Dispelling stereotypes and building capacity: repairing the leaky pipeline between high school and post-secondary engineering education through participatory action research

by

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Dissertation goals: Influencing social action today.

Positionality

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Engaging nominalists in action research

Action research methodology

Dissertation research goals

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Population details

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Research activities

Survey design

Deployment schedule

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Standpoint Theory

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Chapter 1 – Introduction

Women make up 12.8% of the engineering population in Canada and, despite decades of efforts by engineering educators and practitioners to recruit and retain women (Beddoes & Borrego, 2011; Blickenstaff, 2005; Chesler & Chesler, 2002; Hersh, 2000), Engineers Canada (2016) reports that this number has only slightly improved in the last few years. Yet this doctoral research found that girls in British Columbia in the Greater Victoria school districts make up roughly half of Physics 11 classrooms and data from Camosun College in Victoria indicate that women make up roughly 40% of students with transfer credit for Physics 11 (Tarnai-Lokhorst & Hodgson, 2015). Therefore, girls who successfully complete Physics 11 and demonstrate an aptitude for engineering persist in choosing non-engineering careers (E. Smith, 2011; Thornton, 1998).

The Leaky Pipeline

Feminist scholars investigating male dominated science- and math-related professions often refer to the “leaky pipeline” when talking about girls and young women deciding to turn from a particular career option (Blickenstaff, 2005; Lauer et al., 2013; Levin, Xie, Shauman, Ray, & McDonnell, 2005; Vitores & Gil-Juérez, 2015; Watt et al., 2012). Many researchers of the engineering pipeline focus on STEM (science, technology, engineering and mathematics) education in primary or middle school years; some look earlier at pre-school detractors like the “pink and blue aisles” in toy stores (Feminine pink and macho khaki: toys exploit gender differences, 1996; Gold, 2008; Sweet, 2013; Zuckerman, 2017). Organizations and professional regulators typically fund research investigating later leaks, focusing on improving the retention of women in university programs and in the work force (Knight, Carlson, & Sullivan, 2003;

**Gendered Careers**

Generic studies of high school influencers indicate that girls make their career and education choices through the recommendations of their community, family members, school counsellors and teachers (Levin et al., 2005). The leaky pipeline phenomenon is a social issue instead of an aptitude or interest issue (Sawtelle, 2011): women demonstrated engineering abilities throughout the last century in spite of negative bias, most famously during the two world wars when women provided the necessary technical design and manufacturing skills to support war efforts (Bix, 2013; Porter, 2014; Wakewich, 2014).

Population data from Camosun College, a comprehensive college in Victoria, British Columbia, correlating high school transfer credits with first programs of study gives some insight

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Enrolment of Students with Physics 11 Transfer Credit at Camosun College by Sex</th>
</tr>
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<tbody>
<tr>
<td>1980s</td>
<td>1990s</td>
</tr>
<tr>
<td>Female</td>
<td>23</td>
</tr>
<tr>
<td>Male</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>58</td>
</tr>
<tr>
<td>%Female</td>
<td>40%</td>
</tr>
</tbody>
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*Note: excluding 1970s data because of the small data set (<5) during that year (Tarnai-Lokhorst, Hodgson, & Biluziak, 2015).*

Table 1: Enrolment of students with Physics 11 transfer credit at Camosun College by Sex. Figure 1: Number of students starting at Camosun College with Physics 11 transfer credit by sex; 1970s data excluded due to small data set (<5) (Tarnai-Lokhorst et al., 2015).
into student career decisions when they enter post-secondary education. Since the college’s inception in 1972, roughly 40% of the students who had successfully completed Physics 11 were women (Table 1); the graph in Figure 1 clearly shows the consistency of the distribution across the half-decades. The majority of these students, male and female, elected to register for programs that lead to careers other than physics or engineering. As shown in Table 2, 34% of these female students selected business programs and 43% entered the college with undeclared program choices. Only 5% of women with Physics 11 transfer credit chose engineering-related programs. There are clearly over-looked social factors leading to these low numbers. One possibility is social dominance, a circular self-sabotaging risk in which society affirms stereotypical behaviour because it is the expected norm. In the case of careers in science, this manifests in four ways: one, in media portrayals of women in stereotypical non-scientific careers (Parrott & Parrott, 2015); two, in textbook usage of gender stereotypical examples in exercise problems (Kelly, 1985; Lemke, 2011); three, in science teachers tending to spend more time with male students because they believe more boys will more often pursue careers in physics and engineering (Levin et al., 2005); and; four, through parents encouraging girls to pursue the same careers as their mothers (David, Ball, Davies, & Reay, 2003). A second possibility is gendered career objectives, in which workplace culture, interactions with colleagues, opportunities for advancement, and the lack of a clear vision about how the work makes the world a better place fails to inspire, enthuse, recruit and retain female employees (Fender, Davidson, Vassileva, Ghazzali, & Croft, 2011; Fouad & Singh, 2011; Kaul, 2009; Kirkland & Bohnet, 2017). A third possibility is the influence of teaching paradigms on student perceptions of gendered careers. The dominant teaching method in physics and engineering is lecturing, which disconnects
lecturer from student, and lowers retention of knowledge, reducing student motivation and their engagement with the concepts, and possibly turning women away (Hrepic, Zollman, & Rebello, 2004; Syh-Jong, 2007).

**Gendered Teaching**

Studies investigating post-secondary teaching and learning methods reveal minimal gender differences between men and women on both sides of the desk: knowledge transmission and facilitation differences are primarily discipline-based rather than gender-specific (Nelson Laird, Garver, & Niskodé-Dossett, 2010; T. Scott, Gray, & Yates, 2012). Most engineering and physics educators prefer to employ lecture methods for the transmission of knowledge in the classroom and reserve team-based learning for laboratory experiments or capstone projects (Rosser, 1998). Adding in-class applied learning activities, in contrast, enhances students’

| 2010s – Camosun College programs chosen by students who completed Physics 11 |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | men | women | %women in program* | %women’s population |
| Engineering                 | 615 | 109   | 15%              | 4%                        |
| Science                     | 123 | 145   | 11%              | 2%                        |
| Trades                      | 383 | 49    | 54%              | 5%                        |
| Health                      | 11  | 47    | 81%              | 2%                        |
| Nursing                     | 31  | 157   | 84%              | 6%                        |
| University Transfer         | 1338| 1172  | 47%              | 43%*                      |
| Business                    | 1119| 947   | 46%              | 34%                       |
| Arts                        | 137 | 125   | 48%              | 5%**                      |
| total                       | 5521| 3626  | 42%              | 100%                      |

* Calculation for %women in program: %women=(#women/(#women+#men))%
** Rounding errors here produce apparently erroneous total

Table 2: Program choices in 2010s of Camosun College students with high school physics transfer credit, by sex. “Engineering” programs include mechanical, electrical, civil engineering, environmental technology, computer science (Tarnai-Lokhorst et al., 2015).
engagement and, ultimately, their learning and comprehension (Syh-Jong, 2007). As lecture methods require much less effort on the part of students than group work or in-class activities (Hrepic et al., 2004; Rosser, 1998), instructors who introduce interactive techniques tend to receive student push-back and, consequently, poor reviews from a vocal student minority (Lavin, Korte, & Davies, 2012). Of course, students who are intrinsically motivated to learn reportedly value the challenge and subsequent knowledge that they acquire (Syh-Jong, 2007). It may appear that a correlation exists between non-engineering courses with increased innovative exploratory instruction techniques and their approximate gender-balance, but significant research disproves the hypothesis that teaching techniques are gender-specific (Bullough, 2015; Lavin et al., 2012; Nelson Laird et al., 2010; T. Scott et al., 2012): teaching techniques are discipline-specific and all students adapt to the teaching methods presented in their chosen fields. However, lectures create a disconnect between the teacher and the student and between the concepts and their applications (Madsen, McKagan, & Sayre, 2013; Whitman, 1990); classes that enable students to best comprehend the real world applications of concepts by using inquiry-based discovery methods may attract more women (Adams et al., 2006; Rahm & Downey, 2002).

The connection between concepts and context is an important factor in workplace satisfaction for women (Fouad & Singh, 2011). Studies indicate that men and women have overlapping needs for motivation and satisfaction to differing degrees. While compensation plays a larger role for most men, women who expressed satisfaction with their work cited an increased desire for intrinsic motivators like social connections and knowing their work makes a positive influence on society (Gordon, 2005). Women typically earn less than men in similar roles with similar responsibility (Alksnis, Desmarais, & Curtis, 2008; McDonnell & O’Neill, 2009) yet they
express greater concern about having fewer opportunities for professional development and for participation in decision-making (Chow & Crawford, 2004). While these indicators inform discussions on improving the retention of women in the workplace, they also apply to the development of recruitment strategies of women to engineering education.

When do young men and women make their choices in terms of career options and post-secondary education? Some children and youth scholars suggest youth make their future career decisions during the early years (Buchmann, Diprete, & McDaniel, 2008; Gilchrist et al., 2010; Watt, 2004). However, outreach work currently underway appears to successfully motivate young girls to persist in mathematics and science through elementary and middle school (Pomerantz & Raby, 2011; Shapka, 2009). Math and science programs in the early grades are so successful that some scholars have become concerned that boys are losing out, although dissenting views insist the seats taken by girls in higher education are additive and do not replace seats available to boys (Evers, Mancuso, & Livernois, 2006; “The gap in achievement between boys and girls,” 2014). Today, girls comprise over 45% of Physics 11 classrooms in the United States (Ivie & Ray, 2005; Levin et al., 2005) and, as mentioned above, roughly 50% of Physics 11 classes in the Greater Victoria region. As a predictor of a student’s aptitude for engineering, Physics 11 is considered a key course for analysis in this doctoral research.

To summarize, early education is sufficiently preparing girls and boys for entry into post-secondary engineering studies such that equal numbers of girls and boys choose Physics 11 as an elective science course, yet the girls in Physics 11 typically do not choose engineering education (Madsen et al., 2013). Men and women use similar teaching methods in physics, predominantly lecture-based, and minimal gender gaps exists in student learning preferences (T. F. Scott,
Schumayer, & Gray, 2012; Syh-Jong, 2007). Yet, although girls equally participate in high school physics, a gap persists in women’s participation in post-secondary physics and engineering (Docktor & Heller, 2008; Lauer et al., 2013; Madsen et al., 2013). Studies in the Pacific Northwest reveal that girls in Physics 11 classrooms are not choosing careers in physics or engineering for various reasons; in addition to social preconceptions based on family and media portrayals, girls fostered a belief that physics was a dead science – there was nothing left to discover – and could not see how to use physics to make the world a better place (Sawtelle, 2011). This latter is similar to motivators for the retention of women in the workforce (Gordon, 2005). The qualitative high school information requires quantitative substantiation for dissemination to a pragmatic engineering population (Yardley & Bishop, 2008). I coalesced on my research objective: identifying, implementing and verifying an intervention method to change the perceptions of girls in Physics 11 so that more of them choose engineering studies and the profession achieves gender diversity.

**Author Standpoint**

I embarked on this research path for very personal reasons and it is necessary for me to acknowledge the potential conflict of interest: I want to create a better workplace for engineering women. I enjoy the challenges of solving engineering problems, teaching engineering concepts and leading engineering projects, yet acknowledge occasional feelings of isolation in the workplace. An outsider suggested to me that the reason was likely because I am the only woman in my workgroup.

My experience is not unique. Subsequent conversations with my undergraduate cohort, with female engineer associates and with professional peers revealed stories similar to mine:
enjoyable work experiences coloured with nebulous feelings of discontent. Probing systematically, I found significant research on this topic documenting that women and men leave their professions because of similar feelings of isolation, lack of advancement opportunities and discontent with the general work culture (K. R. Buse, Perelli, & Bilimoria, 2009; Hersh, 2000; Mills, Mehrtens, Smith, & Adams, 2008). Female students in mechanical engineering classes at my college regularly seek me out, questioning whether they are in the right program when they have such different interests, values and goals from the male colleagues who typically comprise over 90% of each cohort. Would changing the gender balance in the classroom or the workplace change the culture sufficiently for women there to be happy?

**Impact on Professions**

This doctoral project followed a preliminary investigation into the impact of professional diversity on organizational success as measured by financial viability and sustainable practices. A broad review of research into the effectiveness of diverse teams compared with homogeneous teams revealed improvements to organizational culture and increased job satisfaction resulting in greater productivity (Cropsey et al., 2008; Gordon, 2005; Lindorff, 2011). Common themes among women who claim to be happy with their work beyond their duties include that they received opportunities for learning and advancement and they “love the people they work with” (Gordon, 2005, p. 8); employees of both sexes who report happiness at work indicated that the respect of peers alone could add sufficient meaning to their jobs, building the emotional capital necessary for satisfying work (Seligman, 2004).

Professions that successfully changed their demographics to better reflect the overarching population achieved measurable organizational benefits. Lawyers, accountants and doctors, for
example, moved from predominantly male professions in the early 20th century to the gender balanced or majority female populations they are today (Bertakis, 2009; Dau-schmidt, 2008; Davie, 2005). Although gender parity is only apparent in junior and intermediate level positions, demographic changes have had demonstrable influences on employee retention, satisfaction and motivation leading, in turn, to higher productivity and financial success (Drinkwater, Tully, & Dornan, 2008; Forbes, 2011; Lindorff, 2011; Price et al., 2005).

**Research Objective and Activity**

With Physics 11 identified as the key course through population data and qualitative analyses, and with the identification of the knowledge gap around interventions that could possibly close a gap in the leaky pipeline to engineering, I identified the research question: How can girls with aptitudes in physics be inspired to explore career options in the physics sciences? Therefore, the aims of this project are twofold: to raise awareness of the social narrative and behaviours that perpetuate perceptions of gendered career options for high school students; and to implement and test a solution for systemic change to reduce perceived barriers to young women entering engineering education. The research hypothesis is that although current teaching methods do not in themselves lead to gender differences, teaching physics labs using discovery-based, collaborative and innovative methods may overcome the disconnect resulting from lecture methods and reveal the daily relevance of applications of physics, which may result in higher motivation and engagement, and greater transition rates for girls to engineering education than previously realized. In addition, the students who pursue engineering education will have a better understanding of what the career entails. In other words, this research may result in more women
entering engineering education. The null hypothesis is, therefore, that no change in perceptions and inclinations will occur.

Using the methods of participatory action research, I engaged five physics teachers from the Greater Victoria region to develop an inquiry-based (discovery-based) lesson plan for our use in their classrooms. I introduced the concepts of engineering design, proto-typing and verification testing; together we explored innovative techniques for facilitating the exploration of physics concepts in their classes by using the engineering design process. We decided on a consistent facilitator to minimize the factors that could confound the results. All sessions with teachers and students were recorded for research purposes only requiring a significant, multi-level ethics review. Students completed a detailed survey with questions relating not only to the relationship between high school courses and potential careers but also to their sense of belonging in community, school and physics classroom and their feelings of destiny and control. The survey was deployed three times: once within a week prior to the activity in their classroom, once within the week following the activity and once 4-5 months later to test for the persistence of any perception shifts.

**Chapter Conclusions**

Addressing the leaky pipeline to engineering careers by changing social beliefs and perceptions has potential to be highly impactful. This research focuses on the gap between high school and post-secondary education, recognizing that Physics 11 classrooms have near gender parity but engineering classrooms do not (Levin et al., 2005; Sawtelle, Brewe, & Kramer, 2012). While gender does not influence the teaching methods employed in various educational disciplines (Nelson Laird et al., 2010), gender factors do play a role in optimizing the methods to
engage and motivate students: more women tend to look for ways to make the world better in their work so if teaching methods augment this perception of a career, more women will gravitate towards a particular field of study (Fender et al., 2011). This research focuses on an intervention in Physics 11 to teach young men and women how physics can be used to improve their lives and make the world a better place.

**Research Roadmap**

The following chapter explores attempts made by other professions to diversity their populations and social factors that propagate beliefs in gendered careers in curriculum and in the engineering profession. The strategies employed by non-engineering organizations achieved varied levels of success in education and in the workplace; overcoming social norms that persisted through the developing waves of feminism in the last century may take several more decades to achieve in spite of the work done to date across economic sectors and academic disciplines (E. Anderson, 2012; Beddoes & Borrego, 2011; Gaskell, McLaren, & Novogrodsky, 1991).

The next chapters detail the procedures and data from new research conducted in Victoria, BC, over two years, ending June 2016. The timeline was very tight due to the high school academic year and the accessibility of both teachers and students. Some unexpected ethics approval constraints almost set the work back a full year, however the researcher was able to negotiate an innovative multi-stage approvals process.

Chapter 3 describes the methodology choices and decisions and outlines the process used including the selection of the study population. This section presents the full project plan, complete with projected and realized timelines and work flow. Extrinsic requirements dictated
the teacher population selection process, resulting in lower gender balance than preferred. Ultimately, however, the student population ended up representing a broad range of gender, racial and socio-economic factors.

Multiple feminist theories are at play in this project; this work necessarily focuses on only three aspects when developing the research hypotheses. Chapter 4 outlines the theories considered in developing the research hypothesis. As the research progressed, however, it became apparent that unanticipated behaviours exhibited in the classrooms and by teachers confounded the original assumptions, necessitating an expanded theory discussion. The chapter includes an overview of these developments.

The subsequent two chapters present the quantitative and qualitative data, and discuss the basic trends and themes. Chapter 7 presents interpretations of the data. The concluding chapter includes a discussion on the limitations of this research and recommendations for future research directions.
Chapter 2 – Gender Effects

Engineering persists as a female-deficient profession in North America. Although women studied engineering in the late 19th and early 20th centuries, those who “invaded” the engineering institutions and graduated with degrees typically returned to being homemakers or adopted roles as managers in their fathers’ or husbands’ businesses (Bix, 2013). Their influence on society was limited to family guidance and social volunteerism (Gaskell, 1973) until the two world wars. With the demand for military personnel, insufficient male engineers were available to meet the ongoing need for rapidly manufactured advanced technology (airplanes and weaponry). Industry therefore pushed educational institutions to recruit women with aptitudes for high school science into engineering programs through intense promotional campaigns and sponsored seats at universities (Bix, 2013). Some, like Iowa State University, established segregated classes for women to complete accelerated programs; these were viewed by male students and faculty as inferior to ‘real’ engineering studies. Regardless of the opinions of classmates and professors, women who earned engineering degrees during this time, like Elsie MacGill, the first woman in Canada to graduate as an electrical engineer, worked outside the home in manufacturing and engineering design (Wakewich, 2014). They represented up to 40% of the workforce in some companies such as Car and Foundry Co. Limited, a site of aircraft manufacturing in Fort William, Ontario, which later became part of the city of Thunder Bay (Wakewich, Smith, & Lynes, 2017). However, when World War II was over, returning men displaced these workers and women’s participation in engineering was visibly reduced, with most women returning to their unpaid work in the home.
Not all women were satisfied with these post-war developments. This period, often referred to as the second wave of feminism, saw significant numbers of women and men pushing for gender equity and access for women to career training and vocational recognition (Panton, 2004). In response, the Canadian government authorized a commission to “inquire into and report upon the status of women in Canada, and to recommend what steps might be taken by the Federal Government to ensure for women equal opportunities with men in all aspects of Canadian society” (Bird et al., 1970, p. vii). On the recommendation of the Royal Commission on the Status of Women in Canada (1970), academic institutions were required to allow women into their faculties and subsequent decades saw increasing involvement of women in many professions like medicine, law, accounting, and marketing, in which women now comprise 40-60% of both student and industry populations (Jonung & Ståhlberg, 2009; Moore, Mahler, & Ashton, 2011). Yet, in 2015, only 12.8% of the 2015 Canadian engineering population were female (Chehaiber, 2016). The gender parity achieved in non-engineering professions was a result of dedicated and coordinated ongoing efforts on the part of regulators, academics and industry representatives.

This chapter provides an overview of non-engineering professions and the work undergone to approach gender balance followed by a brief historical overview of the feminist influences on education in British Columbia (BC) and on Canadian society. The analysis of professions develops a foundation for addressing feminist issues in engineering (Beddoes & Borrego, 2011). The subsequent discussion on the influences of curriculum on feminist thought segues into a detailed analysis of data trends introduced in Chapter 1: the data from a BC college relate transfer credit records with the first program in which students choose to register at the post-
secondary institution. These trends demonstrably mirror societal shifts and the ongoing gendered career choices made by BC students.

**Professions and Gender Parity**

This section explores the motivations and strategies for demographic shifts in various professions. Each profession included here existed as a male-dominated profession through the mid 20th century and, therefore, serves as a suitable benchmark for engineering. Some successfully shifted their gender balance, others did not.

**Economists**

Demand for graduates in the field of economics grew rapidly during the latter part of the 20th century; economics classes at Canadian universities subsequently endeavoured to recruit large numbers of women (Siegfried, 2011). While first year economics programs achieved near parity, however, there had been no concentrated effort to retain women in the education stream, resulting in persisting graduate rates of only around 30% (“Accounting Enrollment, Hiring Increase.pdf,” n.d.; Siegfried & Round, 2001). Most of the women enrolled in economics programs in their first year typically transferred to business programs. Therefore, in spite of growing demand for professionals and ongoing industry interest in achieving gender balance, the percentage of female economists remains low (Burton & Humphries, 2006; Jonung & Ståhlberg, 2009). Hence, the will to create diverse gender representation in a profession is insufficient in itself to recruit and retain women for the profession.

**Accountants**

Accounting firms took on the challenge of recruiting high numbers of women in the early 1990s because female clients began to demand female accountants who might better understand
their values and needs (Hooks, 1996). This client-driven initiative, fuelled by threats to transfer their accounts, influenced corporate strategic planning among accounting firms, resulting in the development of tactics designed to change the workplace culture. These initiatives included the launch of employee family programs, job-sharing opportunities and clear pathways for career advancement for women (Johnson, Lowe, & Reckers, 2012). Nevertheless, with the percentage of female accounting graduates increasing to 50% and women making up 40% of the accounting profession, female accountants earn only 83% of that earned by male accountants, with the difference more pronounced as seniority increases. While it may seem as though any remaining differences will accordingly be phased-out over time, this is unlikely because more women accountants are employed at lower level positions, gendered differences persist in childcare choices, and the percentage of female accounting partners remains low, at 25% (Transition to Transformation: CPA Canada Annual Report 2015-2016, 2016). Recent studies indicate this is an ongoing concern (Gago & Macías, 2014; Johnson et al., 2012).

**Physicians**

Another client-driven initiative, now firmly entrenched in social expectations, is gender balance amongst physicians. Women officially practiced medicine as early as the mid-1800s, but historically participated in the field long before that through midwifery and nursing. These roles originally held higher authority for prescribing medicines and practicing minor surgeries than they do today (Blake, 1990). The US Medical Act of 1858 introduced licensing and regulation to the United States of America, which initially restricted access to women by requiring practitioners to acquire qualified degrees and experience. Similarly in Canada through to the 1990s, women’s role in healing professions persisted as predominantly midwifery and nursing.
(Gorham, 1994). Through those years, however, the number of women in medical schools steadily increased and today over 50% of physician graduates are female (Canadian Medical Education Statistics, 2016). Women comprise over 50% of practicing family physicians and over 33% of specialists (2014 National Physician Survey, 2014). This being said, job satisfaction and employee retention are low as physicians tend to move around, trying to find better workplace fit; surgeons face female recruitment challenges because, although highly-paid, work demands often interfere with family and other lifestyle choices that women typically require for employee satisfaction (Adamo, 2013; Park, Minor, Taylor, Vikis, & Poenaru, 2005; Rogers, Creed, & Searle, 2012).

**Lawyers**

Some scholars theorize that positive social benefits presented in popular fiction are key to influencing girls and their caregivers about career choices and contributed to the increase in female participation in medicine (List, Collins, & Westby, 1983). Television series such as Dr. Quinn, Medicine Woman and The Mindy Project portray women and minorities as successful physicians, capable of making positive change in their communities (Elber, 2012; Greenfield, 2003; Keveney, 2012). The current gender balance in medical training appears to support the idea that popular fiction effects social change (Van Evra, 2008). In a similar way, programs like Street Legal and Law & Order and movies like Legally Blonde may play a similar role in the recruitment of girls into reading law. Recruitment, however, is insufficient to provide a profession with the gender balance necessary to best serve the public interest: while the legal profession successfully recruits more than 50% women to their educational programs, women
represent about 34% of practicing lawyers in British Columbia and only 29% in full-time private practice (Berge et al., 2009).

