or newsletters.

In order for you to participate, the university requires that you understand the nature of the study in which you have agreed to participate. *After reading this document, please sign below if you agree to participate.*

I need your help and support in order to do this research, which should give valuable insight into the experiences of doctoral students in physics. Thank you for considering this request.

Sincerely,

Allison Gonsalves
Ph.D Candidate
Eastern University Faculty of Education
Phone: 514-398-1510
E-mail: allison.gonsalves@mcgill.ca

………………………
1. Please make sure you understand and agree to the following statements before giving consent to participate.

- I understand the purpose of this study and know about the risks, benefits and inconveniences that this research project entails.
- I understand that I am free to withdraw at anytime from the study without any penalty or prejudice.
- I understand that this research will not affect the evaluation of my progress in the program.
- I understand how confidentiality will be maintained during this research project.
- I understand the anticipated uses of data, especially with respect to publication, communication and dissemination of results.
- I understand that observation notes, photographs or audiotapes may be made of activities I attend related to this research.

2. Please indicate below how you choose to participate

I have read the above and I understand all of the conditions. I freely give consent and voluntarily agree to participate in the following aspects of this study. I understand that my identity will be protected and that all records will be coded to guarantee anonymity; audio and videotapes will be used only for research purposes.

____ I agree to participate in several weeks of non-intrusive participant shadowing.
____ I agree to allow the researcher to attend and report on informal group events.
____ I agree to be contacted for interviews.
____ I allow researcher to use anonymous quotations from my writing (quotations that do not identify me).
____ I allow researcher to use anonymous quotations from my interview responses (quotations that do not identify me).
____ I allow the researcher to use photographs in her reports that do not reveal my identity.
____ I allow the researcher to use photographs in her reports that do reveal my identity.
____ I agree to allow the researcher to attend and report on laboratory meetings if observation occurs on days during with meetings are scheduled.
____ I allow the researcher to videotape interviews with me, or to videotape my daily practices in the physics department

Name (please print) ____

Chosen alias (please print) -
____

Signature _____________________________________ Date ____________

Appendix D: Timeline of Data Collection and Methods

Dates	Activity	Participants
April 2007	Pilot Study	Molly, Myself
May-August 2007	Analysis of results, revision of research methodology, drafting interview guides, consent forms, photo-journals, obtaining written permission from PI's, recruitment of participants	Myself
October 2007-February 2008	Initial meeting with participants; distribution and collection of consent forms; explanation and distribution of photo-journals	Myself + 10 Participants (Laura, Victor, Said, Peter, Carol, Lily, Ruby, Alice, David, Sandra)
February 2008-April 2008	Observations (including drafting of field notes and reflections on theory, methodology and researcher subjectivity)	Myself + 11 Participants (Laura, Victor, Said, Peter, Carol, Lily, Ruby, Alice, David, Sandra, Molly)
April 2008-September 2008	Interviews; photo-elicitation	Myself + participants
September 2008-February 2009	Transcription of interviews, initial analysis of field notes	Myself
February 2009-February 2010	Coding of interview transcripts	Myself

Appendix E: Sources of Data

Origin	Type of data	Method of collection
Researcher	Observational field notes	Attending meetings (supervisor/student; lab group); seminars, Astro-tea, Neutron-star Coffee Field notes taken during and after observation
Researcher	Reflective journal	Notes written after each observation and interview with my feelings about the interaction. Journal included notes about my own (related) experiences.
Participant	Photographs	Participants took digital photographs using their own cameras. Instructions were provided (see Appendix F), and participants e-mailed me their photographs as zipped files, or compiled them in a photo-journal using iPhoto (depended on the availability of the technology to each participant).
Participant	Photo-journal	Blank photo-journals (with questions) were provided in hard-copy to each participant (see Appendix F). Participants were asked to fill out one entry per photo.
Participant + Researcher	First Interview	Three stages of first interview (90 mins): 1. Photo-elicitation (Harper, 2002) 2. Life-history interview (Mishler, 1999) 3. Semi-structured conversation (Kvale, 1996)
Participant + Researcher	Second Interview	Second interview (~60 mins) utilized an unstructured conversational format, following up on details from the first interview or issues that the participant raised (Kvale, 1996).
Participant + Researcher	E-mail	On-going e-mail conversations with participants post-interview. These exchanges were to clarify events that I had observed or terms and topics that came up in interviews or at meetings. E-mail conversations also occurred after a draft of the analysis was sent out to the participants, transcripts of which were used in the dissertation. In some instances, e-mails were used as data sources.
Participant + Researcher	Informal conversation	Informal, unrecorded conversations with participants in the department, at social events and during random encounters outside of the research site. These conversations were not included in the analysis, but contributed to rapport-building and were often informative to me as they helped me understand particulars about projects, meeting structures, departmental structure, etc.