**Engineers**

In 2015, Canadian women comprised less than 13% of new engineering licensees; British Columbian licensees were 15.6% women (Chehaiber, 2016). Enrolment figures noted previously indicate 20% female participation, indicating the pipeline leak between graduation and employment has yet to be stemmed. The national concern for gender diversity among regulators is increasingly shared by the engineering profession and is now used as a marker for organizational success (Chehaiber, 2016). Engineers Canada recently declared a 2030 target of 30% women among newly licensed engineers. This goal is based on the 2005 United Nations report on this topic which states that 30% of a minority group provides the critical mass for agency, enabling and empowering individuals to participate equally as decision-makers\(^1\) (*Equal Participation of Women and Men in Decision-Making Processes, with Particular Emphasis on Political Participation and Leadership*, 2005). The engineering regulators for each province and territory unanimously endorsed this goal and subsequently appointed 30-by-30 Champions to advocate for women’s issues in their Council deliberations and promote activities, language usage and behaviours that support the 30% by 2030 goal (Chehaiber, 2016).

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\(^1\) Studies on critical mass for minority empowerment demonstrate that the value lies somewhere between 25% and 40%, depending on the players involved (Chaney, 2012; Childs & Krook, 2008; A. Powell et al., 2006). Fewer assertive individuals may experience empowerment within a receptive majority group. Many organizations as noted above adopt 30% as a reasonable guideline.
Engineering is facing global shortages as the average population age continues to increase, even considering the addition of new licensees (McDonnell & O’Neill, 2009). Canadian engineering companies repeatedly recruit foreign-trained engineers to meet their organizational needs, exemplified by the increasing rate of registration of internationally educated professionals in British Columbia (2015-16 Annual Report: APEGBC, 2016). However, attrition rates among professional engineers, especially women, remain a concern (K. Buse, Bilimoria, & Perelli, 2013; Fouad & Singh, 2011). Focusing on the mechanical and electrical engineering areas, the disciplines that most rely on the application of physics concepts to develop and maintain technologies that benefit society, female enrolment is unchanged since the 10-12% recorded in 2012 (Wlotzki, 2016).

Engineering students

In 1987, nine women were in the graduating class of 96 mechanical engineers from the University of British Columbia. Thirty years later, in 2016, over 30% of the registered first year engineering students in the same institution were women, while the University of Toronto registered an unprecedented 40% women and Waterloo University registered 37% women in their first year engineering programs (Chehaiber, 2016). This seems like slow but good progress for women entering a profession typically held to suit men. However, these numbers are anomalies in Canadian engineering institutions, not indicators of national or provincial trends. Across Canada, including these three large institutions, only 20% of engineering students were women (Figure 2), with 12% women in mechanical engineering programs (Wlotzki, 2016).

The University of British Columbia graduates the greatest number of engineers in the province and has worked diligently to attract and retain women in their engineering programs, as
can be seen by the high percentages of women graduating from many disciplines (Table 3). Biosystems, environmental and geological engineering award roughly equal numbers of degrees to women as to men. The computer and software engineering programs across the province award the smallest percentages of degrees to women at 9%. Of note is the low percentage of degrees awarded to female graduates in mechanical engineering, with only 4% at UBC Okanagan, in Kelowna, and 9% at Simon Fraser University in Burnaby and 9% at the University of Victoria. Interestingly, these mechanical engineering departments also have low percentages of female faculty teaching in the programs (Wlotzki, 2016).

Although graduation percentages for women continue to be low in most disciplines, recruitment has increased at all institutions (Wlotzki, 2016). UBC Vancouver’s enrolment of women in mechanical engineering reached 22% in 2015 and all other institutions reported 10% women in their mechanical engineering programs. The new mechanical engineering program at the British Columbia Institute of Technology achieved 5% in their first reporting period but they have no female faculty in their program and have not yet initiated gender-specific recruitment strategies. These trends are encouraging and hopeful but still insufficient to meet anticipated demand in the near future. Fortunately, the BC Ministry of Education recently announced an expansion to engineering programs which may open sufficient seats, which can be filled by women.
Registration percentages gently fluctuate year by year, yet the profession of engineering will never reach functional gender diversity unless the cohorts of newly registered professional engineers across the board achieve a sustainable critical mass of around 30-45% women (Karataş-Özkan & Murphy, 2010; Lortie-Lussier & Rinfret, 2002; A. Powell, Bagilhole, & Dainty, 2006; Torchia, Calabró, & Huse, 2011). From this section’s review of the work within the professions of law, medicine and accounting, engineering employers and educators need to operate concurrent strategies to successfully retain women in the workforce while improving recruitment rates: a single strategy is insufficient to achieve gender balance. The discussion focused on mechanical engineering as a physics-related discipline but the general engineering numbers are only marginally better: women comprise 13.8% of engineers in British Columbia.

![chart](chart1.png)

Figure 2: Undergraduate engineering enrolment by gender (Wlotzki, 2016).
DISPELLING GENDER BARRIERS AND BUILDING CAPACITY

and only 13% nationally, due to variations between each province (Chehaiber, 2016).

Perpetuating Perceptions of Gendered Careers

Young women occupy an increasing percentage of the seats in high school physics classrooms yet they do not, for the most part, enter post-secondary programs in the physical engineering sciences or physics (Ivie & Ray, 2005; Levin et al., 2005). Women’s participation in engineering slowly increased since their first official inclusion and subsequent marginalization following the two world wars (Bix, 2013; Chehaiber, 2016) yet young women demonstrably make gendered career choices in spite of the advances of feminist influences on society and on curriculum (Ivie & Ray, 2005; Levin et al., 2005). Some authors suggest gendered careers arise from differing interests between men and women (Su, Rounds, & Armstrong, 2009) but it is more likely that, when interpreted against the backdrop of social change, this phenomenon can

<table>
<thead>
<tr>
<th>Institution</th>
<th>Biosystems</th>
<th>Chemical</th>
<th>Civil</th>
<th>Computer</th>
<th>Electrical</th>
<th>Engineering</th>
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<th>Environmental</th>
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<th>Industrial or Manufacturing</th>
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<tr>
<td>BCIT</td>
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<td>UBC</td>
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Table 3: Total undergraduate degrees awarded to women in British Columbia by institution and discipline, 2015 data from Wlotzki (2016). The variations in percentages are drastically different for those institutions actively recruiting women to engineering. Civil, mechanical and electrical engineering programs typically register the largest cohorts.
be attributed to unintentional persisting sex discrimination by practitioners and educators (Beaulieu & Searles, 2016; Lanaj & Hollenbeck, 2015; Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012; Williams, Li, Rincon, & Finn, 2016; Williams et al., 2014).

**Feminist influences over the last century**

Feminist activism has had pervasive influences on society, far beyond the acquisition of desired rights and privileges (Adshade, 2012; Briskin & Coulter, 1992; Cherubini, Hodson, Manley-Casimir, & Muir, 2010; Gaskell, 1994). Three waves of feminism influenced changes to kindergarten through high school curricula in British Columbia. Those changes correspond to changes to the gender gap in post-secondary education within STEM areas: science, technology, engineering and mathematics (Gaskell et al., 1991; Swirsky & Angelone, 2015).

Feminist researchers refer to three or four waves of feminism (Bowell, 2011). The first wave represents the initial period of increasing participation of women in political and social life, and their rising levels of education in the late 1800s through early 1900s. Women acquired the right to vote during this period and some worked outside of the home in teaching and clerical occupations. Regardless, women continued to be responsible for all aspects of domestic work and responsible for most social and political activity, including caring for the ill, raising funds for shelters and orphanages, and interacting in the political sphere and complementing the contributions of working-class men, mostly farmers or labourers (D. Anderson, 2014; Clark, 2005). In her dissertation research, Jane Gaskell (1973; 2004) reviewed BC history textbooks to investigate their inclusion of feminist issues. Early textbooks rarely mentioned women’s contributions to society, however, first wave feminists attempted to initiate changes to the curriculum in their role as teachers, setting lesson plans and writing submissions for textbooks
designed to introduce students to women’s issues as related to life in the home\textsuperscript{2}. These first wave works built the foundation for – or possibly contributed to – the second wave (Clark, 1998, 2005; Coulter & Greig, 2008; Franzosa, 1998; Gaskell, 2002; Mujawamariya & Hamdan, 2013).

Although sparked by events following the return of men from World War II, the second wave of feminism is better known for the militant activism of the women’s liberation movement. By the 1960s, tension grew such that, in Canada, the Royal Commission on the Status of Women was enacted (1970). The Commission made 167 recommendations, including legislated equality for women in work, education and law. The activism of the second wave of feminism produced the majority of feminist additions to curricula, thoroughly addressing women’s roles in history but instigating rising concerns about the effect of a feminized curriculum on boys (Evers et al., 2006; Gaskell, 1973). Coinciding with racial activism, the second wave was replete with militant affirmative action (Bird et al., 1970), which alienated some from the growing women’s liberation movements across Canada, the United States and Britain (Brown, Western, & Pascal, 2013; Coulter, 1996; Riley, 2013).

Today’s third wave, also called post-feminism, is a time of confusion for many girls and women who believe they live in a society of equality but experience sexism in obvious and hidden ways (Munro, 2013). British Columbian curriculum documents cease to mention feminist requirements but focus instead on aboriginal and racial diversity, reflecting an apparent post-

\textsuperscript{2} Early textbooks included little feminist information on the early settlers, in which the family home became the setting for women’s paid labour as dressmakers, tutors, farmers. Later feminist influences incorporated details based on journal entries from the time, incorporating “complex [accounts] of the intricate connections between the private domestic activities of spinning, weaving and childbirth and public, political, economic and legal events in New England” (Clark, 2005, p. 245).
feminist cultural assumption that women are now equal and sexism no longer needs mentioning. The post-feminist constructs of ‘Girl Power’ and ‘Successful Girls’ (Pomerantz & Raby, 2011) send the message that girls can do and have anything, yet barriers to engineering and other careers in the physical sciences continue to deter women from entering those careers. Researchers posit that the “superwoman” construct of the second wave of feminism set up a conflict for women of science, combining the intersectional role expectations. Not only were women in science expected to exceed female attributes, they were also expected to excel at male attributes (Pomerantz, Raby, & Stefanik, 2013).

If one could ask a female engineer or physicist of the third wave, she might say she self-identifies without a gender tag because she will have grown up in a society that values diversity and the ability to appreciate and incorporate multiple standpoints in decision-making, a society in which all things are possible for all people. Yet she may also likely say she has experienced direct sexism at some point in her life – through disparaging actions or comments at work or discouragement at home – and felt powerless to overcome it (Pomerantz et al., 2013). In the last few years, however, young women seem to have reinstated the gender tag in what some call fourth-wave feminism: a way of being successful in science and business while maintaining or even flaunting their femininity (Munro, 2013). These fourth-wave feminists are recognizable in post-secondary STEM classrooms in recent years by their unmistakable femininity and calm self-assurance.

Changes to curricula over the last century reflect the waves of feminism to a point where education today generally presents women’s issues, usually as sidebar discussions but sometimes imbued throughout the main text (Clark, 2005). Gendered career choices and occupational
sexism persist, however, in many disciplines. Exploring the limitations to the feminization of curricula reveals ongoing issues and possible strategies to support girls and women in STEM areas and their pursuit of traditionally male professions.

The BC Curriculum over the last century

Studies from the 1970s identified several beliefs that persist today: that girls have both opportunity and access to all careers but teachers tend to unconsciously persuade them to gendered courses of study; that parents and friends give unintentionally erroneous information about high demand for and easy entry into careers similar to their own, perpetuating trends of gendered careers; and that women do not pursue leadership positions because they do not aspire to them (Gaskell, 1973, 1983a, 1983b). The result was and is that women with university degrees more often work clerical jobs while men with university degrees more often work in management (Adshade, 2012; Gaskell & Riecken, 1988). According to these unsupported popular beliefs, further explored in Chapter 4, if women aspired to high achievement they would pursue high achievement, regardless of discrimination.

Canadian society began to overcome some of these patterns and misconceptions through the third wave of feminism and educational reformers increased their efforts to “address the goals, direction and strategies of feminist curriculum change” (Franzosa, 1998, p. 155). Predictably, they had a difficult time reaching consensus on whether to reconstruct curricula to incorporate women’s issues and enrich existing curricula, deconstruct existing curricula to transform them, or develop entirely new stand-alone courses (Burbules & Rice, 1991). Typically, textbooks in British Columbia added content about women’s issue in textboxes and asides from the main text, as “filler feminism” that, unfortunately, trivialized the contributions of women and
depicts a subservient, lesser role for girls. In some BC districts, school boards purchased textbooks commissioned by other Canadian provinces and territories. Those books varied in their incorporation of women’s issues, some providing broad and balanced context, others presenting women as ‘larger than life’ and ‘tough as nails’ (skewed ‘Girl Power’ and ‘Successful Girls’ representations that are difficult for girls to emulate), creating images of social equality that do not exist (Clark, 2005; Pomerantz et al., 2013).

Studies indicate that girls continue to face sexual harassment and sexual violence in the early years of high school (Pomerantz et al., 2013). These same studies also show that girls consistently outperformed boys on tests and college examinations through the 1990s and 2000s. Academic researchers continue to explore why boys are struggling to keep up in school yet continue to dominate in the workplace (Evers et al., 2006; Fender et al., 2011; “The gap in achievement between boys and girls,” 2014).

Influences on girls’ lack of persistence in mathematics beyond high school include: pervasive beliefs that mathematics is a male domain, teachers’ predetermined expectations about their students career interests, students’ experiences in mathematics classrooms, and whether their teachers are gender role models (Li, 2004; Seegars & Boekaerts, 1996). Of greater effect, according to Dorothy Smith, Paula Bourne and Liza McCoy, is “the school’s ‘hidden curriculum’ that teaches girls that they are less important than and subordinate to boys -- thus creating among girls an inner sense of inferiority that is self-silencing” (1998, p. 56). Several longitudinal studies in various countries confirm the ‘hidden curriculum’ effect and the specious perception of boys’ mathematical ability or talent, which are readily contradicted by test scores (Eccles et al., 1989; Frenzel, Goetz, Pekrun, & Watt, 2010; Jacobs, Lanza, Osgood, Eccles, &
Wigfield, 2014; Nagy et al., 2010; Shapka, 2009; Watt, 2004; Wigfield et al., 1997). Curiously, girls’ motivations for achievement are not affected by the hidden curriculum, only their final career choices. Quin Li (2004) found that British Columbia mathematics teachers prefer idealistic, liberal and democratic educational philosophies that inspire girls to study math and physics, yet continue to reinforce traditional occupational pathways regardless of their students’ interests or talents.

1990s reviews of British Columbia science curricula rarely mention gender except to indicate that there were little or no differences in achievement between girls and boys (Monkman, 2001; Mujawamariya & Hamdan, 2013). A transitions study of rural schools in British Columbia indicated women had a positive perception of the learning environment in high school learning environments but not in post-secondary education. Canadian scholarly women responded negatively to implications that there are barriers to attaining their educational goals because they had already demonstrated proficiency at balancing academic success with conforming to conventions of femininity (Raby & Pomerantz, 2013; Shapka, 2009). The challenge, then, is not to ask the opinions of women who have already achieved academic and professional success. Rather, it is to remove the barriers to women who are not as proficient at both balancing the often contradictory role requirements of the female scientist and withstanding “the experiences of sexism both in and out of school, and the belief that they will have to do better than boys throughout their lives, just to be seen as equal” (Pomerantz & Raby, 2011, p. 561).

The messages of the ‘Girl Power’ and ‘Successful Girls’ constructs from the 1990s – that girls can do, be and have anything they want while surpassing boys in schools and work-places –
“have made naming sexism in schools [in the 2000s] difficult for girls because they are now seen to ‘have it all’…[and have made] cries of gender injustice appear not just unfounded but implausible” (Pomerantz et al., 2013, pp. 185–186). Post-feminist constructs mislead girls into thinking they should not be experiencing the sexism they encounter, so they feel responsible when sex discrimination or harassment occurs. Out of the dichotomy of this feminist experience, of disempowerment and success, arises the new feminist way of thought, that some call fourth-wave feminism (Munro, 2013). This is the idea discussed in the previous section that women can be successful while continuing to portray and celebrate their femininity. I pass a few fourth-wave feminists in the hallways at Camosun College and live with two of them who are my daughters\(^3\): they inspire me to believe change can happen in engineering.

**High School Physics Transitions**

Many researchers have explored the benefits of mixed-gender versus single-sex classrooms on student learning, but controlling for multiple confounding variables, like socio-economic standing and prior achievement, this has proven difficult. Alison Little (2009) explored the possibility of increasing girls’ success in math and physics using a pilot teaching program in single-sex schools. Her study posits that gender differences occur in active learning interests, such as girls preferring to work in small groups with practical hands-on activities like poster projects, presentations and discussions. The School of Engineering in the University of

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\(^3\) One of my daughters is currently a doctoral candidate in physics and astronomy, my other daughter is a science fiction author. Both successfully completed Physics 12 and both understood feminism long before I began this research and discovered for myself what the word means. They encourage me to share my ideas, to teach with authenticity and to be who I want to be without worrying about blending in with my male colleagues.
Tasmania, which runs a project with a goal to attract girls in upper primary and secondary schools to engineering studies, similarly found that practical experiments encouraged girls to be more creative with their hands and helped them to better connect with the physical sciences (Little & León de la Barra, 2009). Mixed-gender classroom studies show that boys typically assume more active roles, a role behaviour that is established as early as kindergarten (Vingilis-Jaremko, 2010). However, when girls are left to take on the passive role of note-taker, they disengage from the lessons and lose both confidence and interest in STEM (Shapka & Keating, 2003). This is not to say that single-sex schooling is the answer. There are some indications that transitioning from single-sex schools to mixed-sex post-secondary education can have negative impacts on performance due to “reduced opportunities for cross-sex socialization” (Shapka & Keating, 2003, p. 930). Girls tend to feel a decline in self-esteem and self-confidence during high school, both of which are predictors of decreased interest and competency in math (Acker & Oatley, 1993; Eccles et al., 1989; Shapka, 2009). Coeducational schools that establish same-sex science classes may capture the best of both worlds: enabling girls to gain confidence and experience in physical sciences and learn mixed-gender socialization skills, which provide benefits in life-long success (Shapka & Keating, 2003).

All this being said, girls in British Columbia participate at a relatively high level in Physics11 classes. Whereas most BC post-secondary institutions require two of three high school sciences\(^4\) for admission (“Admission Requirements,” 2015, “Canadian High School,” 2015, “Undergraduate Programs and Admissions,” 2015), girls are frequently including physics as one

\(^4\) in addition to one high school language and normal graduation requirements; the science choices are physics, chemistry and biology
of those sciences. In the late 20\textsuperscript{th} century, therefore, BC high schools apparently managed to significantly reduce barriers to girls’ pursuit of mathematics and physics through the middle and high school years, repairing one of the leaks in the pipeline to engineering (Watt et al., 2012).

Through my affiliation with Camosun College, in British Columbia, I acquired the transfer credit dataset of all students at the college since 1972 to attempt to substantiate these assertions about BC girls’ participation in high school physics.

\textbf{Physics participation and post-secondary transitions in a BC college}

Engineering education in Canada is provided by publicly-funded universities, colleges and institutes and mandated by the Provincial Governments. British Columbia is the westernmost province with a population of approximately 4.6 million people, doubled from 1972 (\textit{British Columbia Population Projections: 2014 to 2041}, 2014). Five of the fifteen publicly-funded colleges and eleven publicly-funded universities offer engineering diplomas and degrees and four offer comprehensive post-secondary training. Privately-funded colleges and universities in BC have narrower mandates than public institutions and do not provide accredited engineering education.

Four decades of student data collected from a comprehensive community college in British Columbia provide an insight into the program choices of students in the region. Camosun College first opened its doors in Victoria, British Columbia, in 1972 as a comprehensive vocational school. Early programs included trades training and university transfer courses in art, language, and social and natural sciences. The college introduced engineering technology programs in the late 1970s and established qualification requirements including the satisfactory completion of prerequisite courses equivalent to current versions of Physics 11 and Math 12.
The purpose of this analysis is to identify the percentage of girls who successfully completed high school physics credits and their post-secondary educational choices. The analysis preceded the doctoral research and is not assessed for its statistical significance in predicting provincial or national trends. Rather, the analysis indicates the choices of student at one Victoria, BC, college over time, positing the influence of the feminization of curriculum in the region’s high school system and recommends further study to establish generalizability.

**Key course**

The data set used in the following analysis consists only of the segment of the Camosun College student population who registered with existing Physics 11 credit between 1972 and 2014. Physics 11 is the prerequisite physics course for admission to engineering courses at Camosun (“Civil Engineering Technology: Admission Requirements,” 2015, “Electronics & Computer Engineering Technology- Renewable Energy: Admission Requirements,” 2015, “Mechanical Engineering Technology: Admission Requirements,” 2015); therefore it is used as an indicator of capability in the physical engineering sciences. The assumption of pre-requisite courses is that students who successfully complete Physics 11 should have the capability to successfully apply physics in broad applications, especially those concepts required for the physical engineering sciences with regards to the identification and analysis of forces within systems. In the British Columbia curriculum, Physics 11 is the prerequisite for Physics 12, which was for many years the physics requirement for admission to BC university engineering

**Career decisions of students with Physics 11**

Camosun College was formed in 1972 and has kept electronic student grades since that time. As mentioned earlier, the college provides a comprehensive suite of programs, including courses in business, health, nursing, science, sociology, arts, trades, engineering and technology. Although early data are sparse in the 1970s due to small start-up class sizes and the small number of programs offered, the student population steadily increased from around 250 students to approximately 18,000 students by 2014 (*Strategic Plan 2014–2017*, 2014). This population provides good numbers for analysis of the later decades.

For the purposes of this analysis, the comparisons concern which programs women with high school physics chose to first register in at Camosun, how women’s choices differ from men’s choices and what percentage of each sex enter each program. To reiterate, this data are pre-segmented to only include those students who successfully completed high school physics as these students would qualify and have an aptitude for entry into engineering programs. This

<table>
<thead>
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<th>Recoded program variables, 1980s data</th>
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<tbody>
<tr>
<td><strong>Recoded variable: SciEngTrades</strong></td>
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<tr>
<td>Civil Engineering Technology</td>
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<tr>
<td>Computer Systems Technology</td>
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<td>Electronics Engineering Technology</td>
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<td>Mechanical Engineering Technology</td>
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<td>Nursing</td>
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<td>Public Administration (MOA)</td>
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<td><strong>Recoded variable: UT-ARTS</strong></td>
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<td>Academic General Studies</td>
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<td>College Preparatory</td>
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<td>University Transfer</td>
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<td>English As a Second Language</td>
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<tr>
<td>Recreation Leadership</td>
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</tbody>
</table>

Table 4: Recoded program variables, 1980s data, Camosun College. Six programs’ data is combined into the SciEngTrades variable, six into the the UT-ARTS variable. This table serves as an example of the recoding undertaken for datasets from each decade.
segmentation reduced the number of units in each cross-tabulated cell when considering each individual program, necessitating recoding to combine similar programs into single categories.

The combination of programs for variable recoding is complex because programs are regularly under development or modification. The range of 1970s college programming consisted of much fewer programs than programming in the 2010s. As very few registered students in the 1970s completed high school physics courses, the 1970s data are necessarily masked to protect the students’ anonymity. In the 1980s, the data indicate only 17 women and 30 men registered at Camosun with high school physics credits. This number is very small, therefore the data recode for this decade combines science, physics and trades program students into one SciEngTrade variable and all other program students from the arts and languages disciplines into another category called UT-ARTS (Table 4).

In the 1990s, the student population that registered at Camosun College with high school physics credit had grown considerably. Of course, the population of British Columbia also increased by almost 40% between 1980 and 1995 (British Columbia Population Projections: 2014 to 2041, 2014), so it is not surprising that the student population would also increase. The recoding in this decade could be more specific, so the SciEngTrades variable is split into two discrete categories, “Science” and “Engineering & Trades”, where the Science variable includes health sciences. It would be preferable to set Health as a distinct variable but insufficient units existed in the individual cells once they were cross-tabulated with sex. The UT-Arts category is split into UT-Arts and Business programs because sufficient data exist in this period to leave enough units remaining in each cross-tabulated cell to render a stable analysis.
By the 2000s, students with high school physics were so numerous and entered such a variety of programs that variable recoding could create eight categories with sufficient units in each resulting cell. The categories chosen were: Arts, Business, Engineering, Health, Nursing, Science, Trades, and University Transfer. Each is sufficiently populated through both the 2000s and the 2010s so these decades can be directly compared with only minor program name changes necessary. The Arts variable includes sociological and fine arts credentialed programs. Some programs that are delivered in the School of Arts & Science are grouped with the engineering programs because the applications of science principles taught mirror engineering principles. For example, Applied Chemistry and Biotechnology is a program that teaches students how to apply the principles of chemistry and biology to solve problems that arise such as crop control or medical experimentation. These develop skills for creative, innovative design solutions that reflect the basis of engineering design. Similarly, Web Design, a program delivered in the School of Business, uses consulting and design techniques also related to engineering. Efforts were made to combine courses that teach design principles similar to those of engineering into the same category variable.

| Table 5 | Students at Camosun College who used Physics 11 as a transfer credit |
|---|---|---|---|---|---|
|  | 1970s | 1980s | 1990s | 2000s | 2010s |
| men | 5 | 30 | 324 | 5521 | 3757 |
| women | 1 | 17 | 215 | 3626 | 2751 |
| %women | 17% | 36% | 40% | 40% | 42% |

Table 5: Students at Camosun College with high school physics transfer credit cross-tabulated with sex, decades.
Physics 11 to Camosun College

Interestingly, roughly 40% of students at Camosun who have high school physics credits are female (Table 5). Except for the anomaly of the 1970s when very few students registered for courses at Camosun College with transfer credit for high school physics, the percentage of women is consistent. Although women comprised less than 5% of engineering students, including computer science and the two science technologies mentioned earlier, through the years, the percentage of women with high school physics credits persisted unchanged through the third wave of feminism.

Career transition choices of women and men with high school physics credits did change over the years. Although the 1970s numbers are too low to include in a statistical analysis, the six students with Physics 11 registered in either the electrical trades, arts or the medical technician program. Registration for women in the 1980s was mostly in nursing, pharmacy tech or preparatory courses. In this decade through the third wave of feminism, girls experienced increased support for studying math and physics in high school. Coinciding with the publicity of space flights by American Sally Ride and Canadian Roberta Bondar, female interest in studying

| Table 6 |
|-----------------|----------|-----------------|-----------------|
| 1980s – Camosun College programs chosen by students who completed Physics 11 | men | women | %women in program | %women’s population |
| Science, engineering & trades | 9 | 3 | 25% | 18% |
| University Transfer | 21 | 14 | 40% | 82% |
| total | 30 | 17 | 36% | 100% |

* Calculation for %women in program: %women=(#women/(#women+#men))%|

Table 6: Program choices in 1980s of Camosun College students with high school physics transfer credit, by sex.
and applying physics increased (Table 6). Male enrolment trends were unchanged through this period.

The number of students who began Camosun programs in the 1980s with high school physics transfer credit is too small to reveal specific numbers in each program. The data were therefore masked to protect individuals’ anonymity and recoded to combine science students with engineering and nursing students. The number is too small for generalizability, nevertheless it is interesting that women with Physics 11 comprised 12% of their science community, 40% of their non-science community, and 36% overall of all students at Camosun who completed high school physics.

In the 1990s, the numbers increased sufficiently to permit a finer breakdown in recoded variables but not sufficiently to break out engineering students on their own. Still, women comprised only 23% of the science education community even though they made up 40% of the population of students who completed high school physics (Table 7). The Science, engineering and trades recoded variable includes all students with high school physics transfer credit who registered in the engineering technologies, including civil, electrical and mechanical engineering

<table>
<thead>
<tr>
<th>1990s – Camosun College programs chosen by students who completed Physics 11</th>
<th>men</th>
<th>women</th>
<th>%women in program</th>
<th>%women’s population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science, engineering &amp; trades</td>
<td>172</td>
<td>51</td>
<td>18%</td>
<td>15%</td>
</tr>
<tr>
<td>Health &amp; Criminology</td>
<td>6</td>
<td>32</td>
<td>73%</td>
<td>20%</td>
</tr>
<tr>
<td>University Transfer</td>
<td>83</td>
<td>72</td>
<td>44%</td>
<td>34%</td>
</tr>
<tr>
<td>Business</td>
<td>63</td>
<td>61</td>
<td>49%</td>
<td>31%</td>
</tr>
<tr>
<td>total</td>
<td>324</td>
<td>215</td>
<td>40%</td>
<td>100%</td>
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* Calculation for %women in program: %women=(#women/(#women+#men))%
and environmental tech, trades programs, and the Associate Degree in Science programs. At Camosun College, the engineering technology programs started up in 1994 so it is reasonable that the numbers of registrants would increase. Of interest here, however, is the high numbers of women entering university transfer (undeclared majors) and business programs: 72 and 61, respectively, out of the total of 215 female students with high school physics credit. In other words, 28% of the women who had high school physics credit, who demonstrated an aptitude for physics by successfully completing the high school course, chose to enter a business program at Camosun College. In contrast, 63 men out of the total of 324 who had physics credit from high school or 19% of their population chose to enter business programs.

Women comprised 84% of 1990s health and criminology students, indicating either that many more women enter the health and criminology programs with or without high school physics credit, or that more women who entered these programs choose physics as their second high school science credit than men who entered these programs. Also of note, 49% of business

<table>
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<th>Table 8</th>
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<td><strong>2000s – Camosun College programs chosen by students who completed Physics 11</strong></td>
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<tr>
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<tr>
<td>Engineering</td>
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<td>Health</td>
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<td>Nursing</td>
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<td>University Transfer</td>
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<tr>
<td>Business</td>
</tr>
<tr>
<td>Arts</td>
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<tr>
<td>total</td>
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</tbody>
</table>

* Calculation for %women in program: %women=(#women/(#women+#men))%*

Table 8: Program choices in 2000s of Camosun College students with high school physics transfer credit, by sex.
students with high school physics credit were female in the 1990s. This number decreased only slightly in the 2000s to 43% (Table 8) but then increased to 46% in 2010s (Table 9). The 2010s data are more robust because Camosun expanded the list of available programs and increased its recruitment activities (“About Us,” 2015). At this time, as well, the population of British Columbia was almost double that of 1970 (*British Columbia Population Projections: 2014 to 2041*, 2014); this population increase expanded the recruitment pool for the college and directly contributed to the institution’s increasing student body.

An in-depth qualitative study would be required to discover these students’ intentions, which is outside the scope of this foundational study conducted to ascertain my doctoral research direction.

The Camosun College data demonstrate that students in the Victoria region who complete Physics 11 or equivalent in high school, thereby demonstrating the requisite science ability and

| Table 9 |
|-----------------|-----------------|----------------|-----------------|
| **2010s – Camosun College programs chosen by students who completed Physics 11** | **men** | **women** | **%women in program** | **%women’s population** |
| Engineering | 615 | 109 | 15% | 4% |
| Science | 123 | 145 | 11% | 2% |
| Trades | 383 | 49 | 54% | 5% |
| Health | 11 | 47 | 81% | 2% |
| Nursing | 31 | 157 | 84% | 6% |
| University Transfer | 1338 | 1172 | 47% | 43% |
| Business | 1119 | 947 | 46% | 34% |
| Arts | 137 | 125 | 48% | 5% |
| total | 5521 | 3626 | 42% | 100% |

* Calculation for %women in program: %women=(#women/(#women+#men))%  
** Rounding errors here produce apparently erroneous total  
*** “Engineering” programs include mechanical, electrical, civil engineering, environmental technology, computer science

Table 9: Program choices in 2010s of Camosun College students with high school physics transfer credit, by sex.
knowledge for registration in engineering education programs (“Civil Engineering Technology: Admission Requirements,” 2015, “Mechanical Engineering Technology: Admission Requirements,” 2015) are choosing a variety of programs that do not require a knowledge of physics, such as in business or health, consistent with findings from the broader population (Jacobs et al., 2014; Watt et al., 2012). Using the metaphor of the leaky pipeline, men with an aptitude for engineering also leave the stream at alarming rates.

The image in Figure 3 depicts the paths chosen by men who successfully completed high school physics as a transfer credit and registered for programs at Camosun College between 2000 and 2014\(^5\). The thickness of each arrow is proportional to the percent of men who chose the specified program discipline, based on the data presented in Table 9, the 2010s data. One might suggest using 2000s data since that dataset represents the entire decade, but at the time of this research the number of students registered during the decade of the 2010s was already more than 70% of those who registered throughout the 2000s, so this sample seems a better representation of current trends (6508 students with high school physics registered at Camosun between 2010-2014; 9147 registered between 2000 and 2009).

\(^5\) Attrition rates have been as high for men as for women in engineering at around 50% out of first year (Besterfield-Sacre et al., 1997).
Again, this data present students’ first program of choice at Camosun College. This may not be the post-secondary program from which they eventually graduate, but is the choice they made coming out of high school or after a few years of work. The leaks in the women’s pipeline exist in similar locations but are greater (Figure 4). The percentages of men entering each program discipline are fairly consistent through the years. Around 10% of men with high school physics credit registered in Trades programs through the 2000s and 2010s; 20% chose engineering programs through the 2000s but only 16% in the 2010s; 2% chose science in the 2000s and 3% in the 2010s; and 24% chose business programs in the 2000s whereas 30% chose business in the 2010s. These variations may be eliminated through the second half of the current decade, but overall these variations are negligible in a pictorial representation.

Figure 3: Where do men go? This graphic depicts the program in which men with high school physics first chose to register at Camosun College in the five years between 2010 and 2014, inclusive. The arrow widths are proportional to the percentage of men with Physics 11 entering the program group in the 2010s.
As shown in Figure 4, the majority of women who graduated high school with physics credit entered business programs. This is consistent with several studies conducted in the United States (Kirchmeyer, 2006; Moss-Racusin et al., 2012; Sadler, Sonnert, Hazari, & Tai, 2012; Waner, Winter, & Mansfield, 2007). Although 2751 young women graduated from high school with physics credit, few chose engineering, trades and science, and many chose the general category of University Transfer\(^6\), which typically consists of general selections of courses that are directly transferable to BC universities but do not combine to qualify for any sort of credential (“University Transfer: Start your university education at Camosun,” 2015). For the

\[\text{Figure 4: Where do women go? This graphic depicts the program in which women with high school physics first chose to register at Camosun College in the five years between 2010 and 2014, inclusive. The “Art” category includes creative writing, drawing/painting and music; “Engineering” includes Applied Chemistry and Biotechnology.}\]

\(^6\) While students in University Transfer may use college credits to transfer to engineering degree programs elsewhere, the majority of students in engineering studies either apply directly to the college’s engineering technology programs or apply directly to the nearby University of Victoria’s engineering faculty.
most part, women with physics from high school are choosing career-training programs in business or have not yet made up their minds about their career directions.

With the broad range of courses and programs available at Camosun College that articulate with universities and provide laddering opportunities to higher education, the institution attracts students from across the province and region. Camosun’s comprehensive suit of vocational and educational options appeal to a wide range of student applicants, from varying socio-economic backgrounds, ages and abilities. In other words, this 2015 data from the Colleague Datamart used for this brief study likely provide a generalizable snapshot of the BC student population. A complete analysis of data from the larger provincial population substantiate whether the Camosun dataset could be used to predict behaviours in the broader population.

**Research Hypothesis**

This research tests the hypothesis that the perceptions of physics and engineering, in particular, as potential careers can be enhanced by introducing into Physics 11 laboratory settings the intersectionality of engineering, student experience and context-based applications of physics (Ghavami & Peplau, 2012). In order to avoid the zero-sum perspective often expected in gender initiatives (Ruthig, Kehn, Gamblin, Vanderzanden, & Jones, 2016), the desired increase in the participation of women is in addition to enhanced participation of men. The research objective is to encourage more youth with an aptitude for and interest in science to explore the idea of a career in an engineering discipline by enhancing their knowledge of engineering through new curricula that enables students to apply physics concepts to situations they define from their own life experiences. Directly connecting the applications of physics to clearly making the world better in some way appeals to women as a motivating work outcome (Gordon, 2005); this
research tests whether an in-class activity that emphasizes the practical dimension can somehow enhance young women’s interest in applying physics as a future career.

Chapter Conclusions

The brunt of feminist curriculum changes came out of the second wave of feminism. Most of those changes, however, transpired by inserting women’s issues into the existing curriculum as side-bars or added text boxes or, by adding entire separate streams of women’s studies courses and programs that are not integrated into occupational training programs like engineering (Franzosa, 1998). In recent decades, new research has focused on how girls prefer to learn, placing knowledge within their life experience and enabling girls to feel safe while exploring new yet disruptive content (Raby & Pomerantz, 2013; Shapka, Domene, & Keating, 2012; D. Smith et al., 1998).

The relationship between societal beliefs and gendered career choices is becoming clearer: the analysis of data from the British Columbia (BC) school system presented in this chapter indicate curious tendencies in relationships between the choices students make in high school, the abilities of high school students and their subsequent choices for post-secondary education. This doctoral project tackles the registration rates of women into engineering education programs. The analysis of post-secondary student data identify Physics 11 as a key course in which women evidently make their decision not to pursue engineering (Levin et al., 2005).

The dual efforts of industry leaders and educators made several significant inroads to gender parity in the Canadian workforce over the last century (Moore et al., 2011; Price et al., 2005). Organizations that determinedly transformed their workplace cultures to be more inclusive of diverse ways of knowing and being achieved parity in both educational program
student registrants and in the lower levels of their professions. This change is not pervasive, however, leaving ongoing gender wage gaps and perceptions of gendered careers even in those professions where parity is achieved in education and entry-level positions (Burton & Humphries, 2006; Park et al., 2005). In spite of the inroads, negative views of the workforce for women persist.

The four waves of feminism shaped the current state of Kindergarten through Grade 12 (K-12) education through the last century. Women’s issues in social studies textbooks moved from derogatory after-thoughts to side-bar text-box inserts to fully rewritten discussions written from a feminist standpoint (Gaskell, 1973) and women appear more frequently and in more-active roles than in early science texts that rarely mentioned women at all (Kelly, 1985). Thus, the “hidden curriculum” became redressed as inclusive of all genders and women’s issues exposed to establish safe learning environments (Li, 2004; D. Smith et al., 1998). These changes led to the current gender parity in Physics 11 classrooms but leave a gap in the leaky pipeline to engineering education.

Women with high school physics credit continue to choose business programs or enter college with undeclared majors rather than pursue careers that study or apply physics. Combining the preceding feminist analysis of curriculum changes and organizational developments over the last century with the analysis of transitions data from the last few decades, Physics 11 stands out as a key course for the design, development and verification of an intervention strategy to close another leak in the pipeline to engineering. The intention of this research project is to test the effectiveness of a high school strategy in improving girls’ perceptions about engineering as a viable career option. The next chapter presents the methods
DISPELLING GENDER BARRIERS AND BUILDING CAPACITY

considered for creating, implementing and testing the strategy, while achieving the greatest change possible through the process itself.
Chapter 3 – Research Goals: Methodologies and Methods

Male and female students participate equally in Physics 11 classes (Levin et al., 2005). According to data from Victoria, British Columbia, presented in Chapter 2, women make up 40% of the population of students who successfully complete Physics 11 and register at Camosun College. Yet, of those students, more than 35% choose business programs and more than 40% enter the post-secondary institution undecided about their future career direction. Only 4% chose career programs that apply Physics 11, like engineering. Admittedly, this trend in first course of study at the college may not be representative of the province’s post-secondary transitions trend. If it is, however, then intervention tactics that change the perceptions and beliefs driving this Victoria trend may effectively increase the overall number of women choosing to study engineering.

Michael Levin and his colleagues (2005) heard from girls in Physics 11 classrooms who deliberately did not consider pursuing careers in physics or engineering. Some said they disliked studying physics because they felt like visitors in the physics classroom or believed that physicists simply confirmed existing concept knowledge and they wanted to explore new ideas. Others said they had enjoyed physics and math in the past but became “dulled by the mechanistic routines and practices characteristic of traditional [higher level] physics courses” (Levin et al., 2005, p. 584). The intended research outcome of this dissertation is for Physics 11 students to identify the use of physics in their lives today, explore new applications of physics concepts, and discover the breadth of knowledge yet to be created so they can appreciate the range of possibilities within careers that apply physics.
There is something peculiar about why young women in Physics 11 entertain the above beliefs and perceptions; perhaps it is due to the way we teach physics. I developed a multi-faceted research program to expand the body of knowledge defining why these young women, after successfully completing high school level physics classes, choose not to enter engineering education and why women who do pursue engineering education ultimately leave the profession. The complete research program that I developed is extensive, so only two goals form the basis of the doctoral research project presented in this dissertation: using a feminist approach to action research by identifying the perceptions of high school teachers and female students about careers in engineering, and developing, implementing and assessing a participatory process for modifying those perceptions.

Participatory action research is a methodology that directly involves participants in the research program design in order to maximize buy-in through the co-development of effective tools and implementation strategies (Bidee et al., 2013; Luthans & Stajkovic, 1998). The methodology also moves the project forward along the tight timeline required for this project, creating the potential for immediate and persisting change (Cornish & Dunn, 2009; Whyte, 1991). The action research process in social science parallels project management techniques, facilitating the dissemination of research findings to the key stakeholders in this research: teachers, professors, engineers and students. The second research goal adds a quantitative measure to provide concrete numerical outcomes that should appeal to pragmatic engineers (Yardley & Bishop, 2008).

This chapter presents the rationale behind choosing two research goals from a more expansive research program. The introduction of the goals in this section briefly references
relevant research methodologies. The methodologies most suited to the dissertation project goals and strategic deliverables align well with values typical of engineering and physics educators (Metcalfe, 2008). More detail on the selected methodologies along with the array of methods identified for acquiring the necessary qualitative and quantitative data follow the goals listing. The chapter closes with a summary of the goal, methodology and methods choices.

Situating the research

Throughout our lives, communities, friends and family influence our thoughts and opinions about potential future careers. The progression of women to engineering careers is referred to as a “leaky pipeline” because of the many points from which women leave the path or line to an engineering degree as they respond to society’s influence (Cropsey et al., 2008; Griffith, 2010; Levin et al., 2005; Sadler et al., 2012). The descriptive metaphor may have become dated over the last decade, but its vivid image continues to be useful in the current British Columbian political environment of developing and maintaining oil pipelines: leaks are undesirable.

One of the earliest leak points in women’s pipeline to engineering, depicted in Figure 5, paralleled by the division of children’s toys into so-called ‘pink and blue aisles’ (Feminine pink and macho khaki: toys exploit gender differences, 1996; Gold, 2008), thereby presenting exclusive sets of playtime choices for preschool girls and boys, and establishing perceptions and beliefs around gender differences. Debbie Sterling is one engineer trying to stop up the leak by producing GoldiBlox toys: stories with design-focused activity boards (“Goldie Blox,” 2013)
that provide a shopping alternative to the princess paraphernalia and kitchen sets that typically fill the shelves for little girls.

The next leak point lies within the grade school system in which peer pressure influences children’s playtime and study choices. Programs that promote mathematics as “cool for girls” successfully increased the number of girls who continue to succeed at mathematics, at least through to Grade 8 (2011/12 Summary of Key Information, 2012, Gender Equity in Education: A data snapshot, 2012, International Association for the Evaluation of Educational Achievement Trends in International Mathematics and Science Study (TIMSS), 2011 Ontario Report, 2012).

At the other extreme end of the timeline, professional associations – examples include the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC),

Figure 5: The Leaky Pipeline to Engineering. This schematic demonstrates the various leak points in the poorly constructed pathway for girls to engineering, even after entering the profession. Each circle represents the sphere of influence of a school or workplace. Each new institution needs its own retention strategies. Some of the leaks between institutions have been stemmed through constant attention to intervention methods, like high school outreach programs and elementary school math competitions. In the pipeline metaphor, the space between circles are the weaker connection points.
Engineers Canada (EC), Women in Science and Engineering (WISE) and the Canadian Coalition of Women in Engineering, Science, Trades and Technology (CCWESTT) – provide professional mentoring opportunities and promote organizational policy development that arguably improve retention of women in industry.

The transition where this doctoral research is situated is the leak between high school and post-secondary education: Why is it that although we have equal representation of young women and men successfully completing high school physics classes, significantly fewer women choose careers in engineering? My research goal is to increase the percentage of women in engineering by increasing the transition rate of young women from high school physics to engineering education. The chosen methodology is mixed: qualitative participatory action research to develop the research tool and direct the implementation of the tool in Physics 11 classrooms, and quantitative survey analysis to measure and statistically test student perceptions. Three survey deployments establish baseline data, and measure the possible existence of immediate and long-term change.

**Creating knowledge**

Today’s feminism is imbued with a prevailing sense of women’s accomplishment since the time of the militant feminist: women now enjoy increased access to all occupations and a growing equality in compensation (Alksnis et al., 2008). However, many women, including female engineers, remain at a significant career disadvantage as they face gender-based discrimination in the workplace both in terms of the kind of work they do and the availability of opportunities for career advancement (Fouad & Singh, 2011; A. E. Smith & Dengiz, 2009). This will not systematically change until there is gender balance or at least a critical mass of women
at all levels of organizations (Chaney, 2012; Pennington & Heim, 2016), which in turn cannot occur until employers disrupt gender-based discrimination.

Engineering education provides an opportunity to introduce feminist epistemology, a holistic way of creating knowledge that can enhance the positivist, logically linear and pragmatic masculine traditions of engineering. In engineering ethics courses, for example, context-based, nuanced challenges are discussed and debated yet feminist viewpoints are rarely explored (Prince, 2006; Ramani, 2011). Although the last two decades have seen increasing racial diversity in most engineering classes (Wlotzki, 2016), women’s perspectives are seldom presented or fully comprehended by the students. Donna Riley (2013) explored this lack of feminist language in engineering ethics, even by feminist scholars, solely by using language she believed to be accessible to the existing male population of engineers. Unfortunately, avoiding the use of feminist language reinforces the existing masculine language and the androcentric experience of engineering, with female engineers often promoting the masculinity of the profession (A. Powell et al., 2006). So, perhaps incorporating feminist epistemologies in engineering education “can break the hold of positivism in engineering and open new possibilities for the profession” (Riley, 2013, p. 203).

The feminist approach is imbued in all goals of my research program. The focus is on the transition from high school (secondary school) into post-secondary engineering education. Early research indicates high school physics students wish to make positive change in the world yet they do not see that engineering or physics studies provide the skills or opportunity to do so (Adams et al., 2006; McDonnell, 2005). Much research needs to be done to make improvements
Research plan goals

As stated earlier, engineering gender balance is a valuable pursuit in addressing both business issues and women’s issues. While some schools record increases in the number of young women participating in high school physics classes, the transition to engineering education continues to be low (Ivie & Ray, 2005). Preliminary statements of high school physics participation rates are intriguing and may reflect the level of success of interventions aimed at closing early pipeline leaks. However, the fact that these young women typically choose careers other than physics and engineering indicates something may need to be done. This led to my first questions: Are Canadian high schools experiencing near-gender balance in physics classes? If so, did changes to grade school curriculum lead to this outcome? And why do these young women, if they do equally participate in physics classes with boys, continue to avoid careers in physics and engineering? Ultimately, I wish to discover whether perceptions about engineering cause it to be a gendered career. Framing the question to a measurable, action-oriented perspective: how can girls’ participation in high school physics be leveraged into higher numbers of women in engineering education and, eventually, in the profession? These questions warrant further study.

This section describes the goals that make up the overall research plan, mentions the knowledge necessary to accomplish each goal and the values-based mode of inquiry that best creates the relevant knowledge. Within each goal section, therefore, I simply note appropriate methodologies and methods. Later, I describe the decision process for choosing the doctoral
research goals and fully define the selected methodologies. The section closes with the preferred methods for achieving each goal.

**Goal 1: Immediately increase the number of women who transition from high school physics to engineering education**

Short of coercion, the easiest path to immediately increasing participation in engineering education is through direct interactions with potential students, describing current inaccuracies in social perceptions about engineering and its suitability for young women in high school physics classes today. Many of the goals in this chapter align well with action research methodologies. Participatory action research garners rapid change because it is an interactive process directly involving the subjects as participants in research (Cook, Heykoop, Anuntavoraskul, & Vibulphol, 2012; Whyte, 1991). Participatory research applied to this goal could include activities such as engaging students and teachers in candid discussions about perceptions and beliefs, facilitating further debate, and co-creating innovative role-based activities that engage each subject in self-directed learning about engineering design. My role as animator would be to prompt the dialogue while being open to their comments, questions, input and feedback.