Appendix F: Participant Information Packages and Photo-journals

SSHRC-Study Participant Guide – September, 2007

Researcher: Allison Gonsalves
allison.gonsalves@mcgill.ca
Education Building, Room 416 tel: 514-398-1510

Dear

Thanks again for agreeing to participate in this study about your experiences of graduate physics practice. Part of the study that you agreed to participate in involves the construction of what I will call a Photo-Log. Participation in this portion of the study requires you to take photographs of representations of physics and physicists, and places, people and objects that you feel accurately represent who you are either as a member of the physics community or somewhere on the periphery.

What is the purpose of photo-journal in this study?

This study aims to uncover the ways that graduate students learn how to become physicists. Often, learning in this context requires the acquisition of cultural habits (presentation style, ways of writing, speaking), or the participation in cultural events (Astro-Tea for example). However, these cultural aspects of physics are rarely represented visually, even though the public image of the activity of physicists carries a very strong stereotypical connotation. The use of photographs in this study is meant to stimulate deeper discussions into what it is like to be a physicist and how the interaction between your 'self' and the places you inhabit function to shape identities as physicists (either as members or as outsiders of the physics community).

Photovoice has been used previously as a tool that allows people to reflect on the "everyday social and political realities that influence their lives" (Wang et al., 1998). It enables participants and researchers to engage with photographs that represent feelings of alientation or identification with the places in which they live and work. For you, these places may be your homes, your city, your offices/labs or other places which you feel you identify with or are alienated from. The purpose is not just to document what you do in a day, but rather to draw attention to places, things and people that are enablers or barriers to you becoming members in the physics community (they may be real or imagined enablers or barriers).

Photographs, especially the kinds that I am asking you to take, are personal in nature. As such, I will ask you to consider when picture-taking is appropriate, to ask people for permission to take their photographs, and to explain to people who you wish to include in photographs the purpose for taking the photo.

A. Protocol for Photo-journal

I will provide you with a detailed journal template to help you record your thoughts as you are taking photos. When considering what to take photos of, think about what being a physics graduate student has meant to you, and how best to represent that. Think about elements of physics culture that you do or do not identify with. How has membership in the physics community helped or hindered your progress with your personal and academic development? Can you represent a time when you have really felt a member of the physics community, or that you were really a physicist?

B. Interviews

I will be asking each of you to participate in two 60-90 minute interviews after the photo-logs are wrapped up and the photos have been developed. Prior to the interview, I will ask you to consider a number of things:

1. Were there things about being a physicist that you wished you could show in photographs, but were unable to represent (for possibly a variety of reasons).

2. When was the time that you most felt like a physicist?
    a. What were you doing?
    b. Who was involved? What role did they play in your experience of this feeling?

3. When was a time that you least felt like a physicist?
    a. What were you doing?
    b. Who was involved? What role did they play in your experience of this feeling?

Please take the time to consider these three questions, and if you have the chance please send some quick answers along with your journals before the interview.

PHOTO-JOURNAL (please fill in and return to me along with used cameras).

Name:

Photograph #1

What is represented in this photo?

Why did you take this photograph?

Does this photograph represent an event that made you feel like a physicist?
Why or why not?

Does this represent an event or a place that you identify with or that you feel alienated from?

Would you be willing to show this photograph publicly?
Yes ☐ No ☐

Appendix G: Interview Guide

1. Preparation for interview
   a. Review photo-journal and photographs
   b. Informed consent
2. Photo-elicitation
   a. Arrange for photo-journal and photographs to be submitted at least a week beforehand.
   b. Ask participant to indicate photographs that represent significant events or themes.
3. Interview Protocol

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1. PREPARATION FOR INTERVIEW

PREP:
- 2 recorders !
- test both before interview
- state date and purpose at beginning of interview recording
- take a copy of the signed consent form to help remind them of what they have consented to previously

BEGIN by reviewing the signed consent form, the purpose of the study; verify options they had agreed to previously.