Involving a high school physics class in a conversation about engineering as a possible career with the purpose of finding ways to influence future classes will not only change the behaviour and understanding of the group but also empower the subjects to make the social changes necessary for their community (Altrichter, Kemmis, McTaggart, & Zuber-Skerritt, 2002; Rahman, 2008). However, this may only be effective with the group involved in the participatory action research because the classroom community is always changing and moving on. This process requires additional or follow-up activities to ensure longer-term results are produced.
Goal 2: Effect long-term changes to perceptions of young women in high school physics about engineering as possible career option

It is important to understand changing trends in perceptions of young women in physics classes before future changes can be plotted. In order to measure these trends, baseline data must be established. Past and current experiences and perceptions of students about career options – including but not restricted to engineering – need to be recorded and compared to the baseline. Professions like law, medicine and accounting, mentioned in the introduction of this dissertation, have achieved gender balance in the educational system and in entry level positions within the professions: the high school experience of young women who eventually registered in those post-secondary programs must also have changed over time. Analysing this data, therefore, may produce interesting recommendations for tactics to test in the engineering and physics classrooms.

Sub-goal 2a: Establish baselines today as Year 0 by understanding current perceptions about engineering as a career option

The first phase for Goal 2 would be to determine current perceptions as a baseline against which change can be measured. These perceptions need to be not only about engineering but also about whatever other career choices the students may have considered. Perceptions are created through experience and learning, therefore the experiences of these young men and women need to be recorded and analysed for themes, commonalities, and potential areas in which gendered beliefs are fostered. Oral history, ethnography and phenomenology are well-suited as methodologies that build rich narratives through the use of interviews or focus group sessions facilitated using the techniques of peer coaching and action research (Miller-Rosser, Robinson-

Alternatively, a comparative case study of two classes with very different transition rates to engineering education may identify and highlight differences in classroom behaviours and practices that can be investigated at a future time (Mulhall & Gunstone, 2012; Sasaki, 2004). A small number of cases allows the acquisition of greater narrative detail leading to a deeper analysis. As a separate study, it may be informative to increase the number of cases, providing a shallower analysis but broader opportunity to determine geographic trends for the development of localized, long-term solutions.

**Sub-goal 2b: Compare historical data to baseline data, looking for trends**

Oral historical records are available in several academic and public repositories such as those at the California Institute of Technology, the British Library and the Canadian Oral History Association. These repositories each contain narratives from retired engineers talking about their experiences. Reviewing the records and teasing out trends and patterns is a valuable historical analysis, building understanding based on periodic shifts to the current situation (J. R. Hall, 2014; Winkel, 2012). The trends in experiences would illuminate challenges and individual responses as the professional culture evolved through the four waves of feminism. The benefit of ethnography and phenomenology is the inclusion of historical, social, racial, and cultural contexts in the narrative review to create robust and intricate webs of knowledge (Miller-Rosser et al., 2009): the influence of world events on changing the actions and behaviours of women in
science and engineering may be useful to effectively design a flexible and responsive long-term plan for creating sustainable gender balance in engineering and other professions.

*Sub-goal 2c: Determine ways to sustain transition rates to engineering and set metrics to measure changes that occur*

Various case study combinations would be useful to deepen the body of knowledge and determine ways to achieve improvements to gender balance through comparative research (Sasaki, 2004). For example, the research could be focused on comparing the experiences of students from the same high school classes but in different post-secondary programs in order to ascertain how different experiences create certain perceptions or generate enthusiasm. Alternatively, comparisons of the experiences of women and men in the same cohort of engineering education, but who graduated from different high schools, could identify possible behavioural trends and classroom activities that inspired pursuing engineering as a career.

*Goal 3: Effect immediate change in perceptions with long-term results*

Effecting immediate change requires using one of the action-oriented methodologies. Although action research is closely related to feminist pedagogy as a holistic, symbiotic and reflexive process (Briskin & Coulter, 1992), its apparent focus on results appeals to the engineer’s positivist logic. Closely related to project management, action research involves key stakeholders in planning and providing input through multiple stages of the project, requires measurable social change outcomes within a defined time-frame, and includes opportunities to make changes to the overall plan through a regular review or iterative cycle (Altrichter et al., 2002).
Sub-goal 3a: Involve key influencers and practitioners (high school teachers) in research

Participatory action research involves research subjects in the research outcomes (Whyte, 1991). The key influencers for long-term change in this research goal include educators in both high school and post-secondary engineering training institutions, engineers in industry, and students; together they can identify what it is in the classroom experience that influences high school physics student perceptions and determine what is necessary to change perceptions of future students. Participatory action research team sessions involve educational, discussion and development components. The participatory action research activities include finalizing the research objectives and co-developing, verifying and implementing the research tools. This methodology is closely related to action research, which employs an iterative process through which the researchers develop best-suited activities for the group (Figure 6).

Sub-Goal 3b: Explore effect of bullying prevention programs on gendering of careers

It is a reasonable consideration to use Victoria as the participant community: the Capital Regional District (CRD) includes fifteen secondary schools and two receiving engineering education institutions. Interestingly, the CRD was involved in a bullying prevention program that may have resulted in the region being an anomaly or special case. The region piloted the WITS anti-bullying program through the 1990s. The program since expanded to over 400 schools in North America (Leadbeater & Sukhawathanakul, 2011). It would be interesting to discover if intimidation and bullying play a role in the gendering of careers, therefore a study of student perceptions in each of the school districts could create insightful knowledge. For comparison, the Greater Vancouver region, with three post-secondary institutions that teach engineering


disciplines and almost a hundred high schools, would be suitable, whether or not the study is constrained to the pilot program period.

**Sub-Goal 3c: Determine if/how perceptions have changed over time**

In participatory action research, key stakeholders help to design the research program by identifying possible themes and appropriate questions to draw out the desired information. They can also assist with determining who the research subjects could be (Whyte, 1991). This ethnographic information can be qualitatively analysed to establish themes, trends and correlations. For example, gendered perceptions of careers may correlate to school culture, teaching methods, gendered teaching styles, content timelines, frequency of experiments, mode of experimentation, and parent association culture. The facilitation challenge will be to lead the stakeholders to identify these possibilities along with their own. Some of this general information is included in the literature survey presented in Chapter 2, however the participating stakeholders have the opportunity to influence the direction of deeper thematic analysis through their knowledge of the specific populations they can identify.

**Goal 4: Determine if this is a good place to focus attention (high school physics grads transitioning to post-sec engineering education) and develop background information**

Background data must be analysed at some point in this research program. My inclination was to conduct this piece first so that the ethnographic or phenomenological research is well grounded, which will be necessary to find and fill gaps in the body of knowledge collected to date. In addition, the trend of participation numbers of young women in Canadian high school
physics classes needs to be confirmed beyond the Camosun College analysis conducted and presented in Chapter 2.

**Sub-goal 4a: Determine the number of young women in high school physics classes and the percentage of those transitioning to post-secondary engineering education**

My preliminary survey identified vast provincial and national educational datasets that can be mined to establish full-population gender participation trends in physics education. British Columbia keeps longitudinal records of provincial examinations, potentially dating back to the 1960s; it is possible to access post-secondary registration data through academic contacts in each institution. The quantitative analysis should be straight-forward, considering the computer power available to today’s researchers, and can verify anticipated trends including but not limited to: the percentage of young women successfully completing high school physics classes, changes and locations; rates of conversion to engineering by women who successfully completed high school physics, changes and locations; and rates of conversion to other disciplines by women who successfully completed high school physics, changes and locations.

**Goal 5: Determine whether gender differences in physics teaching/learning styles influence perceptions of youth**

This is the question that originally piqued my interest and launched my pursuit of a doctoral degree. Based on experiences at Camosun College and conversations with students, with women in engineering and with women of science in other post-secondary degree programs, much of the career path decision-making process appears to be dependent on student engagement in high school physics. Anecdotal complaints include: high school science teachers who are not physicists and lack enthusiasm and knowledge about how to apply the content in real world
settings; teacher beliefs that men have more science aptitude than women (boys than girls) influencing which students receive more attention; lack of freedom to apply individual creativity in laboratory experiments; old-style experiments and dated equipment; and too much focus on examples with limited hands-on experience (Hyde & Mertz, 2009; Longbottom & Butler, 1999; Moss-Racusin et al., 2012; Reiss, 2005). Do these concerns influence girls more than boys?

Sub-goal 5a: Do physics teachers use different teaching/learning styles than teachers in topic areas that attract more women?

Case study comparisons of teaching styles between courses that attract mostly women, mostly men, or are gender-balanced, can highlight gendered teaching methods and learning preferences. Questions to explore include: What is it that attracts different students to different disciplines – does it have anything to do with teaching methods? Do teaching methods influence retention? This quest for correlations is well suited to quantitative methodologies, possibly using survey questions or thematic interviews. A broad sample is required to identify statistical differences, therefore depth and contextual influences would be ignored but the effect of teaching style could be confirmed or dismissed.

Comparisons with teaching styles in other disciplines can highlight the appeal of different techniques that potentially attract learners to different professions. Reviews of curriculum documentation may ascertain variations from and correlations with programs that have or have not seen improvements in gender balance; those curricular themes could be mirrored and tested for effect in physics and pre-engineering courses. Explorations could focus on looking for activities, problem-based-learning examples, lecture styles, experiment styles and types, and
whether content experts are teaching at the high school level, with particular attention paid to any
teaching methods that may be gender-biased.

On the other hand, a feminist approach may enhance knowledge about the true attraction
for women to different careers: does family history play a larger role in the decisions students
make for career options than previously thought, for example, or do social networks provide the
greatest influence on career pathways? Perhaps aptitude tests are on the wrong track and
phenomenological explorations create more accurate pictures of the true decision matrix used by
students. Comparisons of oral historical accounts, narratives from engineering practitioners,
engineering students and high school physics students, “even fiction”, would develop a
comprehensive longitudinal account (Hekman, 2007, p. 540).

Goal 6: Assess the current body of knowledge concerning gender balance in engineering

Before embarking on any trend-based research goal, a thorough but broad literature review
would determine the extent of the current body of knowledge and identify where the gaps are
that require further inquiry. Significant research has been and continues to be conducted on
gender issues at all ages beginning with pre-school children, the interaction between boys and
girls, educational techniques and gendered curriculum from kindergarten to graduation and
beyond (Beddoes & Borrego, 2011; Lavin et al., 2012). Oral histories exist from many prominent
female engineers, but are they already be available from current scientific celebrities like
Governor General and Astronaut Julie Payette who recently shared the experiences and
challenges of her youth (Rakobowchuk, 2014).

It is important that this doctoral research not repeat work already conducted in the specific
focus areas. For example, does data exist from other regions on rates of young women who
completed high school physics transitioning into engineering programs or on the perceptions of high school students regarding engineering as a desirable career option. Would research in British Columbia supplement that which exists elsewhere? Have ethnographic researchers recorded dialogues with recent or current university students about perceptions of variety of careers and final choices? Regardless, any literature presenting analyses or comparisons of the experiences of men and women in high school science classes and in post-secondary science programs will highlight issues not yet considered. This extensive literature survey will determine whether the body of knowledge regarding gender balance in physics and engineering education is current and complete.

Many of the methodologies presented for the above goals certainly add breadth and depth to the body of knowledge, but do not lend themselves to producing change within the short-term. Therefore, an action-oriented methodology like participant action research mentioned in the first goal addressed in this section is deemed more suitable for the doctoral research project.

**Dissertation goals: Influencing social action today**

Originally, upon first considering potential research goals, I was inclined to arrange them in an order such that they built upon one another. However, my detailed review in preparation for this doctoral research revealed that the goals are not entirely interdependent, rather they support and augment each other in building a body of knowledge around the effect of teaching on career choices. For this reason, I elected to begin my research by working on Goal 3, which provides the best opportunity for effecting immediate and lasting social change through carefully designed participatory action research with teachers. The following subsection outlines the chosen
methodology after describing my positionality, in the hope that revealing my standpoint I can maintain my integrity and conduct professional unbiased research.

Positionality

My experience through high school in North Vancouver, BC, was very positive. I was academically successful, and signed up for all the music and science classes that I could fit in my schedule. The people who influenced me the most at that time were my choir directors and my Physics 11 teacher, Mrs. Murphy. My father encouraged me to attend a professional career program and, since I had learned that science is fun and easy, I followed his advice by pursuing engineering. When I graduated from the mechanical engineering program at the University of British Columbia in 1987, there were nine women in my class of 96 students. Although this 10% figure would remain the highest for over two decades, the percent of women in UBC mechanical engineering grew to 15% in 2015, an unexpectedly remarkable achievement as the national average is 12% (Canadian Engineers for Tomorrow: Trends in Engineering Enrolment and Degrees Awarded 2007-2011, 2012).

Becoming proactive

Since 2007, I have been exploring options to encourage women to join and stay in the engineering profession by attending leadership workshops and mentoring retreats for women in engineering, and even starting up a pilot mentorship program for female students at Camosun College where I teach courses in mechanical engineering. Still, the overall Canadian numbers for female engineering students are unchanged since I completed my undergraduate degree: 20% women across all disciplines with national highs of over 40% in biosystems and environmental
engineering, and national lows of 10% in mechanical engineering (Wlotzki, 2016). Globally, women similarly comprise less than 20% of the engineering population (Fouad & Singh, 2011; Hersh, 2000).

Deciding I needed to be more proactive and self-reliant, I began the Doctor of Social Science Program at Royal Roads University in order to explore why so few young women choose engineering. I chose this graduate program because of its interdisciplinarity and because I wonder whether my questions relate to metaphysical, abstract, societal beliefs about the abilities of women and the requirements of engineering. My dissertation therefore focuses on the transition of young women from high school physics classes to post-secondary education towards careers in engineering. I have chosen to execute as much social change as I can today so that resulting changes today can fuel future research projects. The supporting research can occur later.

Engaging nominalists in action research

Engineers are often immersed in the physical world and our general lack of attention to the metaphysical world greatly influences our social reality. As social creatures, we naturally create labels for social groups to help our understanding of how individuals and groups interact, which give rise to stereotypes (Nosek et al., 2009; Rahm & Downey, 2002). While stereotypes assist with our comprehension of social behaviours, they can limit our ability to recognize an individual’s uniqueness. I see behaviours in engineering classrooms that seem to indicate that many young engineers allow stereotype labels, gender and racial, to shape their understanding of others. Similarly, the common misperception of engineers as a socially inept group with an
inability to communicate and an excessive focus on the inanimate is another such label that may influence the career choices of young women in high school physics.

While engineering is not as rigid as a well-defined caste system, there is an expectation of hierarchies to which engineers adhere; workgroups, therefore, create linear chains of command that potentially overlook the strengths of individuals in the group. However, not all people in the group will agree to or exhibit the group's expected behaviour. Because of this, for example, I tend to seek out women and other allies in the workplace who are unfortunately not engineers, so I can step out of the implied expected role of the female engineer – a physically weak individual, less than capable (especially of understanding mechanical systems) and more inclined to respond emotionally while trying but failing to be “one of the boys” – and regain my ability to overcome the challenges I typically face as a minority in my workgroup.

Engineers commonly rely on intuition and imagination to develop innovative solutions for today’s needs. Aircraft design, for example, was originally accomplished through experimental discovery, a technique now missing from most fundamental physics classes: the initial design is imagined, built and tested; the results are analysed for strengths and weaknesses; the craft is redesigned for improvement and the cycle continues. This is also the way of critical realism, a switching between events and mechanisms as a means to shift attention to what produces the events, not just the events themselves (Elger, 2010). In a similar way, the intention of my research program is to oscillate between qualitative methods that identify and describe the events leading to perceptions of gendered careers and quantitative methods that can identify verifiable correlations to attempt to describe why these events occur.
Due to this similarity between the design process and critical realism, action research is likely to be readily accepted by my engineering colleagues. Quickly achieved gains will garner support for my social scientific work within the engineering community. The similarities between project management techniques and the action research plan-act-observe-reflect cycle (Figure 6) should create a sense of familiarity with this research process and be quickly understood. For these reasons, too, it is wise to slowly shift the process of knowledge creation towards social science epistemology, using minimal jargon as I deconstruct social expectations and reinvent engineering culture.

**Action research methodology**

Action research is an outcomes-oriented methodology that engages key influencers, in my case teachers and possibly students themselves, in knowledge creation (Altrichter et al., 2002). The methods are very similar to the co-active coaching techniques taught through the Coaches Training Institute, a program promoted by the Camosun College Peer Coaching program for which I am a peer coach. The basis of co-active coaching is that “people are naturally creative, resourceful and whole” (Kimsey-House, 2010, p. 1) and have the resources to find their own solutions to issues they face; the coach role is to

![Figure 6: The spiral of action research cycle (Altrichter et al., 2002), gives researcher and research team opportunities to modify and improve the procedures while working through the process of the research plan.](image)
simply ask questions that instil curiosity. Similarly, action research allows the subject to find the solution that best suits themselves, regardless of whether the facilitator has a solution in mind. The focus is on developing “practical situations and competencies of the participants without substantively prescribing objectives to be achieved” (Altrichter et al., 2002, p. 127). This methodology, therefore, is a very good fit with the values stemming from peer coaching.

In participatory action research, the team assists with the research program design by identifying the possible themes, the appropriate questions to draw out the desired information, and the research subjects (Rahman, 2008; Whyte, 1991). Acquired ethnographic information is qualitatively analyzed to verify or establish the actual themes, trends and correlations. For example, gendered perceptions of careers may correlate to school culture, teaching methods, gendered teaching styles, teacher sex, content timelines, frequency of experiments, mode of experimentation, and parent association culture, all potential confounding variables (Freedman, 2007; Michael, 2002; Webster & Sell, 2007). The facilitation challenge is to lead the stakeholders to identify these possibilities along with their own (Cornish & Dunn, 2009; Whyte, 1991).

Within the action research plan, I initially proposed the involvement of students in high school physics and perhaps students in chemistry or biology classes in a conversation about careers in engineering with high school teachers of science. Once I worked through a potential plan, identifying the necessary tasks for such comparative conversations, I realized that this would create a much larger scope than would be possible to complete within the doctoral time frame. I therefore constrained the project team to only high school physics teachers, whose energy could be focused on developing the in-class activities for delivery in their Physics 11
classes. The teachers’ close involvement in the process ensures their voices are heard, maximizing their sense of ownership of the solutions we develop together and establishing a process with the greatest opportunity for long-term, sustainable success. The purpose of this research, therefore, is to generate the data necessary for determining trends of behaviour, expectations and perceptions through qualitative analysis, and to act on the changes arising through our interactions.

**Dissertation research goals**

The final research plan focuses on two principal research goals:

- **Goal 1:** Improve teacher self-efficacy in teaching physics and reduce persisting unintended sexist behaviours in physics classrooms
- **Goal 2:** Effect long-term change to the perceptions of young female students in high school physics about physical engineering science as a possible career option

Participatory action research is the methodology applied to Goal 1, to engage, educate and involve teachers in the design of the intervention activity. Survey deployments will measure students’ perceptions about careers that use physics and their sense of belonging and self-efficacy in the physics classroom before and after students experience the in-class activity. The participatory action research team will assist with shaping the final form of these goal deliverables. A quantitative methodology was selected to measure outcomes from goal 2.

**Research methods**

This section briefly introduces the general or broad research population and the methods chosen to achieve the research goal outcomes. The methods address the mix of qualitative and quantitative methodologies defined above. The research plan design engaged teachers and
students of Physics 11 in the Victoria region, or Capital Regional District (CRD). Chapter 5 contains detailed information about the sample population of students and teacher who participated in the research.

**Population base**

The regional population from which the sample population was drawn consists of high school physics teachers in Greater Victoria, an area known as the Capital Regional District (CRD). Located within the CRD are thirteen public and private secondary schools and two receiving post-secondary institutions that deliver engineering programs. As indicated in sub-goal 3b previously, the elementary schools in the CRD piloted the WITS anti-bullying program through the 1990s. This program since expanded to over 400 schools in North America (Leadbeater & Sukhawathanakul, 2011). Although not a part of the research proposal, it would be interesting to discover if intimidation and bullying play a role in the gendering of careers; the comparison of student perceptions in each of the school districts could create insightful knowledge.

The pilot program may confound data retrieved from the region because the WITS program experience may be perceived as a unique influence on later perceptions and beliefs of teachers and students. Therefore, data from this population may not be generalizable to the broader population. The WITS program introduces the concepts of inclusivity and social responsibility which may result in female Physics 11 students feeling a greater sense of belonging in all classrooms than similar students in other regions. This will have to be tested at a future point. Should a larger population be required for generalizability and for the elimination of confounding factors, the nearby Greater Vancouver educational system has three post-secondary
institutions that teach engineering disciplines and almost a hundred high schools. Vancouver was not part of the pilot program and would provide an excellent comparative sample for post-doctoral research. Regardless of the potentially confounding influence of the bullying program early pilot, the CRD may nonetheless be sufficiently large to provide statistically significant information about the general population of high school physics teachers. Otherwise, should using Victoria as the study population reduce the generalizability of the acquired knowledge, knowledge from this region still provides a good baseline to which other populations can be compared. The possibility of a lack of generalizability will be considered in the final discussion on research limitations.

**Population details**

The CRD provides several benefits as a target population for this research project. The population is large, with thirteen public high schools and five independent high schools. Most of the schools operate on the semester system and offer Physics 11 in both semesters. In consultation with the school Principals, I generated a contact list of 26 physics teachers in 18 schools across the region. The student population in the CRD provides a good potential sample for the project. Each teacher was responsible for at least one class or section of Physics 11 in each semester, with some responsible for as many as 4 classes per semester; the teaching assignments averaged roughly 2.5 classes per teacher per year. Conservatively rounding down to two classes per teacher and estimating an average class size of 40 students (student numbers cannot be confirmed until one week after classes begin), the region’s schools teach Physics 11 to as many as 1600 students each year.
My pre-candidacy examination inquiries to the 26 teachers resulted in twelve teachers expressing interest in participating in the research and only five declining to participate in any way. These teachers recommended that the new lab procedure be designed in early September, so they could implement it when they came to run the lab in both October and March, thereby doubling the student sample size. Should the timeline be too tight to undertake, we would still have the option to bypass one set of lab groups. In this way, even a small number of teachers could potentially provide a statistically significant student sample of at least 150-200 students (Tolmie, McAteer, & Muijs, 2011a).

**Initial timeline**

The original research timeline for Goal 1 activities is shown in Table 10. Initial calls for participants needed to go out no later than the end of May, leaving time for email, telephone and face-to-face communications. Working backwards from that deadline, the school boards needed to be contacted by mid-May with ethical clearance acquired by early May. Since the first population contacted consisted solely of adult teachers, limited provisional ethics pre-approval was quickly obtained and the communications plan approved. I began to approach teachers in early May, 2015, signalling the launch of the research program.
Research activities

As mentioned above, participatory research is an applied research methodology that can effect immediate change because it is based on an interactive process directly involving the subjects as participants in research (Cook et al., 2012; Whyte, 1991). Participatory research activities for this project include engaging teachers and students in candid discussions about engineering, promoting creative thought about potential solutions to problems, and prompting creative role-based activities that serve to engage each person in discovering their capacity for the engineering design process. My role as facilitator is to provoke and guide the teachers’

<table>
<thead>
<tr>
<th>Action Item</th>
<th>Activity Description</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethics Pre-Approval</td>
<td>Submit ethics review documentation for pre-approval to permit team assembly</td>
<td>May 2015</td>
</tr>
<tr>
<td>Assemble Action Research Team</td>
<td>Invitations sent to teachers of physics in the Greater Victoria area; plan workshop meetings; verify timeline (confirm periods of physics classroom teaching)</td>
<td>May/June 2015</td>
</tr>
<tr>
<td>Teacher Workshop I</td>
<td>Facilitate day-long workshop to sign permission and confidentiality forms, introduce research plan, verify support for research project and commitment to engage, begin preliminary design of teaching methods</td>
<td>Sept/Oct 2015</td>
</tr>
<tr>
<td>Teacher Workshop II</td>
<td>Complete design, method descriptions, review/detail/verify curriculum documentation as required.</td>
<td>January 2016</td>
</tr>
<tr>
<td>Classroom Implementation</td>
<td>Acquire signed permission forms from students &amp; parents; arrange in-class activity; attend in-class activity (data recording, material collection, survey); focus group interview with students.</td>
<td>February/March 2016</td>
</tr>
<tr>
<td>Teacher Workshop III</td>
<td>Debrief of in-class activities; debrief research process; focus group interviews; surveys</td>
<td>May/June 2016</td>
</tr>
<tr>
<td>Individual Teacher Follow-up Interview</td>
<td>Designed to review process, elicit feedback about process improvements and about student responses one year later.</td>
<td>April/May/June 2017</td>
</tr>
</tbody>
</table>

Table 10: Original milestone timeline for Goal 1 – participatory action research activity plan
ensuing dialogue and the activity design while being open and receptive to their comments, questions, input and feedback. Involving high school physics students in conversations about engineering has the dual purpose of changing the students’ understanding about engineering careers and of empowering them to make the social changes necessary in their external communities (Altrichter, Kemmis, McTaggart, & Zuber-Skerritt, 2002; Rahman, 2008).

The activities and milestones necessary to complete the quantitative objectives of Goal 2 (Table 11) include both data collection and data analysis, the latter of which is comprised of both thematic discourse and quantitative regression. These activities overlap chronologically with those of Goal 1. The first tactic of Goal 2 is to measure the current perceptions of the student sample as a baseline against which action research outcomes can be compared. These perceptions are not only about engineering but also about whatever other career choices the students may have considered. Perceptions are created through experience and learning, therefore the experiences of these young men and women were recorded and analyzed for themes, commonalities, and potential areas in which gendered beliefs are fostered. The benefits of ethnography and phenomenology are the inclusion of historical, social, racial, and cultural contexts in the narrative review to create robust and intricate webs of knowledge (Miller-Rosser et al., 2009): the influence of world events on changing the actions and behaviours of women in science and engineering were useful in effectively designing a flexible and responsive long-term plan for creating sustainable gender balance in engineering and other professions. For the
purposes of this dissertation, some of the rich aspects of phenomenology and the concrete analysis of quantitative methodologies are drawn on through interviews and surveys before and after the various activities.

Data from the teacher workshops were collected via video recordings, communal flip-chart plans and signed documentation. Each session’s data were returned to the group in report form for verification and approval prior to building upon that work in the next session. Workshop reports were sent via email to all participants. The final interviews was audio recorded for

| Table 11

Milestones for Goal 2 – Measuring change to perceptions of gendered careers

<table>
<thead>
<tr>
<th>Action Item</th>
<th>Activity Description</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot Teacher &amp; Student Surveys</td>
<td>First drafts of the teacher and students surveys to be tested on Claremont Pilot Project class (Courtesy of Graeme Mitchell).</td>
<td>June 2015</td>
</tr>
<tr>
<td>Teacher Survey I</td>
<td>Implementation of updated/modified survey instrument to measure teacher self-efficacy and perceptions of gendered career issues prior to commencement of participatory action research.</td>
<td>Sept/Oct 2015</td>
</tr>
<tr>
<td>Theming of Focus Group Data</td>
<td>Following transcription of documentation and video data of first teacher workshop, arising themes will be recorded, data grouped into those themes and first report generated for vetting by teachers.</td>
<td>Nov/Dec 2015</td>
</tr>
<tr>
<td>Student Survey I</td>
<td>Implementation of updated/modified survey instrument to measure student physics self-efficacy, intended career direction, perceptions about engineering.</td>
<td>Feb/March 2016</td>
</tr>
<tr>
<td>Student Survey II</td>
<td>Implementation of same survey following in-class activity (designed by participatory researchers).</td>
<td>Feb/March 2016</td>
</tr>
<tr>
<td>Student Survey III</td>
<td>Time permitting, implementation of same survey as verification of lasting effect of activity and what career path the students eventually chose.</td>
<td>April/May/June 2017</td>
</tr>
<tr>
<td>Teacher Survey II</td>
<td>Reimplementation of teacher survey (at end of research activities).</td>
<td>April/May/June 2017</td>
</tr>
</tbody>
</table>

Table 11: Original milestone timeline for Goal 2 – measuring quantitative short- and long-term change to perceptions of gendered careers
inclusion in this dissertation. All data from the workshops will be destroyed upon successful defense of the dissertation to preserve data integrity, confidentiality and address privacy issues as per Tri-Council ethics requirements (“Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans,” 2010).

**Survey design**

The primary survey instrument for both students and teachers was created using some questions and scales from existing studies that explore the concepts of self-efficacy, a sense of belonging and self-esteem (Schissel, n.d.; Schissel & Dickinson, n.d.; Schissel, Zong, & Nelson, 2000). The terminology used in the questions was modified to relate specifically to the physics classroom and to considerations of the application of physics as a career option (Appendix A). The survey explored student and teacher beliefs about their perceptions of important aspects of careers, such as income, benefits, flexible work hours and proximity to childcare, while gathering the typical data necessary to categorize the respondents, such as gender, race, region and socio-economic status. This survey did not test for competency in physics concepts, as competency was identified through student physics grades. Instead, the survey focused on experience of learning physics and participation (as dependent variables) measured in various ways. The teacher survey design paralleled that which the students received during the in-class portion of this research in order to ascertain mirroring of perceptions and beliefs.

**Deployment schedule**

The Gantt chart in Figure 7 depicts the interrelatedness of the research tasks. Administration of the pilot survey instrument was more open-ended in the initial phase and fully
defined following the pilot deployments, ensuring that the questions in the quantitative surveys elicited the information necessary for optimal data acquisition (Keeter, 2005; Punch, 2015).

Ethics pre-approval included the original open-ended surveys of the pilot phase; final ethics approval included the final instruments that were used for later survey deployments. The survey data analysis will be shared with the participants and destroyed five years following successful completion of the dissertation defense. Ethics approval includes student contact information retention for five additional years beyond the dissertation defense so that I can contact the sample population at a later date and determine the post-secondary programs from which the students finally graduate. In this way, data will exist for post-doctoral research investigating whether the effect of the curriculum intervention was persistent in the longer term.

Figure 7: Gantt chart of original dissertation research plan. The pale blue activities relate to Goal 1 while the purple activities relate to Goal 2. Data analysis and writing tasks are coloured brown.
Limiting scope

The original project scope encompassed beliefs and perceptions of students, teachers and practitioners within and outside of engineering. The research was necessarily constrained to Physics 11 teachers and their students. In designing the survey instrument, I included broad definitions of self-efficacy, belonging and self-esteem in addition to the beliefs and perceptions of courses that lead to viable careers and career preferences. The surveyed topics are very broad and will lead to opportunities for multiple post-doctoral analyses. I limited the action research team to high school physics teachers because they are the first level of influence on physics students. I limited the number of classes to those taught by teachers involved on the action team to constrain the number of activities and survey deployments.

Chapter conclusions

The broad research program was much too ambitious for a single dissertation. The methodological analysis segmented the full program into realistic chunks, allowing the determination of which aspects would be most appropriate to pursue first in this doctoral project. The pragmatic epistemology underlying action research methodologies met my need for achieving immediate results. The methods incorporated in action research parallel the methods of engineering project management. The dissertation therefore presents its findings through a methodological process that is familiar to engineers, while introducing feminist modes of creating knowledge.

Future research opportunities include identifying general trends in engineering education, identifying gaps in knowledge and data, defining the feminist issues, and verifying potential future intervention strategies. These could be accomplished through a variety of methodologies
including action research, oral history or phenomenology to explore why women of science pursue non-scientific careers in greater depth. Together, these explorations can help us understand how society teaches girls and young women about potential career choices. This doctoral research focuses on Physics 11 and may inform future curriculum modifications that can mitigate the cultural belief of gendered careers. Finally, in order to build credibility for my research and findings in the engineering community, I incorporate quantitative research techniques that relate to the engineering understanding of scientific rigor and the core methodology for creating engineering knowledge. The scope of this doctoral research plan was necessarily limited to an achievable set of project outcomes and a realistic timeline. Chapter 4 explores the theories that provide both the foundation for these methodological decisions and defines the framework for the analysis in Chapter 6 of the data presented in Chapter 5.
Chapter 4 – Theories at Play

Theoretical Developments

The challenges women face in male-dominated professions have been investigated at pragmatic and positivistic levels over the past few decades, mainly with a focus either on an array of targeted intervention initiatives or simply on demographical reporting (Chehaiber, 2016; Fouad & Singh, 2011; Hooks, 1996; Little & León de la Barra, 2009). Kacey Beddoes and Maura Borrego (2011) conducted a deep survey through articles submitted to broad-reaching journals for engineering educators, such as *Journal of Engineering Education* (JEE), *European Journal of Engineering* (EJEE), and *International Journal of Engineering Education* (IJEE). The authors found 88 articles that set women or gender as their focus. However, none applied feminist theory in their discussions or analyses. Instead, these researchers considered and applied theories of “self-efficacy, communities of practice and situated cognition/learning, mentoring, career choice, team functions, identity formation, critical cultural theory, cultural capital, and structuralism” (Beddoes & Borrego, 2011, p. 281), which form a general foundation for interpreting engineering experience or commentary, male or female. These theories are certainly appropriate to analyzing behaviours of the general population but do not delve into the dominant-subdominant dynamics prevalent when minority groups exist (Naples, 2007). The alternate approach employed by engineering researchers investigating gender issues has been to avoid male-female comparisons entirely because, they posit, in the engineering framework women show up a deficit of the masculine skills and attributes typical to a male-dominated profession (Ruthig et al., 2016). From the feminist perspective, theory applications considering
both gender-specific modes of behaviour and gender interactions serve to illuminate feminist viewpoints within the engineering context, enriching the knowledge base (Rolin, 2002).

This chapter begins with a discussion of feminist theory and the validity of its application to engineering. Ensuing sections explore various social theories that describe the interactions between dominant-subdominant hierarchical groups and address, in part, gendered career choices and the recruitment of women to engineering. I then assess the gender focus of these social theories and how they apply to this dissertation.

**Feminist Theories**

Discussions of theory help to situate research into the social science framework and to relate the research contribution to the greater body of knowledge. As this doctoral project focuses on women’s issues, in terms of recruiting women to engineering and changing girls’ perceptions of the expectedly masculine disciplines of engineering that apply physics, theoretical discussions must inherently be rooted in feminist theory. However, feminist theory itself is a nebulous construct that must somehow include multiple modes of knowledge creation and theory development. Therefore, it may be best to image feminist theory as an overarching web of interconnected theoretical ideas relating to the various aspects of women’s epistemology (Beddoes & Borrego, 2011; Frye, 2014; Jackson, 2006; Ritzer, 2005). For example, standpoint theory, which suggests that an individual’s standpoint necessarily influences the way knowledge is constructed, forms one such link.

**Standpoint Theory**

Feminist standpoint theory specifically addresses how women’s perspectives are best identified and studied from the standpoint of women (Bowell, 2011). Although this feminist
standpoint may first appear to prejudice research, the mitigation of standpoint bias is easily accomplished by 1) acknowledging the potential for bias, and 2) ensuring the inclusion of and discussing dissenting viewpoints while 3) including feminist contributions in the epistemological process (Beaulieu & Searles, 2016; Lanaj & Hollenbeck, 2015; Rolin, 2002). Feminist standpoint theory further explains how modes of scientific discovery and engineering design principles developed predominantly by men evolved into knowledge constructs often inaccessible to women as outsiders (E. Anderson, 2012). In other words, the ways that knowledge was created in science and engineering have been traditionally masculine, which apparently excludes women because the creation process was not feminine, regardless of women’s abilities to comprehend and work within the masculine construct. For this reason, feminist epistemology is necessary within these fields in order to remove the exclusionary epistemic authority and to acknowledge the strengths inherent in the feminist way of knowing (Rolin, 2002).

Standpoint theory may explain the lack of feminist history in early British Columbian grade school curricula and the exclusion of women from science and engineering curricula, reflecting the social roles accessible to women at that time. As discussed in Chapter 2, early BC curricula written from a masculine standpoint rarely discussed the contributions of women to early Canadian history, with the result that women’s issues were relegated to afterthoughts or, later, side-bar commentaries about how women interacted with men of the period (Gaskell, 1973). Later textbooks written from a feminine standpoint presented an account of history that integrated men’s and women’s accomplishments and social changes that occurred through the years (Clark, 1998). Written from the standpoint of women, many of whom had not seen the influence of feminist epistemologies in their own grade school learning, these authors included
events they perceived to be of importance to supporting gender equity and fairness of representation (Gaskell, 1996). Similarly, engineering and science curricula developed by masculine groups use knowledge descriptions that relate specifically to that group, resulting in the use of closed turns of phrase. For example, thought-provoking questions intended to stimulate dialogue that ask if “anyone [has] ever smashed a transistor radio” (Kelly, 1985, p. 137) exclude girls who are unlikely to have experienced such an activity, based on stereotypical expectations of girls’ interests. In addition, the language use (smashed) relates better to the male adolescent tendency toward being tough. Although recent research from female scholars adds feminist epistemology to the body of knowledge for engineering and physics, they receive a lower rate of acceptance than similar works by male scholars (Coulter, 1995; Linehan, Buckley, & Koslowski, 2009; Price et al., 2005).

It must be noted that issues explored using feminist standpoint theory are not necessarily generalizable to all women, because feminist standpoint theory does not account for differences in an individual woman’s experience and culture (Beddoes & Borrego, 2011). In a similar way, curricula written from the feminist standpoint cannot necessarily include sufficient depth about the impact of colonialization that is produced when written from the aboriginal standpoint (Cherubini et al., 2010). The inclusion of women’s perspectives and modes of knowledge creation in engineering, however, serves to introduce new questions, theories and methods to scientific pursuits, resulting in the enhanced organizational benefits and growth opportunities noted elsewhere in Chapter 2.
Social role theories

Several social science theories seek to explain developmental and social reasons for the ongoing perception of gendered careers. Examples that relate to this research project include social dominance theory (Gaucher, Friesen, & Kay, 2011; Ghavami & Peplau, 2012; Pratto, Sidanius, & Levin, 2006; Ruthig et al., 2016), social role theory (Bruun & Brewe, 2013; A. H. Eagly, 1997; Woodington, 2010), and the theory of precluded interest (Cheryan & Plaut, 2010; Forsman & Barth, 2016). These theories describe the friction between social groupings defined by race, gender, age, or other characteristics. The theories may explain the social behaviours that promote a specific set of career paths to girls and may illuminate some of the reasons behind female engineers’ inclinations to leave their male-dominated profession, a phenomenon which further influences girls’ career choices.

Social dominance theory

Social dominance theory identifies perceptions of power between social groups, specifically as a belief of dependence on another’s power resulting in increased rates of nondecisions or uncertainty in the presence of the other (Ford, 1994). The theory describes how society intrinsically sorts itself into stratifications based on a social hierarchy dictated by dominance and privilege, phenomena and effects often so deeply rooted that most subjects are unaware that they uphold the hierarchy in their personal decision matrices (Gaucher et al., 2011; Pratto et al., 2006). Those with power and privilege, according to social dominance theory, have greater access to information, research data and commodities than individuals lower in the hierarchy, who have trouble acquiring the access because of typically invisible barriers or impediments that require additional navigation (Ghavami & Peplau, 2012). Apparently benign
and positive social constructs inadvertently serve to promote this power imbalance; for example, chivalry subliminally implies that women all need the care and attention of men, which further implies that men are socially dominant over weak women (Farkas & Leaper, 2016).

The hidden curriculum inherent in many textbooks and lesson plans in grade school education (such as images of Mother cutting a cake to demonstrate ratios) perpetuate social hierarchies and stereotypes, creating the social constructs that help explain social dominance theory (Kelly, 1985; Rich, 2010). Perhaps due to the masculine standpoint of early curriculum authors, the hidden curriculum is presented through the use of language that supports gender stereotypes and reinforces girls’ sense of being inferior or subordinate to boys, a feeling that persists through to adulthood and is thought to contribute to social identity threat (W. M. Hall, Schmader, & Croft, 2015; D. Smith et al., 1998). This hidden curriculum also contributes to the social construct of gender roles (Kelly, 1985).

**Social role theory**

Social role theory predicts that subdominant group members exhibit a greater sense of agency, or independence, assertiveness and control, when in roles typically occupied by their social group (A. H. Eagly, 1997; Steinmetz, Bosak, Sczesny, & Eagly, 2014). In a simplistic example, a small group of children would have a lower sense of agency when outnumbered by adults than at a playground where children are the majority. Gender role theory takes social role theory to the next level by cyclically relating the perpetuation of gender stereotypes to expectations of gendered roles. Similar to an aspect of social identity threat, a prediction of gender role theory is that the bias that men are more suited for leadership positions than women results in the prevalence of men in leadership positions regardless of the percentage of men in the
profession (Lanaj & Hollenbeck, 2015). This is apparent in law, medicine and accounting, which have achieved equal numbers of men and women in post-secondary education and in the workforce, but persist with few women in leadership roles (Drinkwater et al., 2008; Hooks, 1996; Leowski, 2006). Thus, the predominance of male leaders substantiates and perpetuates the role bias (Alice H. Eagly & Karau, 2002). A similar self-perpetuating bias exists in scientific exploration, some theorize, in which the strategy to overcome gender bias by focusing on the benefits of feminine viewpoints as distinct and precluded from masculine epistemologies delineates and emphasizes differences between men and women (Moss-Racusin et al., 2012; Rolin, 2002). Farkas and Leaper’s (2016) study exploring the paternalistic beliefs of youth mentioned in the previous section, that women need the protection of chivalrous men, further reveals clear yet parallel distinctions that exist between the occupational aspirations of boys and those of girls posited to be solely due to gender role constructs.

**Theory of precluded interest**

Overcoming social biases by redefining stereotypes is a paradox many engineering organizations believe can only be overcome by consciously constraining decision-making and knowledge creation to logical procedures based on the application and use of empirical data (E. Anderson, 2012). In this way, programs aimed at recruiting women to science, technology, engineering and mathematics typically resort to role modelling activities and assess their effectiveness by assessing raw survey data (Park et al., 2005; Swirsky & Angelone, 2015). This is the theory of precluded interest, suggesting that stereotypes influence the choices of future generations especially with regards to career options (Cheryan & Plaut, 2010). Precluded interest serves to explain why women with mathematics capabilities choose careers that do not use
mathematics because they evaluate themselves against prevailing stereotypes and cannot see themselves in those gender-segregated roles (Forsman & Barth, 2016). Since women cannot see themselves in masculine-dominated careers, they do not choose them, resulting in future generations continuing to see only masculine-dominated fields.

Interestingly, when women resist the pull of precluded interest and exhibit behaviours outside the expected feminine role, expectancy-violation theory predicts a pendulum swing of over-compensation: women are expected to excel in any demonstrated masculine attributes and exceed male expectations especially in terms of agentic skills like leadership and control (Lanaj & Hollenbeck, 2015; Rudman & Glick, 2001). So, when a woman is deemed unable to excel and exceed masculine expectations, the original gender stereotype belief that women are less capable than men is confirmed and strengthened, increasing any feelings of negativity and dissatisfaction towards women in the workplace (W. M. Hall et al., 2015).

It is a strategy of the theory of precluded interest to invite female role models into middle and high schools as engineering presenters and leaders of interactive design activities on the assumption this will assist in disrupting stereotype beliefs. In social role theory, society expects women to be more community-oriented, emotionally expressive and sensitive to interpersonal concerns than men, who are expected to be more agential (A. H. Eagly, 1997). Granted, stereotypes are necessary to help individuals in society cope with the magnitude of information they must daily process (Woodington, 2010). However, identifying the misconceptions about stereotypes, specifically those social expectations of behaviour that exclude women from some professions, helps to reshape stereotypes. A study conducted in Japan and Germany demonstrated that not only are social roles culturally defined, but that these roles can be quickly
dispelled with brief descriptions of the stereotypes at play (Steinmetz et al., 2014). The combination of education and role modelling, therefore, can be effective in redefining stereotypes.

Precluded interest and social role theory predict the hidden curriculum that reinforces the unspoken roles of men as dominant and women as subdominant (Gaskell, 2010; Golinski, 2002). Engineering and science curricula began development from a single social group, the knowledge descriptions use references that relate specifically to that group, resulting in the use of jargon and closed turns of phrase (Kelly, 1985).

Social behaviour theories

Social scientists identify a number of theories that may describe the phenomena explored in this dissertation and help in understanding how society promotes the perception of gendered careers. Some theories, like social role theory discussed earlier, describe aspects of the social reinforcement of role stereotypes on children and youth and emphasize a social delineation between careers to which girls and boys conceivably should aspire. Others, like social cognitive theory described in this section, relate to behaviours and beliefs about oneself that influence the career decision-making process. These theories of self-efficacy and self-esteem attempt to describe the personal drivers that motivate individuals to pursue particular careers.

Social cognitive career theory

Social cognitive career theory focuses directly on the academic interests, choices and performance of students with respect to their career decisions (Lent, Brown, & Hacket, 1994). Derived from general social cognitive theory, which focuses on self-efficacy, goals and outcomes, this pragmatic career theory looks beyond personal traits and capabilities for
contextual motivators for career choices, fitting in well with professional populations (Lent, Lopez, Lopez, & Sheu, 2008; Luthans & Stajkovic, 1998). Social cognitive theory describes the linkage between social interactions and cognitive experience in the creation of both knowledge and behavioural responses. Social cognitive theory goes on to describe how self-reflection, the cognition aspect, can help in honing responses to change future behaviour. Social cognitive career theory focuses on the concept of self-efficacy, one’s personal convictions about one’s own abilities. The hypothesis drawn from social cognitive career theory is that an individual will succeed in a course of study in direct proportion to the strength, magnitude and generality of their convictions (Woodington, 2010). This idea forms the core of expectancy-value theory, that self-efficacy leads to one’s expected enjoyment, leading in turn to the decision to participate in an activity (Watt et al., 2012). Thus, self-efficacy in physics would relate to pursuing a career that applies physics.

**Interactional theory**

Self-efficacy also relates to agency and whether individuals effectively communicate ideas and opinions within a group, a precept of interactionism. First developed to predict recidivism of delinquent youth, interactional theory recognizes the reciprocal influence of interactions within groups on weakening cultural social bounds on behaviour to permit or promote delinquent behaviour (Thornberry, 1987). Interactional theory may explain how social behaviours within teams reflect changing beliefs about stereotypes, especially with student groups in which personal interactions play key roles (R. B. Powell, Kellert, & Ham, 2009). This theory is distinct from interaction theory, which also explains the challenges inherent with male-female interactions with its explanation of specialized non-verbal communications that develop within
closed groups (Gallagher, 2001; Gallagher & Varga, 2014). In other words, interactional theory describes how new groups form bonds to disrupt previously held stereotypes while interaction theory describes the strength of group bonds created through close interaction. Together, these two theories predict that outsiders (women) will be particularly challenged to break into intimate (male) groups but, as (if) they grow in agency as members of small mixed groups, they can reshape outsider (gender) stereotypes. In this way, social behaviours can develop into new beliefs that enhance confidence and self-efficacy of group members.

Circumscription and compromise

The theory of circumscription and compromise predicts that students’ occupational aspirations are independent of their social group because they are deeply seated in broader gender identity schemas (Linda S. Gottfredson, 1981; Nathaniel & Deborah, 2012). Research studies demonstrate that girls and boys equally accept the social constructs of gender roles that some careers are constrained to be male- or female-appropriate. Girls and boys equally compromise on their personal career aspirations in order to meet these conscripted gender role expectations (L S Gottfredson & Lapan, 1997; Whitmarsh & Wentworth, 2012). This is why feminist career coaches recommend using language and imagery in job postings and career descriptors that are either non-gendered or are more feminine than masculine in order to disrupt the circumscription and compromise cycle (Forsman & Barth, 2016): while feminine descriptors do not dissuade men from applying to job postings, masculine descriptors dissuade women (Gaucher et al., 2011).
Theories supporting the research questions

In considering the social implications of feminism on curriculum and the persisting perceptions of gendered careers as evidenced by program decisions made by students in British Columbia, this study applies three social theories: intersectional theory, social cognitive theory, and precluded interest. While multiple theories can describe the various phenomena experienced by girls and women throughout the engineering pipeline, this research does not delve into dominant-subdominant dynamics but instead draws on the specificity of cultural theories to develop concrete hypotheses for expected outcomes of the research goals. For the goal of measuring perceptions and beliefs of gendered careers, the survey instrument includes indicators for self-efficacy arising from social cognitive theory. The qualitative thematic data analysis is built around the precepts of gender roles as an aspect of social constructivism and constrained by the theory of precluded interest, looking for the deconstruction of previously held perceptions of circumscribed professions.