If they raise any questions that you cannot answer about the study or treatment of data, write down the question and let them know you will get back to them.

2. PHOTO-JOURNALS

a. Read over the photo-logs and look at the photographs (Before interview).
b. Ask participant to indicate notable photos—recalling a significant experience or theme
c. If the participant has not selected significant photos, or written a complete photo-journal, ask them to choose 3 photographs that seem most pertinent to identity, discourse production/reproduction, improvisation.
d. Lay out photos for participants and ask them to choose which photographs best represents physics in their disciplinary subfield as they would like to portray it.

3. INTERVIEW PROTOCOL

I am going to ask you questions about a few of the photos you have taken. Let's look at the photograph and I'll read what you wrote in your journal about it.

Photo-elicitation

- Why did you choose to discuss this photo?
- Does this photo represent a time when you have felt like you were really a ___physicist? Why?
- Does this photo represent a time when you didn't feel like a ____physicist? Why?
- Is there something missing from this photograph?

Generally

- Are there things you would have liked to represent visually, but couldn't?
- Is there something that you didn't photograph for whatever reason?
- Can you think of a time when you felt like you were not a ___physicist?
- Did the process of photography reveal to you any elements of being a ___physicist that you had not noticed or thought about before?

b). Personal History—experiences and contexts that have influenced participants' trajectory in physics

- When did you become interested in physics? Recall one or two events from that time.
- What was your high school like? Was there an influential teacher?
- What was your undergrad like—did you study physics?
- What did you think it was to be a physicist?
- Do you see yourself continuing in physics in the future?

c) Discourses of physics and physicists—how do participants' describe their practice?

- Are there any previous experiences or knowledge you wish you had coming into this program?
- Has your experience in physics matched your expectations?
- What are you good at (in ________ physics)? What do you think shaped your ability to be good at this thing? Do you think your ability is particular to the disciplinary subfield you are studying (i.e., do you think you would be a good astro-/solid state-/theoretical physicist)?
- What do you think are important skills, characteristics or expertise needed to become a ____physicist? Can you name some people who you think have these characteristics?
- If you were to describe the ideal physics student, what would they be like? What prior experiences would it be important for this student to have? What do you think of this ideal? Is it something that you seek to obtain?

*******End of First interview. Remind participants that the subsequent interview will focus on cultural ideas about physicists and participants' experiences of physics *******

d) Discourses of physics and physicists—how do participants describe cultural images of physics, doing physics?

- What images do you think society has of physicists—how does that compare to your own idea of physics/physicists?
- Can you think of a time when you weren't sure that you belonged to physics community? What did you do? (If student doesn't feel as though they 'fit in')
- Have you ever thought about the fact that you have chosen a degree program that many people regard as a masculine career?
- Is there a difference between how men and women do physics? Do previous experiences play a role in this?

e) Allow time for follow-up questions from Interview 1 and for participant to ask questions or bring up topics for discussion.

Concluding question

Is there anything that we haven't talked about that you think is interesting, or relevant that we haven't explored, or hasn't been mentioned, or that I haven't asked about?

THANK PARTICIPANT!