The population stratification of students in Physics 11 classrooms in this dissertation is based in essence on intersectional theory. Intersectional theory identifies differences in population epistemology by recognizing social, racial, and other distinctions as important to a subgroup’s way of knowing (Beddoes & Borrego, 2011; Ghavami & Peplau, 2012). Therefore, this study assesses the beliefs and perceptions of only those boys and girls who have an affinity for or interest in science instead of all high school students. This grouping eliminates potentially confounding information and data and is the same premise behind the data selection from Camosun College, which was pre-sorted to assess the program choices of students with high school physics transfer credit by cross-tabulations with respect to sex.
This is not to say that the theories excluded from the analysis do not relate to girls in this study. Rather, this research activity cannot directly measure or verify whether the other theories are at play within the Physics 11 classroom. As mentioned earlier, feminist theory certainly informs the development of the in-class activity and clearly describes the type of research underway. In addition, the feminist viewpoint adds depth to the female students’ experience and their construction of physics knowledge. The nebulous nature of these theories negates the assessment opportunities presented by the social role theories.

**Theories not supporting the research questions**

Social dominance theory could build an interesting hypothesis for assessing the behaviour of male and female student groups and determining the impact of social dominance in the Physics 11 classrooms in this sample population. This is certainly a viable focus for future analysis of the research data. Similarly, social role theory may explain chivalrous behaviour evident in the classrooms and social identity threat theory could provide an interesting framework for future research into measuring whether male or female students take leadership roles in the physics classroom, again not a focus of this research but a potential future use of the data. These theories more often describe gendered behaviours that exist in the workplace but it would be interesting to see if they also exist in high school.

In the same way, while expectancy violation theory appears to apply in the workplace, it would be interesting to examine the research data for evidence of expectations that female students should excel beyond the capabilities of male students to succeed in Physics 11. It may be possible to verify the application of expectancy violation theory in the classroom by interpreting and assessing student and teacher behaviours, however testing this theory would
likely require outcomes data and a more carefully constructed experiment to gather peer and teacher opinions, which is not in the scope of this research project.

The proposed dispelling of stereotypes is based entirely on interactional theory. As the students interact with each other, discussing each other’s experiences of applying physics and constructing knowledge around physics concepts, they begin to form new bonds and build new relationships that disrupt previously held stereotypes. These social behaviours in the physics classroom can strengthen self-confidence, increase a sense of belonging and enhance self-efficacy. This theory predicts a disruption to social constructivism, in which social behaviours construct knowledge about stereotypes. Testing the creation and disruption of stereotypes is another interesting experiment I would like to conduct one day but cannot be directly analysed using this research data.

Conscription and compromise theory may be at play in these classrooms as students indicate preferences for particular careers because of gender role expectations. The research does not test student responses to masculine or feminine descriptions or descriptors. However, the student activity reports (posters) may provide sufficient information to test if students use gendered language or gendered scenarios in describing physics concepts. A conscription and compromise hypothesis might be testable as a future project but does not form part of this dissertation project.

**Chapter Conclusions**

Feminist theory is rarely applied to engineering research studies on the behaviour and interactions of engineers, or to investigations into strategies to recruit and retain women in the profession. Pragmatic and empirical studies are effective in identifying existing issues but do not
address the complexities of standpoint theory and gender roles, the influence of social dominance and precluded interest, nor the impact on behaviour of socially constructed stereotypes. Studies based on social theories that target women in engineering and science are increasingly available in psychology and social science journals. This feminist research is well positioned to bridge the gap between social science and engineering by providing an empirical study that is informed by social theory but designed for engineering and physics educators.

The next chapter describes the research tools and data that empirically demonstrate the disruption of stereotype beliefs through the implementation of a single physics lab. The survey instruments provide both the opportunity for data collection and lay the foundation for the social education to come through the lab activity. Chapter 6 presents an analysis of the data, including the statistical significance, and interpretations of the qualitative findings.
Chapter 5 – Research Activities

Through this doctoral study, I tested the hypothesis that a discovery-based lab experiment paralleling the engineering design process would change the perceptions of students regarding engineering as a viable career option. The deployment of a survey instrument quantitatively measured beliefs and perceptions of youth enrolled in Physics 11 classes in the Greater Victoria Region prior to and following the in-class activity. I used note taking and video recordings to document student and teacher observations, impressions and feedback. The research activities of this doctoral project involved working with minors, which required ethics clearance for all considered modes of data acquisition.

This chapter begins with an overview of the multi-stage ethics approvals process followed by a brief introduction to the study population. I then explain the development of the in-class activity and describe the survey instrument including the source and objective of each question set. The data interpretation and theme identification comprise later chapters.

Ethics Approvals

Prior to collecting data or, in fact, interacting with youth in any way, Canadian projects must complete and receive research ethics approval in accordance with the relevant institutional ethics review policies. Royal Roads University complies with the national Tri-Council recommendations by establishing a Research Ethics Board to review and approve ethics clearance requests using the Tri-Council requirements (“Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans,” 2010). Once receiving clearance, researchers can provide assurance that their methods minimize or mitigate potential risks to human subjects involved in their studies.
In order to provide a reasonable ethical risk assessment, the application process requires specific information about the study population identity, details of the survey instruments or other tools planned for use, and the scope of proposed activities contained in the research plan. School district offices in the Greater Victoria Region each have a unique ethics approvals process that is initiated following university clearance. As the ethics approval timeline constrained access to teachers, I describe these processes below.

**Ethics approvals timeline**

I requested provisional ethics approval prior to completing my candidacy exams in order to reach out to teachers before their summer holidays began. This was necessary because I wished to complete the data collection phase of my project within the upcoming academic year. My interaction with teachers was necessarily constrained to follow the high school teaching cycle, which begins in September and ends mid-June. For the action research team to be assembled in time for a September start, I would need to reach out to teachers in June, to school board offices for approval in mid-May, and to the Research Ethics Board in early May. With the candidacy examinations set for May 2015, I requested permission to initiate my search for research subjects prior to achieving approval for the research plan.

On May 6, 2015, I received approval from the Royal Roads Research Ethics Board to contact schools and request permission to approach teachers. The initial outreach, interactions with teachers and instrument design process could occur concurrently with the research clearance provided all approvals were granted before contacting students.
Ethics clearance: university and school boards

Upon receiving the university’s pre-candidacy provisional ethics clearance, I telephoned directly or sent email requests to the three Greater Victoria school district offices, the Catholic School Board and the principals of the three independent schools in the region for permission to identify and contact the individuals scheduled to teach Physics 11 in their schools during the 2015-2016 academic year. The superintendents of School District 61 and School District 62 (SD61 and SD62) granted instant approval as did the Catholic School Board; I immediately called the district high school principals to request teacher lists. The independent school principals also granted instant approval and directly released their Physics 11 teacher names and contact information. School District 63 (SD63), operating under the business name of Saanich Schools, employs an ethics officer to manage in-school research applications. When I reached her upon her return from vacation, I received, completed and returned the Saanich Schools Request for Research form. While this was sufficient as permission to contact schools., the delay limited access to teachers and shortened they available response time.

Details of university ethics approvals

My submission for pre-candidacy provisional ethics clearance from Royal Roads University used draft versions of the surveys that would be piloted prior to deployment with the entire research population. The university’s Research Ethics Board granted full ethics approval on the condition that the final survey versions be submitted once complete, for review of any resulting changes. The teacher workshop and pilot class activity (described in Chapter 5) identified minor revisions. I submitted the modified youth survey and the updated Student Letter.
of Consent as addenda to the original clearance application. The final survey instruments can be found in Appendix A of this dissertation along with all letters of informed consent for adult and youth participants.

The late addition of School District 63 reduced the available time for reaching potential teacher participants from those schools. However, after telephoning or visiting all Physics 11 teachers in the district, I connected with one who was both interested and available to join the team. This teacher provided the unexpected benefit of supplying his class as an arena to pilot the survey and the in-class activity. I discuss the reasons for this opportunity in a later section of this chapter.

Details of the final university ethics approval are found in Appendix B. The anonymized survey data will be shared with interested participants and the raw data will be retained for five years after completion of the dissertation defense to permit the testing of long-term persistence of changes to perceptions and beliefs. After this period, the raw data will be destroyed. I foresee minimal to zero risk for both students and teachers participating in the research. The possible minimal risk is that survey questions may trigger an emotional response in students. There is no risk to students during the teaching activity due to concerns for privacy or personal safety as anticipated student behaviours and interactions remain consistent with those that already exist in Physics 11 classrooms and laboratory settings. Students remained under the supervision of their

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7 Some survey questions ask about the students’ friends, how many they have and whether they feel they have someone they can confide in. Other questions ask about the students’ home life and whether they feel treated fairly. These questions may be upsetting if the student feels isolated or unsafe in some way. Classroom teachers remained present at all time to watch for concerning student reactions.
teachers at all times therefore students were not alone at any time with the researcher.

Regardless, I completed a Criminal Record Check to allay potential teacher or school administrator concerns.

**Details of school district ethics approvals**

The teachers who agreed to participate in this research project worked at schools within three school districts and at an independent school, hereafter referred to as: SD61, SD62, SD63 and Independent. Each of the school boards had its own process for approving research within its district, which differed from that required by the Independent. The superintendent of SD62 required a copy of Royal Roads University’s ethics clearance documentation. After reviewing the document and the researcher’s credentials and ethical history, he quickly granted approval to proceed. No further information or documentation was required. SD63 staff initially appeared to resist shepherding the ethics approval process along. Once I connected with the ethics officer and received, completed and returned the appropriate paperwork, approval was swift. SD61 gave swift provisional approval to contact schools and teachers. However, the policy for full approval at SD61 was unclear and staff appeared to be less likely to follow up than in the other districts.

The clearance process at the independent school was straightforward: sending the headmistress the university ethics clearance package as approved by the Royal Roads Research Ethics Board (Appendix B). The headmistress granted approval during our meeting in mid-August and introduced me to the Director of Curriculum and Instruction who had previously expressed interest in this doctoral research project. The director arranged an opportunity for me to present my proposal to the science faculty and invited the school marketing department to
write an article on my work in their Physics 11 classrooms (van Hardenberg & DeMerchant, 2016). I have been invited to return to present my findings upon completion of this dissertation.

**Royal Roads University**

I received full ethics approval from the Royal Roads University Research Ethics Board on September 8, 2015. The process mirrors that required by the Tri-Council of the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council and the Social Sciences and Humanities Research Council (“Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans,” 2010). These three bodies provide significant funding for research at eligible universities, colleges and technical institutes in Canada. The Tri-Council formed an advisory panel to ensure that research involving human subjects meets high ethical standards. As such, the clearance process requires detailed information about the researchers, the purpose of the project, the intended subject population and materials planned for use in communicating with the subjects.

The process honed my research plan by forcing me to write concise yet comprehensive descriptions for each topic section. Similar in content to a Project Charter, the Request for Ethical Review for Research Involving Humans begins with brief biographies of the key stakeholders, including supervisor, advisors, sponsors, clients, Principal Investigator, co-researchers and inquiry team. The research proposal summarizes the research purpose, methodology and procedures that I described in detail in Chapter 3 of this dissertation. The ethics approvals documentation contains sections for descriptions of the population and research sample, and the processes for recruiting the subjects and for releasing them from their commitment to participate. In addition, the application addresses potential conflicts of interest,
risks and other negative impacts, including how to eliminate or mitigate potential risks. The risk sections relating to cultural considerations, Indigenous studies and deception do not pertain to this project, however the section relating to the involvement of vulnerable participants does pertain. The final sections provide details on the intended process established to maintain the privacy, confidentiality and anonymity of subjects.

In this research, I worked with youth who are considered a vulnerable population by the Tri-Council (“Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans,” 2010). To protect the youth subjects, the Physics 11 teachers agreed to always accompany me in the classrooms. In this way, we could avoid potential conflicts and assure that all behaviour was above reproach. The easiest method for protecting subject privacy is to avoid collecting personal information that can be used to identify individual participants. Unfortunately, I require personal identifying information so that I can track the subjects’ future program choices and verify the integrity of subject survey deployment links. Therefore, I affirm that this confidential information is kept securely separate from the survey information and is anonymized in all presentations of data, whether in this dissertation or in presentations of my work at conferences and workshops.

The students and their parents or guardians signed the Youth Letter of Consent as their agreement and permission to participate in the research, having read, understood and agreed with the intended activities (Appendix A). No participants were deceived during this research and all subjects were informed they could withdraw from the research at any point until such a time that the data were combined in the anonymized dataset. When the data are anonymized, I can no longer identify or remove a specific set of responses. Although I originally proposed that
students could decline from participating in the activity itself, the teachers deemed the activity to be one whose purpose, structure and content fully align with their original teaching plans.

Teachers often have guest lecturers in their classrooms. Therefore, I make the distinction that the research encompasses only the collection and interpretation of data and I exclude qualitative data inadvertently collected from non-participating students or those who wished to withdraw from the research at that point. I used a numbering system on the surveys to constrain deployment to only those students with signed consent letters, ensuring that no quantitative data from excluded students could be inadvertently collected and that all data are unique. Students could decline to participate in the post-activity survey deployment and withdraw from the research at which point their pre-activity survey would be destroyed. One student withdrew from the research once the activities were underway.

I project a potential population of roughly 25,000 students across the Greater Victoria Region. In the ethics review request, I anticipated that ten teachers might elect to participate in the research activities, which, with roughly 30 students in each class, two classes per teacher, would result in a sample population of around 600 students. I recruited the Physics 11 teachers through individual introductory emails and follow-up phone calls. Once the PAR Team assembled, we discussed the possibility of recruiting students from other physics teachers who expressed interest in participating in this project but were unable to attend the workshops. Ultimately, the scheduling challenges made this expansion prohibitive and we constrained the student sample population to the classes of the Physics 11 teachers who volunteered to participate. The composition of the final sample population is described in detail in the following section.
Research sample

Teachers

The Capital Regional District (CRD) has three public school districts with 13 public high schools and five independent private schools (Figure 8). In May, 2015, I telephoned the superintendents of Greater Victoria School District 61, Sooke School District 62 and Saanich School District 63 (SD61, SD62 and SD63) and received permission to contact the Physics 11 teachers in the district high schools. The public and independent high school principals provided lists of their Physics 11 teaching assignments for the upcoming school year, 2015-2016. By May 19, 2015, I had a complete listing of physics teachers from the region. Before the end of the month, five teachers indicated their interest in participating in this project. I continued to contact Greater Victoria high school physics teachers through June 2015, via telephone calls and in-person visits. I informed all teachers that the project had not yet received ethics approval.

Of the 26 Physics 11 teachers identified, three were women; I met with each female teacher during the invitation period. One female teacher had just begun post-graduate studies towards an Education Masters degree and declined to participate. A second female teacher declined, citing that she was too close to retirement to be able to participate through the full period. The third agreed to participate and ultimately joined the action research team.
Four of the Participatory Action Research Team (PAR Team) members were confirmed by August 2015. Three men and one woman attended the first September workshop. One additional teacher connected with me just after the first workshop and joined in the second workshop. The five teachers of the PAR team represented each group of schools: two teachers were from a school in SD61, one teacher from SD62, one from SD63 and one from an independent school. The teachers will be referred to by their school group to protect their anonymity and that of their students.

Figure 8: High schools in the Greater Victoria region. The size of the balls is aesthetically set for approximate relative size of student population.
Teachers

The teachers had similar educational backgrounds and years of experience (Table 12). All completed undergraduate degrees with a science focus, most in Physics. Four of the teachers completed Bachelor degrees in science and four teachers completed Bachelor degrees in education. Three of the five teachers completed Masters degrees. The teachers each acquired between 17-35 years of teaching experience, with 12 years being the shortest time spent in the current school.

All teachers were born and raised in Canada. Three of the teachers grew up in the Victoria region, one in New Brunswick and one in Ontario.

Students

The student sample was drawn from the PAR Team teacher classes. All students in these classes were invited to participate. The students were asked to complete identical paper surveys before and after the in-class activity and once again online several months later. Due to student absences during the second survey deployment, the number of respondents to the paper surveys is unequal. The sample size of students who completed the survey prior to participating in the activity is 250, with 21 responses missing data, leaving 229 valid responses. Of these students,
54% were female, 46% male. Post-activity, 224 students completed the survey with 6 surveys missing data leaving 218 valid responses, of which 52% were completed by female students, 48% by male students (Figure 9). I used paper surveys and achieved a response rate of 100%. During the online deployment, only 71 surveys were completed with 23 missing data, leaving a total of 48 valid responses for sex. Of the online survey respondents, 62% were female.

The use of sex instead of gender is deliberate and intended to eliminate potential confusion surrounding gender identification (Miner, Bockting, Romine, & Raman, 2012). First, quantitative analysis requires a minimum number of responses within each segment of the dataset and because the non-male and non-female self-identifying population is very small, I anticipated these responses could not be used. Second, providing an option of “other” is disrespectful of the many ways that non-male/non-female individuals self-identify. Third, including all options on a youth survey in high school may prompt embarrassing in-class discussions. Regardless, some students wrote comments on their surveys complaining about the binary option for sex responses. As a result, all non-disclosure of sex is eliminated as missing data. From this point forward,

<table>
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<th>School Group</th>
<th>Education</th>
<th>Desire to obtain more education?</th>
<th>Experience (yrs)</th>
<th>Current School (yrs)</th>
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<td>B.Ed. Physics/Math</td>
<td>maybe</td>
<td>25</td>
<td>23</td>
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<td>yes</td>
<td>17</td>
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<tr>
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<td>23</td>
<td>19</td>
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<tr>
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<tr>
<td>Independent</td>
<td>B.Sc., Environmental Science; B.Ed., Science; M.Ed, Curriculum Studies</td>
<td>yes</td>
<td>31</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 12: PAR Team teacher education and experience.
“sex” is used interchangeably with “gender” to align with common social practice (Swirsky & Angelone, 2015).

The Physics 11 classrooms exhibited gender parity. It may be proposed that the data are somewhat skewed by the inclusion of the independent school, which is a single-sex girls’ school. However, the cohort size for that school, $n = 18$, results in a relatively small impact, from 54% female to 50% female for the pre-activity respondents and from 52% female to 47% female for the post-activity respondents. Figure 10 shows the post-activity survey deployment percentages of female students in the sample with and without the independent school population.

The two teachers from SD61 taught a total of seven classes of Physics 11, with two sections scheduled concurrently. The teachers from SD62 and the independent school each taught two classes, and the teacher from SD63 taught one class. I present the distribution of students by school, class and gender in Figure 11. I indicate the sex numbers or percentages for each of the seven class periods from SD61 to highlight that two classes had a majority of female

Figure 10: Post-Activity participation by sex without undisclosed respondents. The data on the left includes the independent girls’ school. The data on the right does not include the independent school.
students, in Period 1 and in Period 7. The class from SD63 also had a majority of female students.

**Workshops**

The original research plan included delivering two workshops for the teachers, one in September and one in May of the same academic year. Workshop 1 would begin with a presentation on existing studies that explore gender stereotypes in education, industry and society and perpetuate beliefs in gendered careers. The presentation would be followed by the development of the detailed design of the research activity and the implementation plan. At the teachers’ request, this first workshop was split across two afternoons one week apart. The first half, Workshop 1a, consisted of the informational presentation and a preliminary discussion of the research plan. The second afternoon, Workshop 1b, focused on the design and implementation of the research activity including: selecting the activity for their classrooms,

![Figure 11: Post-Activity participation by school (and class, in the case of SD 61) and by sex. Note that two classes from SD 61 had a majority of female students: SD 61-1 and SD 61-7. The second number after the dash indicates the section number or class period in the school timetable. SD 61-8 was a combination of two classes, taught concurrently, one by each of the two teachers from this school. I combined the two classes of SD 62 and the two classes of the independent school.](image-url)
defining the activity learning outcomes, identifying necessary tools for the activity, and creating a tentative schedule for deploying the surveys and running the in-class laboratory activity.

During the May workshop, Workshop 2, I intended to and did report on the research plan progress, present findings to date and preparations for data analysis.

All workshop sessions took place at Camosun College, Interurban Campus, in Victoria, BC, starting at 4pm and ending at 6:30pm. The late start time allowed the teachers to travel from their respective schools after classes ended. The early finish time allowed teachers to proceed with their normal weeknight activities. I arranged for tea, coffee and light snacks to be available and hired an assistant to ensure seamless workshop activity transitions, provide ongoing food replenishment and verify that all recording devices functioned well. From a facilitator’s perspective, the workshop arrangements were satisfactory in maximizing participant comfort (Figure 12) and the short time frame generated sufficient pressure to result in highly productive sessions.

Figure 12: Presentation (left image) and PAR Team survey completion at Workshop #1.
I established two data capture methods to minimize data loss: audio-visual recordings and note-taking. I set up video cameras around the workshop room and the research assistant ensured at least one camera functioned adequately at all times to record audio-visual data. The video recordings are used only to ensure that comments are attributed to the correct participant during data analysis, which occurred several months after the workshops. I set up flip-chart paper on stands around the room but with the small group of participants, this became unnecessary. The teachers and I sat around one large table and, instead of using the flip chart stands, I laid sheets of flip chart paper on the table and recorded my notes there. In this way, the teachers could see what I was writing and immediately suggest additions or clarifications. Following each workshop, I typed up my notes and sent them to the teachers for their review and further comments.

**September Workshop – Workshop 1a and Workshop 1b**

Workshop 1a began with a welcome activity during which the participants introduced themselves to each other. The activity generated sufficient trust up front to enable a comfortable sharing of opinions. The teachers discussed their educational backgrounds and teaching interests and compared the administrative processes that resulted in their current assignments to teach Physics 11. Once this discussion wound down, I went over the research agenda and a letter of consent, titled the Informed Consent Form for Adult Participants, which they then signed as their agreement to participate in the research (Appendix A). I witnessed their signatures on the letters and the teachers completed the survey I prepared to record some background information including educational credentials, personal values, and personal interests in high school classes. In addition, they answered questions similar to those in the student survey that probed the
respondents’ perceptions and beliefs about the value of high school courses and whether they lead to meaningful careers. The survey is described fully in a later section of this chapter.

When they completed the survey, we took a brief break before I delivered my presentation on persisting stereotypes of gendered careers and how these may be related to and constructed through social interactions with family, friends, community circles, schools and teachers. I compiled this information from the research literature survey and review discussed in Chapter 2 of this dissertation. Workshop 1a wrapped up with an opportunity for the teachers to reflect on the proposed research plan and activity development that would form the basis for Workshop 1b taking place the following week. I include some of the teacher’s reactions and comments below and include additional reactions and comments as part of the interpretation in Chapter 7 of data collected throughout the research activity plan.

As noted earlier, one team member joined after Workshop 1a was complete. I met with him separately to provide the information shared during that first workshop and reviewed the Letter of Consent that he then signed. The new teacher joined the PAR Team in time for Workshop 1b, sharing in the co-design of the research implementation tool.

The key activities of Workshop 1b included debriefing the teacher surveys, reviewing the purpose of the research activities, initiating the design of the intervention activity for their classrooms and creating a tentative schedule for the student surveys and activities.

In an email communication shortly before Workshop 1b, I asked teachers to bring typical teaching tools with them including:

- their individual course plans, or teaching schedules, with anticipated timelines for delivering each of the discrete physics concepts covered in Physics 11;
- a sample lesson plan or template;
• a list of potential labs to consider for the research activity and
• their reflections on the lesson and lab development processes they typically follow.

After the welcome, quick survey debrief and review of the meeting notes from Workshop 1a, we went over the items the teachers brought with them. As the teachers pulled out the items they brought, their conversation quickly moved on to developing the lab activity and setting the deployment schedule for the student surveys. Relevant points from the ensuing conversation are included in the discussion below and in Chapter 7.

Activity choice

I anticipated that the PAR Team would choose to create a complementary process to the “ticker-tape” experiment (Figure 13) used to test the theoretical formulas for kinematics\(^8\), the study of acceleration, velocity and position. As I developed my research ideas prior to May 2015,

\[\text{Figure 13: Ticker tape apparatus for studying velocity and acceleration in Physics 11 classrooms ("Acceleration Timer," 2017).}\]

\(^8\) In physics, dynamics is the study of kinematics (position, velocity and acceleration) and kinetics (forces due to motion), concepts introduced in Physics 11 that are fundamental to mechanical engineering. Dynamics courses in engineering programs include only kinematics; courses in engineering mechanics cover kinetics.
I spoke with several individuals about their experiences in Physics 11. I spoke with my father who has been an engineer since 1965, my neighbour who is a medical office assistant and completed Physics 11 in the 1970s, and two of my children who completed Physics 11 in the 2000s. All used the ticker-tape apparatus for kinematics experiments and all were surprised at the longevity of its use. I theorized that focusing on this experiment would create an effective activity to achieve my research goals. With an interactive activity developed around this fundamental concept of mechanical engineering, students would learn how to apply physics in contexts to which they directly relate. In addition, student impressions of physics as old and unchanging with nothing new to learn could be dispelled by ceasing to use the same experiment that has been part of the curriculum for more than six decades.

I introduced my idea about modifying or augmenting the ticker-tape experiment in my presentation for Workshop 1a. During Workshop 1b, all teachers in the PAR Team expressed their support for using the ticker-tape experiments as a learning tool. However, as one SD61 teacher said, “the ticker tape is awesome but it’s so loud.” For this reason, three had already been looking for ways to modify the experiment, as voiced by the teacher from SD63: “I’m trying to avoid using ticker tape altogether this year.” The teachers from SD61 (the two teachers on the left in Figure 14) said they use ticker tape to measure the acceleration of a “plasma car” in which they send a student driver down the hallway and use more than 30m of ticker tape for each run. The SD63 teacher (centre in the image of Figure 14) redesigned the kinematics experiment to use position sensors for measuring students walking in the classroom.

Together, the PAR Team eventually compiled a list of formal and informal labs they expected to include in their teaching plans. The teachers defined “formal labs” as those that
require significant preparation outside of class to assemble the equipment, take one or two periods of in-class time to introduce the theoretical equations used for the data analysis, necessitate the collection of relatively precise data and include detailed analyses as part of the student laboratory report. “Informal labs”, on the other hand, leave more room for discovery, play and discussion, and typically wind up within one or two class periods. The team decided that this research activity should replace an informal lab. The time frame simplifies the activity and shortens the time removed from their normal teaching plans. In addition, all team members agreed upon the necessity of maintaining existing formal labs to allow students to practice the care required for collecting data during some types of laboratory experiments.

The teachers regularly went off-track in their conversations when they discussed laboratory apparatus that they use in the classroom, lesson ideas and student experiences (Figure 15). Many times the conversation disintegrated into laughter, other times the teachers would gather around a smart phone or computer to share a software application that one of them was trying out with their class. They would occasionally band together and attempt to convince me to change

Figure 14: PAR Team meeting at second workshop, during which the SD61 teacher describes the plasma car experiment. The teacher from SD62 is missing from this photo.
engineering terminology to that used by physicists. The workshops were filled with fun and camaraderie.

Activity design

The PAR Team identified several topics as good concepts to explore using the engineering design process and eventually decided that the informal friction lab would be the best setting for the research activity. None of the teachers brought sample lesson plans with them. As they said, each of them had so much experience teaching Physics 11 that they could lead classroom activities with minimal notes to remind them of their plans. After Workshop 1b, therefore, I crafted a flow-chart blending the teachers’ ideas with my proposed process for the activity. After many iterations of the work plan documents and several coaching conversations in person and via email about the facilitation process I hoped to test, the team decided that I should run the activity in their classrooms. They assured me that this was to ensure all students received

Figure 15: The PAR Team discussions on labs, apparatus and procedures often followed tangential paths into personal experiences.
consistent activity presentations. Later, however, they admitted that they had not fully understood the process I proposed they use until they witnessed my facilitation of the activity in their classrooms.

The greatest change proposed and eventually implemented relates to the activity process and how the facilitator presents the physics concept (Figure 16). In the existing paradigm, the PAR Team teachers introduce the theory of a new concept prior to running an experiment or discussing contextual applications of the theory. The experimental objective is to verify or support the theory. Teachers then encourage the students to extrapolate implementation contexts.

![Figure 16: Flipping the teaching paradigm. Original activity process (top) as compared to the flipped paradigm process proposed for physics classes (bottom).](image-url)
through discussions that follow the experiment. The focus of the student lab report is on theory, procedures, data collection and applying that data to the theoretical equations. Report conclusions recount how well the experiment matched the theory by expressing the experimental results as within a specific percent error from the expected theoretical result. This process is necessary for reinforcing the scientific method of theoretical proofs that students need to learn.

The new process flips this paradigm to begin with a discussion of context through which students identify potential experiment scenarios from their life experiences. The students then consider how the concept might be modified within their scenario. That is, the students look for a way to improve the current situation or produce a preferred state of the situation by changing a single parameter. This allows for the development of theoretical expressions during the experimental design and verification phase. The activity wraps up with reflections by the students’ on their individual and team learning. The report becomes a presentation of their ideas.
their experiment design, their expected outcomes and their findings, all related to the real life scenario with which they began.

In the new process, the teacher-facilitator guides the initial discussion, promoting student ideas to provide contextual examples from their life experiences. Once a few ideas have been generated, with guidance from the teacher, the students form small groups at lab tables. The small groups discuss their scenarios and select one to explore. They draw the scenario on a large paper and identify possible improvements to the scenario. Next, the students develop a verification experiment to test whether the changes they propose will result in the improvements they predict. Using materials available in the lab or classroom, the small groups design, sketch and build prototypes of their scenario, including some sort of changeable design feature to represent the two configurations they will test and compare. They run their experiment to attempt validation of their hypothesis, quantifying input data with measurable units, generating output data and including all descriptors necessary to distinguish the two scenarios in their data records.

![Image](image.png)

Figure 18: Sample student output. Step one, discuss and select scenario; two, draw scenario; three, create prototype for verification testing. Suitcase example including Student Guide, which this group followed closely.
They analyse the data as they conduct their test for timely verification that their experiment indeed tests what the team intended and to enable immediate changes to the experiment design, as necessary, recording each experiment revision and its purpose. The students report back to the teacher through discussion questions they complete on their scenario sketches, keeping their real-world context front and centre in their thoughts throughout the activity (Figure 18).

Through the experiment phase, the teachers endeavour to constrain their contributions to a purely supporting role, limiting their input to providing assistance in finding tools and materials to construct their prototypes, guidance on recording experimental data, advice on detailing or dimensioning sketches, and coaching the development of theoretical mathematical expressions that relate input to output measures. In this way, teachers maximize student engagement and the creation of physics knowledge that builds on what was learned in previous classes. The purpose of this method is to allow students to play with applying physics knowledge in new ways. The small groups report on their work by answering discussion questions designed to guide their reflection on both the process and the learning they acquired. In the final phase, which may occur in a following class period if the cohort needs more time during the session for their team work, the teacher facilitates a large-group discussion of the outcomes, generating relevant mathematical expressions to enable future theoretical applications. This discussion occurs in the larger group to reinforce shared knowledge creation.

The final lesson plan documentation used during this research is available in Appendix C. The Student Guide provides learners with problem statement examples and guiding questions rather than a specific set of instructions. Students receive the Student Guide when they move to their small groups, after the large group brainstorming session has identified some ideas from
students’ life experiences that could be used in the prototyping process (Figure 18). The Teacher Guide provides facilitators of learning with sample questions to support their facilitation role through the major phases of the activity: large group discussions and small team explorations.

**Implementation schedule**

Once the PAR Team decided on the in-class activity, we produced the implementation schedule, which necessarily relied on the course plans of all teachers. With a few minor last-

<table>
<thead>
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<th>Table 13</th>
<th>School Visit Dates: two surveys, one activity</th>
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<tr>
<td></td>
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</tr>
<tr>
<td></td>
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<td>SD61 activity (61-7)</td>
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<tr>
<td></td>
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<tr>
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<td>Independent activity</td>
</tr>
<tr>
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<td>SD61 activity (61-6, 61-7, 61-8)</td>
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<tr>
<td></td>
<td>SD61 survey 2 (61-6, 61-7)</td>
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<tr>
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<td></td>
<td>Independent activity</td>
</tr>
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<td></td>
<td>Independent survey 2</td>
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Table 13: Survey and activity implementation schedule developed by PAR Team. All post-activity survey deployments were completed within one week of the activity. For clarity, SD61 and SD63 are aligned left; SD62 and Independent, aligned right and italicized.
minute adjustments, we followed the schedule shown in Table 13. I attended the classrooms with a research assistant who monitored the video cameras during the activities.

My contact was unable to arrange a pilot survey deployment in his class, so we used the class from SD63 as an alternate to pilot both survey deployment and activity run-through. This was a good choice because the SD63 teacher taught only one class and he had scheduled the friction topic earlier in his term teaching plan than the other teachers had. The pilot deployment identified a few typographical errors and one instance of complex language that needed to be simplified; I made these changes for the remaining deployments. The final versions are found in Appendix C.

**May Workshop**

The final workshop provided an opportunity to debrief the teachers of the PAR Team by presenting the research program progress. Instead of deploying the teacher survey a second time, I interviewed the teachers to ascertain whether they experienced persisting differences in the way they taught physics and their perceptions of students' behaviour and their own in the classroom. The sample is too small to provide statistical significance for a quantitative analysis. Following the interviews, I gave a presentation on the project to students, administrators and faculty at Camosun College, Ministers of the BC Legislative Assembly, and interested members of the Victoria community. The workshop and presentation occurred at Camosun College, Interurban Campus, in Victoria, BC.

**Survey Design**

The survey instruments include specific and broad-based questions, which I describe in detail in this section. Some questions collect personal information such as demographic
questions on sex, family size and how long they lived in Victoria. Other questions probe the students’ life goals, their career path intentions and more nebulous aspects like confidence or sense of belonging. I address the nebulous concepts through a series of related questions such as comfort working with computers or whether they believe they are treated fairly in the classroom. In total, I asked 122 questions. The students completed the survey in an average of 20 minutes. This may appear to be a short time for each question but I encouraged students to note their first response and not ponder the statements very long. The shortest survey completion took approximately 15 minutes, the longest 30 minutes.

Students responded to questions asking about their understanding regarding the relevance of courses they were taking in high school to viable careers (questions 8 through 20) and if these careers would require further study in post-secondary school (questions 21 through 33) using a 5-point Likert scale that ranged from “very likely” to “very unlikely.” Students responded to questions asking how many years of further study they believed would be required in each of these career areas by indicating which of the following options were likely to be true: “0” years, “1-2”, “4-5”, “7+” or “unsure” (questions 34 through 46). I used generic course names as much as possible to capture the variety of titles given to courses in different schools. For example, the course “music” includes choir, orchestra, jazz band, or other variations on musical education that may be offered at some schools.

Limited question sets examine the students’ beliefs regarding destiny and control, self-efficacy in physics, alienation and independence, and their sense of belonging, expanding the study to enable correlations between perceptions. It is proposed that these aspects, when considered in the context of the physics classroom, will predict the student’s interest in pursuing
a career that applies physics. Students completed the question set for each aspect by indicating their response using a 5-point Likert scale ranging from “strongly disagree” to “strongly agree.”

These questions were derived from the Saskatchewan Youth Attitudes Survey (Schissel, n.d.) and the Perceptions on Gambling Survey (Schissel & Dickinson, n.d.), both written for deployment with high school students. The questions on self-efficacy were further developed using Albert Bandura’s Guide for Constructing Self-Efficacy Scales (2006).

**Destiny and Control**

The 24-item assessment of destiny and control explores the students’ intentionality in participating in physics (Laïdi, 1998). Pragmatism and realism may be relevant factors in the decisions students make about pursuing engineering and may emerge as a desire to make a positive difference in the world (Levin et al., 2005; Pomerantz et al., 2013).

**Self-Efficacy in Physics**

The 11-item assessment of self-efficacy explores the students’ confidence in and comfort with operating analytical tools typically used when applying physics through engineering. Some studies suggest that women have lower self-efficacy in traditional male occupations because they lack spatial representational skills (Blickenstaff, 2005; Ceci & Williams, 2010; Oswald, 2008). Others suggest the relevance of technological capabilities (Besterfield-Sacre, Atman, & Shuman, 1997). This assessment further probes the students’ beliefs in overcoming challenges related to physics education by using “can” statements instead of “would” statements (indicators of preference or choice).
Alienation and Independence

Studies indicate that women who are successful believe that they have good connections to the existing social system, be it school or the workplace (Corbett & Hill, 2015; Mujawamariya & Hamdan, 2013). This 27-item assessment begins with statements relating to the students’ beliefs about their connections in the community and at home, moves on to statements relating to their connection to school in general and ends with statements relating directly to their connections in the physics classroom. The intention of these three layers is to isolate any feelings of alienation and independence related to the physics classroom from the other, broader systems.

Belonging

Eight questions probe the respondent’s social network. These quantitative questions ask how many friends the student has, if they belong to any community groups and if they are satisfied with their family and social life. Similar to exploring the impact of alienation, these statements probe the students’ perceptions of their social connection as a sense of belonging instead of a sense of isolation. Responses to these statements may be found to inform the discourse on how belonging may or may not reduce stereotype threat and empower women to perform better in the classroom and workplace (Arvidson, 2014; Sunny, Taasoobshirazi, Clark, & Marchand, 2017; Swirsky & Angelone, 2015).

These personal perception questions directly address the research goals. The questions that relate to the students’ beliefs about their sense of alienation, belonging and efficacy in physics probe more deeply into social factors that theoretically influence students’ perceptions about stereotypically gendered careers, as discussed earlier. I took the opportunity of presenting a survey that explores a broader range of questions than I could possibly address within a doctoral
project. Although I assess some of these factors, others more appropriately provide an opportunity for future analysis into the complex diversity challenge facing the engineering profession and others.

Chapter Conclusions

Prior to working with Physics 11 teachers and students in the Greater Victoria region, I completed extensive preparations including the detailed ethics clearance application required by the Canadian Tri-Council for Research Ethics. The research institution quickly granted provisional clearance for this doctoral project, enabling a prompt search for participants on the teacher PAR Team. Timelines for ethics approval from the school districts varied significantly and almost excluded some teachers from the project.

The PAR Team modified the research plan by splitting the first workshop into a series of two afternoons, delivered one week apart. The first week’s workshop reviewed the information presented in earlier chapters of this dissertation including the literature survey on feminist influences on curriculum in British Columbia and findings from studies in Physics 11 classrooms that identify and describe girls’ experiences and their perceptions about the relevance of careers that apply physics. The second week’s workshop segment focused on generating the research activity lesson methods for a selected physics laboratory experiment.

The lesson plan also underwent several revisions up to and including the session during which I delivered the pilot activity in the SD63 classroom. This first in-class trial led to the PAR Team’s decision to shift the activity facilitation from the teachers to the researcher. Overtly, this would ensure consistent delivery for all student participants. In addition, the teachers were
concerned at their level of comprehension of the teaching methods proposed, which they indicated became clearer after witnessing the process in their classrooms.

The survey recorded the beliefs and perceptions of the students prior to and within a week following the in-class activity. The questions addressed personal information and many aspects of behaviour evaluation, more than will be analysed in this dissertation. The next chapter presents the analysis of the survey data. I test hypotheses that relate to the theories discussed in Chapter 4. In addition to recording quantitative data from the survey instruments, I collected qualitative information through the use of video recordings and notes. The qualitative information and thematic analysis are presented in Chapter 7 together with interpretations of the quantitative results.
Chapter 6 – Research Data

The research data results provide insight into the challenges facing the engineering community in their efforts to recruit and retain more women in the engineering pipeline. The youth survey (Appendix A) probes the sample population’s beliefs and perceptions about a broad variety of factors. Pragmatic questions address beliefs about the possibility of physics and other courses leading to viable careers and their understanding of the number of years of education required for such careers. These early questions enable the students to consider all courses they take at high school in a logical manner. Other questions probe beliefs about more nebulous concepts such as control over one’s future or perceptions about one’s connectedness to their community. Exploring the social motivations of young women in high school physics may help in diagnosing the low transition rates of women into engineering education and careers.

The preliminary quantitative analyses contained in this chapter test several hypotheses about the validity of destiny and control, self-efficacy in physics, alienation and independence, and belonging as predictors of educational pursuits in a fundamental manner. The analyses examine two cases: potential differences in male or female student responses collected before and after the implementation of the PAR Team’s in-class activity, and differences comparing male and female student responses within each survey deployment (before or after the activity). The original research plan included a near term longitudinal analysis using an online survey deployment three months after the research activity. Unfortunately, the low response rate rendered this dataset ineffectual. The hypotheses help focus on the research questions throughout this presentation and interpretation (Chapter 7) of the quantitative data. The survey
collected much more information than necessary for this dissertation: some information will inform future analyses and comparisons with other research populations.

This chapter begins with a set of major hypotheses that test the research questions. The remainder of the chapter presents data comparisons through cross tabulations. The cross tabulations each test a minor null-hypothesis that differences in the compared data sets are solely due to chance. Rejections of the null hypotheses indicate that the data differences are probably statistically significant and may be generalizable to the broader population with a defined probability. The interpretation of these results, description of the differences, formal testing of the major hypotheses and research conclusions comprise the bulk of Chapter 7.

**Major hypotheses**

It is proposed that the in-class activity will result in changes to the students’ interest in pursuing engineering education due to changes in several social factors. The theories discussed in Chapter 4 lead to the development of several hypotheses for which the survey data are assessed.

**Hypothesis 1, H₁ – educational aspirations**

It is proposed that in alignment with social cognitive theory, the in-class activity will demonstrate the value and social relevance of engineering as a possible career pathway resulting in an increase to the weighting of the educational goal, Question 1d.

**Hypothesis 2, H₂ – interest in physics**

It is proposed that in alignment with social cognitive theory, the in-class activity will demonstrate the value and social relevance of applying physics as a possible career pathway, resulting in an increase to the respondents’ interest in physics, Question 7d.
Hypothesis 3, H₃ – perceived value of physics

It is proposed that in alignment with social cognitive theory, the in-class activity will demonstrate the value and social relevance of applying physics as a possible career pathway, resulting in an increase to the weighting of physics as a relevant course, Question 11.

Hypothesis 4, H₄ – control

It is proposed that in alignment with the theory of precluded interest, the in-class activity will demonstrate the value and social relevance of applying physics as a possible career pathway, resulting in an increase to the factor of control, Questions 47-61.

Hypothesis 5, H₅ – destiny

It is proposed that in alignment with social cognitive theory, the in-class activity will demonstrate the value and social relevance of applying physics as a possible career pathway, resulting in an increase to the factor of destiny, Questions 62-70.

Hypothesis 6, H₆ – self-efficacy

It is proposed that in alignment with social cognitive theory, the in-class activity will demonstrate the ease of applying physics to real world problems, resulting in an increase in the factor of self-efficacy, Questions 71-81.

Hypothesis 7, H₇ – alienation & independence at home

It is proposed that in alignment with the theory of social cognitive theory and the theory of precluded interest, the in-class group-based activity will demonstrate the value and social relevance of teamwork in applications of physics, resulting in a decrease to the factor of alienation in their home life, Questions 82-91.
Hypothesis 8, $H_8$ – alienation & independence at school

It is proposed that in alignment with intersectional theory, social cognitive theory and the theory of precluded interest, the in-class group-based activity will demonstrate the value and social relevance of teamwork in applications of physics, resulting in a decrease to the factor of alienation in their school life, Questions 92-99.

Hypothesis 9, $H_9$ – alienation & independence in the physics classroom

It is proposed that in alignment with intersectional theory, the in-class group-based activity will demonstrate the value and social relevance of teamwork in applications of physics, resulting in a decrease to the factor of alienation in their school life, Questions 100-108.

Hypothesis 10, $H_{10}$ – belonging

It is proposed that in alignment with intersectional theory, the in-class group-based activity will demonstrate the value and social relevance of teamwork in applications of physics, resulting in a decrease to the factor of alienation in their school life, Questions 109-108.

Survey results

Multiple qualitative variables from survey data can be used to predict dependent values or output variables. Typically, the independent variables must be recoded into ratio or numerical variables, with non-answers and extraneous data removed from the analysis. Fortunately, the software combination I employed eliminated most sources of error by automatically recoding most variables into the appropriate format and assigning missing variables accordingly. I used Fluid Surveys, a secure web-based survey package licensed to Camosun College, to collate the paper-based survey data, and SPSS, statistical software licensed to Royal Roads University, to conduct the data analyses.
Two variables required recoding before any analysis could proceed: Sex and Deployment. The sex variable required recoding to collapse all non-binary responses into the system missing variable. Therefore I recoded female to “0”, male to “1” and all other responses combined with the missing values as “system missing.” Similarly, I recoded the deployment variable to “1” as “Pre-Activity”, “2” as “Post-Activity” and “3” as “Online”, with all other responses recoded with “system missing.”

The next step in the data analysis identifies where relationships exist between variable pairs, following any necessary recoding, through the cross tabulation of all variables. The process determines the influence of each independent variable on the dependent recoded variable. In order to segregate each set of surveys, I began by splitting the data file by deployment: pre-activity, post-activity and online. In this way, I could identify differences in responses in the sample between males and females. The full output file of cross tabulations between sex and each parameter for the dataset split by deployment, and the corresponding bar chart graphs, can be found in Appendix D.

Following the split by deployment, I split the file by sex and ran similar cross tabulations on all data points with respect to deployment. In this way, I could compare pre- and post-activity responses by female students separately from male students. I attempted to test the long-term persistence of any significant change by using the online third survey deployment responses. In all cases, I used the initial cross tabulation tables and charts as a visual scan of the split dataset, looking for obvious differences in the response data. Although I included multiple-choice parameters in this initial scan, these data points cannot be appropriately assessed or analyzed in either data split without some sort or combination to consolidate and present the selections. I
include these combinations or consolidations in the discussion below. The full output file of cross tabulations between deployment and all parameters for the dataset split by sex, and the corresponding bar chart graphs, can be found in Appendix E.

In this results chapter, I walk through all survey question sets, identifying variables that demonstrate potentially significant variations between male and female responses. I assess these questions more closely by running significance tests to determine whether the differences are likely to be the result of chance. In this way, I identify two aspects of potential differences, one between male and female student responses within a deployment and the second between deployments for each of the two genders. It is important to restate here that the number of students who did not identify as male or female were too few to provide statistically significant results within this sample population. Therefore results can only be presented for students who self-identified as male or female.

I began the statistical analysis and data presentation with the variables related to self-efficacy in physics, questions 71 through 81. I was most interested in these results as I anticipated they would most closely relate to this research experience. For this first group of variables, I analysed all questions regardless of any apparent significance of differences indicated by the first set of cross tabulations. I discovered patterns that allowed later analyses to focus on only those variables that indicated the potential for significant relationships in the first series of cross-tabulations. While I present the full set of all data in the related Appendices, I only discuss those variables that appear to indicate significant relationships.
Sample population details

Overall the sample sizes pre- and post-activity were very similar. The pre-activity survey sample consisted of 250 respondents of which 21 were missing data (did not self-identify as male or female) leaving a total of 229 valid units. The pre-activity sample population was 53.7% female. The post-activity sample consisted of 224 individual responses of which 6 were missing data leaving a total of 218 units. The post-activity sample population was 51.8% female. The online deployment resulted in 71 responses of which 23 were missing data leaving 48 valid unit. The online sample population was 62.5% female.

Question 1: Top goals

The first survey question asked respondents to indicate their top three life goals from a list of 11 options, including an “other” choice in case the list was incomplete from their perspective (Figure 19). As shown, the respondents were to enter a “1”, “2”, or “3” beside their first, second and third most important goals. Some students misunderstood the instructions and simply entered a check mark beside their goals. This type of mark resulted in a missing response. If the respondent entered “a”, “b” or “c”, the “a” was converted to a “1”, the “b” to a “2” and the “c” to a “3.” The text entries were thereby recoded to numerical value as follows: the first choice

![Figure 19: Survey question options regarding primary goals in life](image-url)
received a value of 3, the second choice received a value of 2, the third choice received a value of 1, and the rest of the options that were not chosen as first, second or third goal received a value of 0. In this way, if a student ranked all goals, only the first, second and third received a non-zero value. Each goal option is then subjected to a simple sum in order to rank the goals for the full sample population. I ranked the goals in the graphs from highest to lowest based on the female students’ post-activity responses (Figure 20).

I asked this question to ascertain in particular whether the students have an identified preference for further education as a future aspiration or goal and whether this preference changes after the in-class experiment is complete. The most apparent change in goals as indicated in the survey responses is the decrease in female respondents’ focus on family and increase in their goal for more education.

![Goals & Aspirations - Female Students](image1.png)

![Goals & Aspirations - Male Students](image2.png)

Figure 20: Goals and aspirations of female and male students before and after the activity. The length of the bars give the relative weight of the goal, with first choices holding a count of “3”, second “2”, third “1”, remaining “0.” The relatively short length of the online deployment reflects the small number of respondents (online surveys = ⅕ paper surveys).
The male responses appear to fluctuate by smaller amounts than the female responses. It is important to note that while 106 females completed the pre-activity survey and 105 completed the post-activity survey, the number of male respondents decreased from 123 pre-activity to 113 post-activity. This accounts for the overall decrease in responses apparent in the figures.