Appendix H: Photographs used in Photo Elicitation

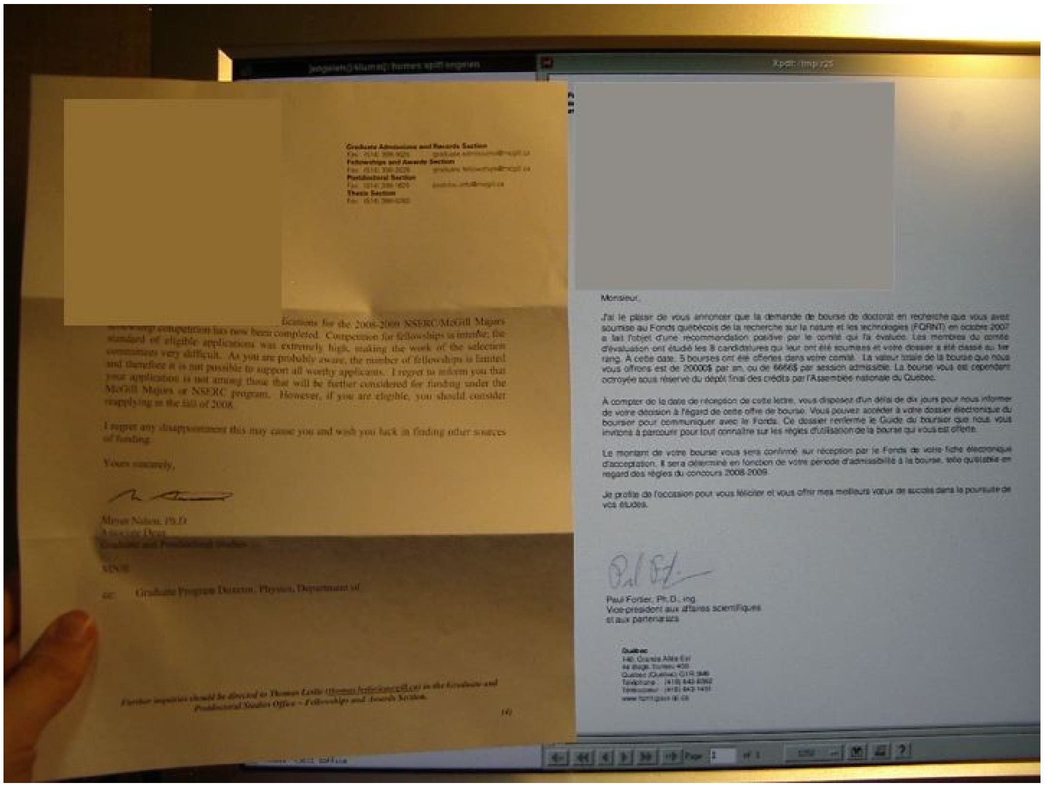

Figure H1: Victor's Photograph of Funding Letters

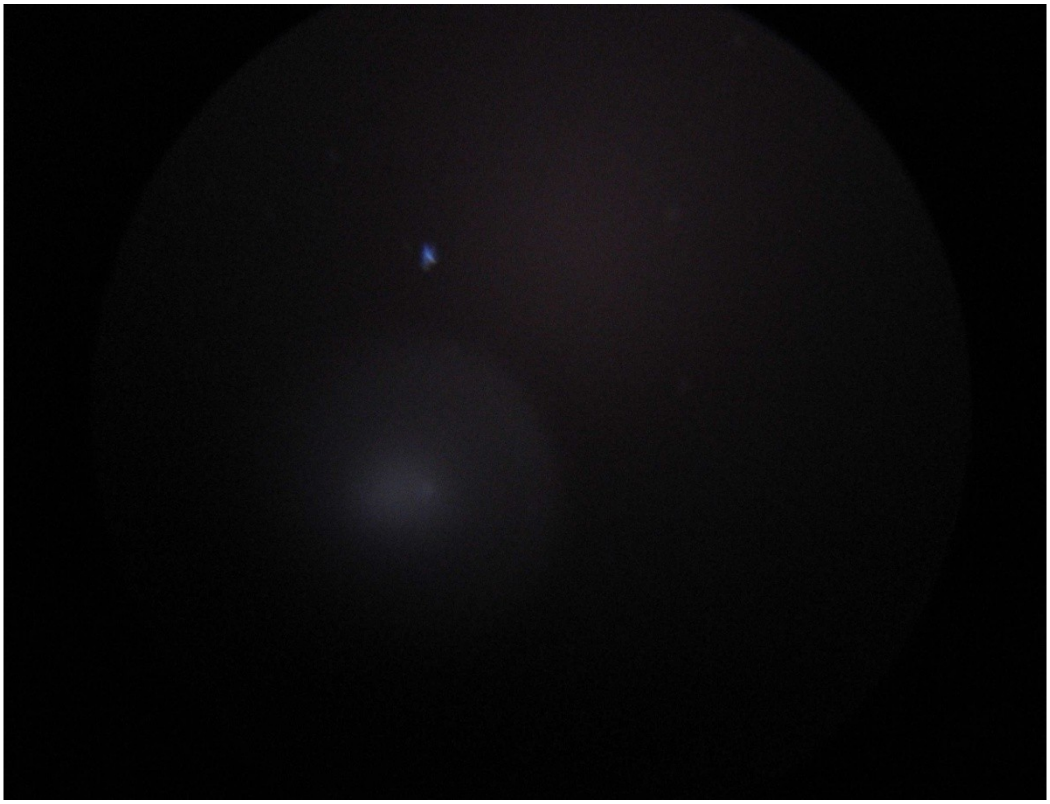

Figure H2: Alice's Photo of a Comet
Note: image quality is poor due to the distance of the comet, and the distortion of the telescopic lens.

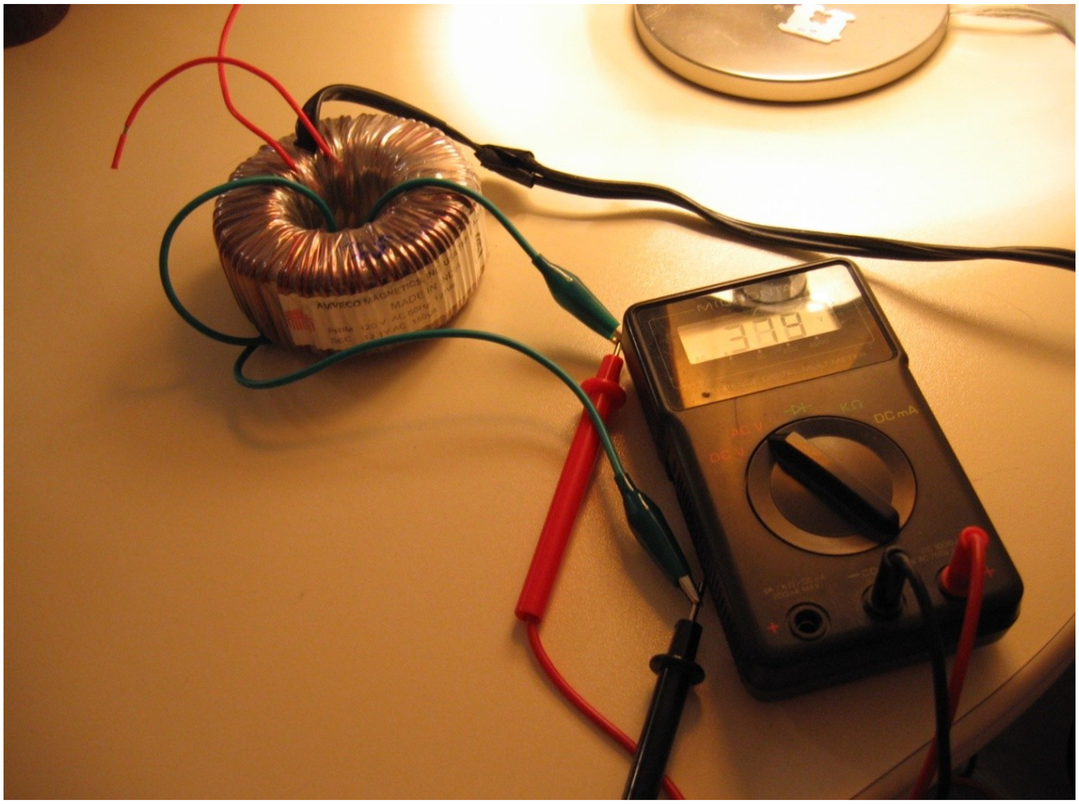

Figure H3: Alice's Photograph of her Work Bench

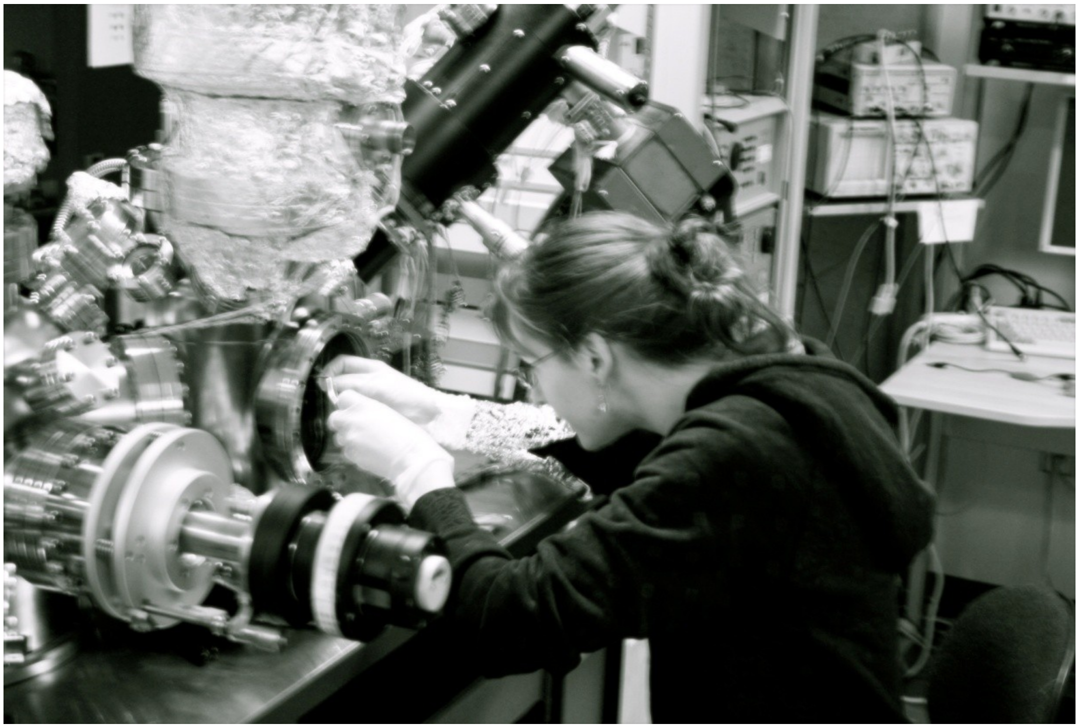

Figure H4: Lily's Photograph of Herself Fixing a Tip on the Scanning Tunneling Microscope

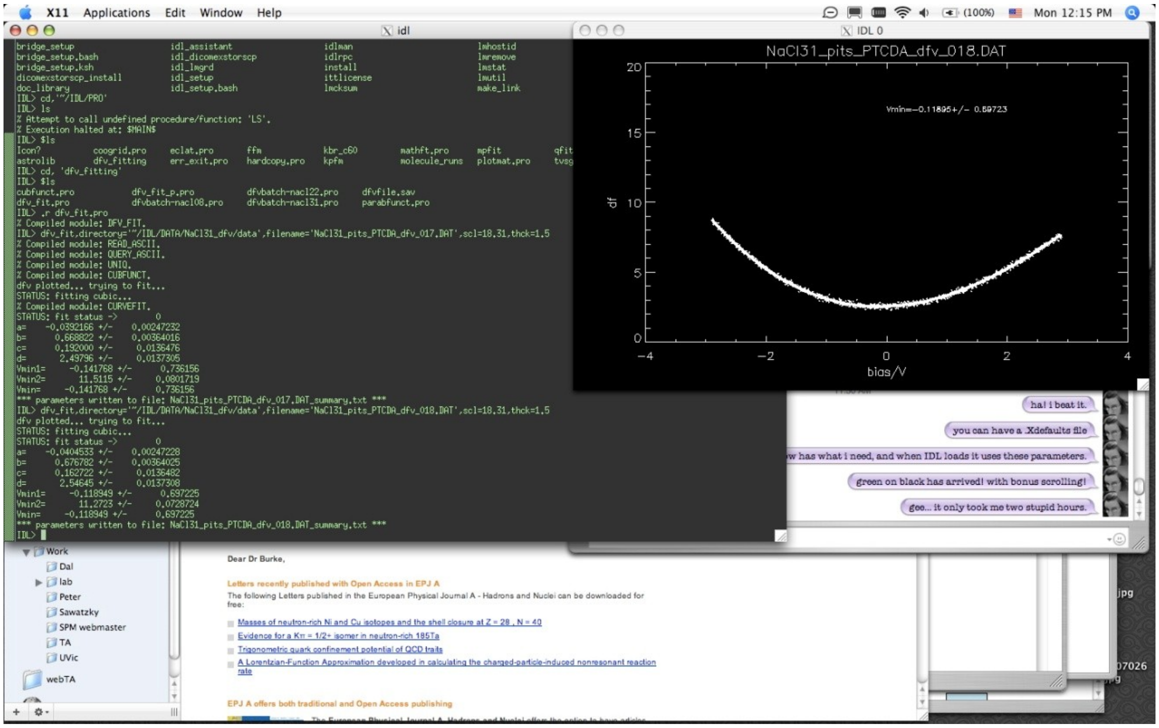

Figure H5: Lily's Photograph of her Virtual Desktop

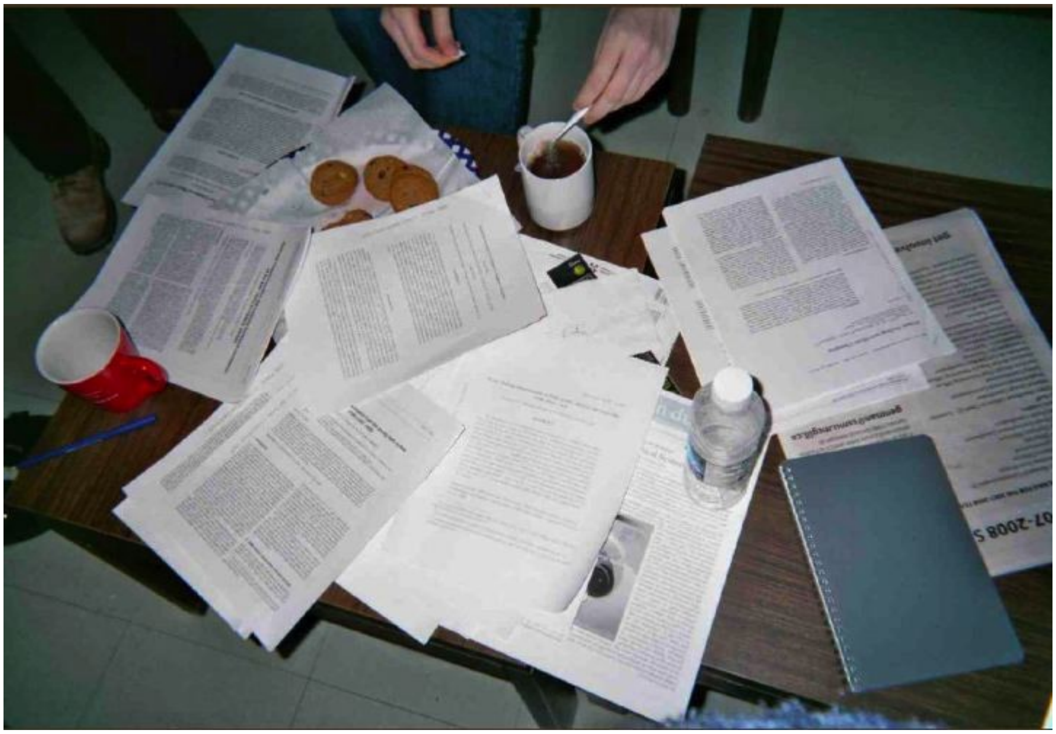

Figure H6: Molly’s Photograph of Coffee and Papers at the Neutron-star Coffee

Figure H7: Lily's Photograph of Herself Holding a Sample Holder and Single Crystals of NaCl

Gender and Discourse in Doctoral Physics

[i] http://www.nserc-crsng.gc.ca/Professors-Professeurs/CFS-PCP/CWSE-CFSG_eng.asp

[ii] A pseudonym

[iii] A summary of interview questions can be found in Appendix G.

[iv] (Collège d'Enseignement Général et Professionnel). This is a post-secondary collegiate institution in Quebec that offers 2-year diploma programs for students out of high school (Grade 11). Quebec students attend CEGEP for vocational programs or before attending university.

[v] Photograph not included in appendix because Ruby did not give permission for photos to be publicly displayed.