The online responses were low, with 18 female and 30 male respondents. These numbers are too small to draw significant information about persistence in any changes to student goals due to the in-class activity by sex. From all deployments, male and female respondents indicated their most important goals are general happiness, having a family and being successful. Male students place more value on money and material possessions than their female counterparts and, as previously mentioned, increased their perceptions of setting education as one of their top three goals after the activity. Money and material possessions seemed to reduce in appeal following the activity. The online responses trend similarly, however the sample is too small to statistically test its significance in this deployment.

Respondents indicate their selections for Question 1 by choosing their top three goals from a list of options. As a multi-select question, the cross tabulations on the split dataset resulted in cells containing frequency counts of less than 5 units. Graphical representations of the data portray an interesting apparent increase in the choices of Success, Happiness and Family as top goals, however the low frequency counts eliminate this data set’s usefulness as a predictor of influence in its current form.
Female responses compared: pre- and post-activity

The top goals and aspirations of female students changed following the research activity, as can be tested with the dataset split by sex. Cross tabulations between deployment and each goal question in all cases but one resulted in four degrees of freedom, df=4, and Pearson Chi-Square values lower than the required value for four degrees of freedom of 5.39 (\( \alpha =0.25 \)), failing to reject the null hypothesis (\( \alpha =0.25 \)) with no relationship shown to exist between pre and post survey responses to the priority of career or personal goals and any apparent differences being the result of chance. In the one goal cross tabulation that resulted with a Chi-Square value of 5.449, question 1h (the goal “To help others”), four cells contained fewer than five units rendering the Chi-Square analysis unstable. Recoding to combine all cells that contained fewer than five units required combining all responses into one single variable, which became uninformative. Therefore, any apparent relationship or difference between female student responses to each individual goal before and after the activity or between male student responses to the same is due to chance.

Questions 2-6: Future activities likelihood

Four questions explored the students’ beliefs regarding the likelihood of achieving their goals within the near future. These questions related to their ideal job, whether they thought they could get their desired type of job, whether they would get more education and whether they thought they might marry or have a family.
**Question 2 – Job preference**

Students overwhelmingly responded to question 2 with preference for a professional job in 5-10 years. In total, 54.6% of the population selected the professional job option prior to participating in the activity. Within this population, 62.6% of female respondents and 45.2% of male respondents selected this choice. A similar percentage of the population, 53.8%, selected this type of job as their preference in the post-activity survey. However, this comprises an increase to 70% of female respondents compared with a decrease to 44% of male respondents.

Analysing this question more closely with the dataset split by sex isolates pre- and post-activity beliefs and perceptions about career preferences for each sex group. However, the analysis fails to predict differences in student selections following the research activity are other than due to chance (Figure 21).

![Figure 21: Student responses to Question 2 demonstrating the overwhelming preference for a professional occupation in 5-10 years for both male and female students. The ranking is unchanged by the research activity.](image-url)
Question 3 – Likelihood of getting desired job

Interestingly, the student responses to question 3, “How likely is it that you will be able to get [your desired] job?”, exhibited apparently significant differences in beliefs about the likelihood of achieving their career goals before and after experiencing the activity. On the dataset split by deployment, the cross tabulation of sex against question 3 resulted in two cells containing fewer than five units. Therefore, I recoded question 3 to combine the responses of “not likely” with “possibly.” In the pre-activity deployment, the cross tabulation resulted in two degrees of freedom, df=2, and a Pearson Chi-Square value of $X^2=0.338$, well below the required values for two degrees of freedom of 9.21 ($\alpha=0.01$) or 5.99 for ($\alpha=0.05$), which fails to reject the null hypothesis that differences between female and male responses are significant.

However, in the post-activity deployment, the test resulted in df=2 and a Pearson Chi-Square value of $X^2=7.150$, higher than the required value for two degrees of freedom of 5.99 for ($\alpha=0.05$), rejecting the null hypothesis ($\alpha=0.05$) with a relationship now shown to exist. Figure 22 shows the distributions for male and female responses to the surveys deployed pre- and post-activity with a significant difference between sexes in the post-activity results.

A direct comparison of female responses before and after the activity confirms the significance. On the data file split by sex, cross tabulations of deployment against the recoded question 3 variable resulted in two degrees of freedom, df=2, and a Pearson Chi-Square value of $X^2=4.736$, higher than the required value for two degrees of freedom of 4.61 ($\alpha=0.10$), which rejects the null hypothesis ($\alpha=0.10$) with a relationship shown to exist and differences are not due to chance (Figure 23).
Question 4 – Likelihood of more education

The graph of responses to question 4 regarding the likelihood of getting more education is skewed, indicating that students more often indicated they believe that it is likely or very likely they will get more education. The sex cross tabulation against Likelihood of Getting More Education resulted in three degrees of freedom, df=3, and a Pearson Chi-Square value of

![Graph of cross-tabulated data of sex with "Likely to get desired job." The pre- and post-activity survey deployments indicate a difference in student respondent perceptions about the likelihood of achieving their desired type of job.](image1)

![Direct comparison of female respondents results indicating a significant difference between pre- and post-activity beliefs about likelihood of getting their desired job. Females responded with an increase in likelihood.](image2)
The Chi-Square test was unstable as originally conducted because one cell contained less than 5 units. Therefore, I recoded the variable to combine “not likely” with “possibly”, resulting in a stable Chi-Square test. The sex variable cross tabulated against the recoded Likelihood of Getting More Education variable resulted in two degrees of freedom, df=2, and a Pearson Chi-Square value of $X^2=1.442$. The required Chi-Square value for two degrees of freedom is 2.77 ($\alpha = 0.25$), therefore the recoded variable also fails to reject the null hypothesis and any differences between these variables is likely due to chance. The analysis of question 4 responses in the pre-activity split dataset mirrors that for the post-activity split of the dataset with a Chi-Square value of $X^2=1.484$.

The online deployment analysis of question 4 seemed promising as an indicator of long-term change in student perceptions with a Chi-Square value of $X^2=6.288$, however four cells contained less than 4 units. This rendered the Chi-Square test unstable. Recoding of this variable is unrealistic because it requires a complete recombination of the split dataset.

All cross tabulations of deployment against question 4 on the dataset split by sex resulted in Chi-Square values too low to indicate that differences are anything other than chance.

Questions 5-6 – Likelihood of marrying and/or having family

Question 5 and question 6, which ask for responses about the likelihood of getting married and having a family one day, both have cells with fewer than 5 units. I recoded these variables in the same way as for earlier questions by combining the “not likely” and “possibly” responses. Although the post-activity response set for the family related question 6 rendered a stable Chi-Square test with $X^2=7.509$, the pre-activity cross tabulation for both questions and the post-
activity for question 5 all fail to reject the null hypothesis that male and female responses are due to chance. I do not identify a research hypothesis related to this parameter but the change in the likelihood of marriage opinion warrants further investigation beyond this dissertation.

**Correlation and regression analysis**

The correlation analysis of questions 2 through 6 for the full sample dataset split by deployment responses indicate relationships as shown (Figure 24). Correlation analysis indicates how tightly the data are scattered when plotting one variable with respect to the other. In social science, the expectation is high that data will be scattered unlike engineering materials data that tightly adhere to linear or curvilinear relationships. Strong correlations indicate that the data are tightly scattered around the linear regression line and give a good indication of the predictability of those variables. The moderate to weak correlations are less reliable as predictor variables although still indicate positive relationships.

Figure 24: Correlation analysis, pre- and post-activity. Numbers in bold indicate weak to high correlations between the gray variables for the full sample population.
The highlighted numbers indicate weak to moderate correlations. According to the guidelines of Tolmie, McAteer and Muijs (2011b), the correlations between education and marriage, and education and having a family are weak relationships with between 21.8% and 22.9% correlation at the 0.01 level. The correlations increased in strength after the activity to 23.2% and 28.5%. Similarly, the correlation between marriage and having a family are consistently strong relationships, rising from the pre-activity 82.1% to post-activity 83.4% correlation at the 0.01 level. Of particular interest is the increase in strength of the relationship between education and getting a job, a weak correlation prior to the activity with 28.6% at the 0.01 level becoming a moderate 41.8% correlation at the 0.01 level.

Question 7 – Favourite courses

Students responded to the question about their six favourite courses or areas of study in high school by indicating their preference using the numbers 1 through 6. I identified several course groupings using generic titles intended to capture related courses. This resulted in some confusion as students appeared to look for specific course titles; if they could not find a specific course, they added that course in the “other” category. Some of the identified “other” courses fall into the defined course groups. For example, “dance” should have been included in the “physical studies (P.E., team sports, kinesiology, etc.)” category. Others were clearly unrelated to the existing categories, such as “cultural studies” or “leadership.” Although over 100 students added a course in the “other” text box, only 20 students selected the “other” course as one of their top six favourite courses.
I recoded the favourite course variables into one weighted categorical variable. I gave first choices of courses a weighting factor of 6, second choices 5, third choices 4, fourth choices 3, fifth choices 2 and sixth choices 1, with all other course choices receiving a weighting of zero. Figure 25 depicts this data for male and female respondents before and after the activity, sorted in order of female highest choices. Sorting aids with the data interpretation and comparison, therefore I produced similar graphs sorted for male highest choices (Appendix F). All students in all cases selected Mathematics as their favourite course. Physics was the second favourite for male respondents pre- and post-activity, while language was the second favourite for female respondents pre- and post-activity. This data confirms the social expectation that male respondents would identify physics as one of their favourite courses (Ivie & Ray, 2005; Kelly, 1985).

**Thematic comparisons – cross tabulations**

The next hundred questions, numbers 8 through 108, ask respondents to indicate their agreement with statements using five-point Likert-type scales. This data are well-suited for

![Figure 25: Favourite courses, sorted by female preferences before and after the in-class activity. For comparison graphs and tabular listing, see Appendix F.](image-url)
statistical analysis through direct comparisons. Cross tabulations on a strategic split of the dataset give good indications of any statistically significant differences between male and female responses before and after the activity. The Pearson Chi-Square analysis identifies whether relationships exist or not between the two sets or whether they are essentially the same and any resulting differences occur simply due to chance. The summary of the correlation analysis can be found in Appendix O. The majority of the results indicate no statistically significant differences between male and female responses except in responses in the next sections, which exhibit significant differences not due to chance and may be used to predict differences in the broader population.

**Questions 8-46 – careers leading from courses**

I ran cross tabulations on the 38 questions that invite students to indicate their beliefs about whether courses lead to promising careers, whether post-secondary education is required for these careers and, if so, how many years would be required for these pursuits. Appendix D includes a complete listing of the cross tabulations and Appendix O includes the results of the analysis. No variables indicate statistically significant differences between male and female responses within the survey deployments except for one pre-activity response and seven post-activity student responses to whether courses in art lead to promising careers or require post-secondary education. Pre-activity survey numbers indicate little difference in the beliefs and perceptions of male and female students in Physics 11 classes about the amount of education required in the pursuit of careers related to high school courses in social science. Pre-activity survey numbers indicate little difference in the beliefs and perceptions of male and female
students in Physics 11 classes about the amount of education required in the pursuit of careers related to high school courses in finance, however female student responses did change with an increase in their perception that finance leads to a promising career.

**Questions 47-70 – destiny & control**

Student responses to questions about destiny and control changed following the research activity. Male and female students gave statistically different responses for several of the variables in this section either before the activity or after. The first set of fifteen questions relate to student beliefs about destiny and control. The second set of nine questions relate to student perceptions about destiny and control. Appendix G includes four summary tables of the Chi-Square results for all variables that indicate changes or differences when comparing male and female respondents or comparing pre- and post-activity responses.

In the first set of questions, relationships exist between male and female responses to four variables prior to the research activity but not after. Conversely, for male and female responses to four different variables, relationships exist after the activity but not before. For all other variables in this section, responses to the pre-activity and post-activity survey questions on destiny and control resulted in Chi-Square values below the required value for the degrees of freedom, indicating that any differences in responses are due to chance. Appendix G also contains the full listing of the SPSS generated cross tabulations for both dataset splits.

**Beliefs of destiny & control**

In all cases, statistically significant differences between male and female responses that arose in the data collected prior to the research activity ceased to exist after the research activity.
In one case, however, an apparently significant difference in post-activity survey results required a recoding that incidentally resulted in a statistically significant difference in the pre-activity data. In other words, the results from question 56 did not result in significance and did not prompt a recoding of the variable until I assessed the post-survey data. I discuss this variable in the next sub-section. I summarize all significant pre- and post-activity survey data comparisons described in the following two subsections in Table G-1 in Appendix G (too large to insert into the body of the dissertation).

**Post-activity male-female differences in responses**

In all cases but one, statistically significant differences between male and female responses to the survey deployed after the research activity did not exist prior to the research activity. Through this Chi-Square and recoding exercise, I discovered one case, question 56, for which differences also exist before the activity; this was determined to be true only with the recoded variable.

**Female pre- to post-activity changes in responses**

The initial analysis using the data set split by deployment revealed several cases of variables for which male and female responses differed. I subsequently split the data set by sex to assess variations between responses before and after the activity for male and female students. Cross tabulations for the data set split by sex between deployments and each belief of destiny and control variable identified several cases for which female students’ responses appeared to change following the activity. In five cases, the small number of units in some cells rendered the
Chi-Square analysis unstable. Therefore, I recoded these variables to combine the most infrequently indicated responses with their next closest response (Table G-2 in Appendix G).

**Male pre- to post-activity changes in responses**

Although this research project proposes to influence changes in girls perceptions and beliefs, it is interesting to explore potential changes to the perceptions and beliefs of male students who participate in activities designed to address barriers facing girls on socially masculine pathways. Changes to male respondents’ beliefs of destiny and control persisted in three variables following the recoding necessary to produce stable Chi-Square analyses. One additional variable demonstrating a difference in responses did not required recoding.

**Perceptions of destiny & control**

Student responded to the eight questions about their perceptions of destiny and control. The analysis of this data indicates little or no difference between male and female responses before or after the activity for all but three questions. Two of these differences no longer exist after the research activity (Table G-3 in Appendix G, presented here as Table 14 as a sample).

**Female pre- to post-activity changes in responses**

As apparent with the variables relating to beliefs of destiny and control, the initial analysis on the data set split by deployment appeared to identify several variables within the perceptions of destiny and control section for which female students’ responses changed following the activity. Appendix G also contains the full listing of the cross tabulations with deployment of this series of questions on the dataset split by sex. However, in each case, the number of units in some cells was fewer than five, which rendered the Chi-Square analysis unstable. Therefore, I
recoded those variables to combine the most infrequently indicated responses with their next closest response (Table G-4 in Appendix G).

Only one variable remained statistically significant as an indicator of a change in female student perceptions from their original responses after the research activity: question 62, “Many of the unhappy things in people’s lives are partly due to bad luck.” Prior to recoding, the cross tabulation between deployment and this variable resulted in four degrees of freedom, df=4, and a Pearson Chi-Square value of \(X^2=7.528\), higher than the required value for four degrees of

Table G-3: Destiny & Control Perceptions

<table>
<thead>
<tr>
<th>Deploy</th>
<th>Q#</th>
<th>Variable</th>
<th>(X^2)-Value</th>
<th>Degrees of Freedom</th>
<th>Required (X^2) (\alpha=0.005)</th>
<th>Required (X^2) (\alpha=0.01)</th>
<th>Required (X^2) (\alpha=0.025)</th>
<th>Required (X^2) (\alpha=0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>63*</td>
<td>There will always be wars, no matter how hard people try to prevent them.</td>
<td>24.497</td>
<td>4</td>
<td>14.860</td>
<td>13.280</td>
<td>11.143</td>
<td>9.490</td>
</tr>
<tr>
<td>Pre</td>
<td>66*</td>
<td>I have often found that what is going to happen will happen no matter what.</td>
<td>21.202</td>
<td>4</td>
<td>14.860</td>
<td>13.280</td>
<td>11.143</td>
<td>9.490</td>
</tr>
<tr>
<td>Pre</td>
<td>67*</td>
<td>This world is run by the few people in power, and there is not much the little person can do about it.</td>
<td>10.760</td>
<td>4</td>
<td>14.860</td>
<td>13.280</td>
<td>11.143</td>
<td>9.490</td>
</tr>
<tr>
<td>Post</td>
<td>66*</td>
<td>I have often found that what is going to happen will happen no matter what.</td>
<td>12.939</td>
<td>4</td>
<td>14.860</td>
<td>13.280</td>
<td>11.143</td>
<td>9.490</td>
</tr>
</tbody>
</table>

*recoding required due to small numbers of units in individual cells.

Table 14: Beliefs about destiny and control. From Appendix G, here for reference only as it is relatively small. All other tables from Appendix G are too large to present in the body of this dissertation. Pearson Chi-Square analysis indicates differences between beliefs of male and female
freedom of 5.39 (α =0.25), rejecting the null hypothesis (α =0.25) with a trend shown to exist. However, two cells contained fewer than five units rendering the Chi-Square analysis unstable. Therefore, I recoded the variable to combine the “agree” and “strongly agree” responses as “agree or strongly agree.” The cross tabulation between sex and this new recoded change variable resulted in three degrees of freedom, df=3, and a Pearson Chi-Square value of $X^2=4.462$, higher than the required value for three degrees of freedom of 4.11 (α =0.25), rejecting the null hypothesis (α =0.25) and indicating a weak relationship exists. This weak relationship suggests a trend in this data that needs further investigation.

**Male pre- to post-activity changes in responses**

Changes to male respondents’ perceptions of destiny and control in three variables persisted following the recoding necessary to produce stable Chi-Square analyses. One variable did not required recoding.

**Questions 71-81 – self-efficacy in physics**

Eleven survey questions relate to the students’ self-efficacy in physics. Cross tabulations between these variables and sex, based on the dataset split by deployment, produced significant results when comparing male and female responses before and after the research activity. I include factor analyses on these variables in the interpretation section of this dissertation. Cross tabulations between these variables and deployment on the dataset split by sex produced low to medium significance for female responses and medium to high significance for male responses.
Pre- and post-activity male-female differences in responses

The majority of cross tabulations between the sex variable and each physics self-efficacy variable resulted in four degrees of freedom, df=4, and Pearson Chi-Square values higher than that required for four degrees of freedom at $\alpha=0.01$ or $\alpha=0.05$. Ten of the eleven variables required recoding because the cross tabulations resulted in at least one cell containing fewer than five units, rendering the Chi-Square analysis unstable. Seven of the eleven variables required a single level of recoding in which I combined the “disagree” and “strongly disagree” responses as “disagree.” Two of the other three variables, questions 73 and 76 (“I enjoy learning new things in physics” and “I feel comfortable in the physics classroom/laboratory”), required a second level of recoding in which I combined “disagree”, “strongly disagree” and “undecided” responses as “disagree or undecided.” The last variable, question 79 (“I am confident I can use computer software to solve problems”), required a second level of recoding in which I combined “disagree” and “strongly disagree” responses as “disagree”, and “agree” and “strongly agree” responses as “agree.” In all cases, the recoding strengthened the relationship between the variables such that the Chi-Square analysis of ten of the eleven pre-activity variables and eight of the post-activity variables rejected the null hypothesis, exhibiting relationships or trends exist ($\alpha=0.01$ or $\alpha=0.05$ or, in one case, $\alpha=0.25$). Appendix H contains summary tables of the Pearson Chi-Square results and the full set of output data for the physics self-efficacy cross tabulations as acquired using SPSS.
Female pre- to post-activity changes in responses

Of the eleven variables in the physics self-efficacy group, only three variables resulted in statistically significant differences in female response before and after the research activity. These variables all presented Pearson Chi-Square values higher than that required for four degrees of freedom at $\alpha=0.25$, but required recoding because cells contained fewer than five units, rendering the Chi-Square analysis unstable.

Male pre- to post-activity changes in responses

Three variables also resulted in statistically significant differences for male responses before and after the research activity, with an additional variable apparently indicating a statistical difference that disappeared following recoding. Prior to recoding, three variables indicated possibly significant differences at $\alpha=0.25$ and one at $\alpha=0.10$. Cross tabulations with the recoded variables resulted in the elimination of one possible significance and changing the level of significance of two others.

Questions 82-108 – alienation and independence

The alienation and independence variables address three realms or circles of student social interactions: within their home or family community, within the broader school community or within the physics classroom. Appendix I contains a summary of the Pearson Chi-Square values for the variable discussed below. I also include the full output series of cross tabulations between sex and each variable in the three sets that relate to alienation and independence. Many of the cross tabulations resulted in low Chi-Square values indicating that any differences between male and female responses to the majority of questions were due to chance.
Community

Of the eleven questions relating to a sense of alienation or independence with respect to the student’s family or community, differences between male and female responses exist in some pre-activity variables. No differences exist between male and female responses to the post-activity survey (Appendix I, Table I-1).

School

Of the eight questions relating to a sense of alienation or independence with respect to the school community, no differences exist between male and female responses to the pre-activity variables. However, a single difference appeared to exist in the post-activity responses to question 97, “feel safe to speak my opinion in the classroom.” Recoding the variable rendered the analysis stable but eliminated the statistical significance.

No significant differences exist within the male responses to this set of questions.

Physics class

Of the nine questions relating to a sense of alienation or independence with respect to the school community, one difference exists between male and female responses to the pre-activity variables. The difference exists in the pre-activity responses to question 101, “My physics teacher will help me if I need it.” In the post-activity responses, four questions indicated the possibility of differences existing between male and female responses that are not due to chance.

Questions 109-114 – Belonging and satisfaction

The penultimate survey section relates to the students’ sense of belonging and consists of eight questions that ask how many confidants students have, how many close friends and
whether they are satisfied with their social life, family life and experiences at school. The population of female students who responded to the pre-activity survey consisted of 123 individuals of whom 94.3% indicated they have “someone [they] can confide in and discuss [their] problems with” (survey question 109, Appendix A). The population of male students pre-activity consisted of 106 individuals of whom 89.5% indicated they have access to confidants. The population mean for 250 pre-activity responses produced a mean number of 1.9 confidants with a 1.414 standard deviation and for 224 post-activity responses produced a mean number of 2.03 confidants with a standard deviation of 1.401 (Appendix G). Female pre-activity responses produced a mean of 2.28 confidants with a standard deviation of 1.296, post-activity produced a mean of 2.26 with a standard deviation of 1.394. Male pre-activity responses produced a mean of 1.82 confidants with a standard deviation of 1.386, post-activity produced a mean of 1.87 with a standard deviation of 1.366 (Appendix J).

All students claimed on average between three and four close friends. The histograms in Appendix J illustrate the responses of female students who indicated they on average claim 3.87 close friends, standard deviation 0.872, before the activity, and 3.74 close friends, standard deviation 0.94, after the activity. Male students claimed on average 3.74 close friends, standard deviation 1.065, before and on average 3.77 close friends, standard deviation 0.888, after the activity. Male students self describe as somewhere between average to fast learners, while female students tend to self-describe closer to average. Within the population, 93% of female students and 90% of male students consider they do well at school. Only 5-11% of male respondents and 3-6% of female respondents indicated they were not happy with their family life or social life, the majority indicating either satisfied or very pleased with both.
Questions 115-130 – Personal information results

Personal information responses inform the dissertation research analysis as a population description to situate the research. The situation permits future comparisons with similar research in other regions and curricula. The responses do not change between the pre-activity and post-activity survey deployments (the same population is surveyed both times) except for a small number that may reflect an increase in knowledge as students ask their parents and guardians for their answers to survey questions. Therefore, I consider the post-activity responses to be more accurate.

Responses to the level of education completed by parents varied slightly with numbers of approximately 60±3% for both male and female students. Wordles effectively represent the frequency of parents’ occupations within the sample population by emphasizing the most recurrent occupations (Figure 26, Figure 27 and Appendix J).

Figure 26: Occupations of fathers of all students (male and female responses combined).
Chapter Conclusions

Comparisons of male and female responses prior to the activity provide interesting information about the differences between the gendered perceptions and beliefs within the sample population group before an intervention is attempted. Pre-activity differences may suggest gender-specific cultural experiences typical to Physics 11 students in the Greater Victoria region. Changes to these differences between male and female responses following the research activity, the post-activity data, imply a change in student opinions due to the research activity. Of course, confounding activities may influence changes in student perceptions and beliefs (I discuss this further in Chapter 7). In some cases, differences between male and female perceptions become negligible following the activity. In other cases, differences between the responses given by male and female students increase.

Specific and distinct comparisons of female pre-activity responses with post-activity responses provide further insight into any gender-based impact of the research activity by

Figure 27: Occupations of mothers of all students (male and female responses combined).
mapping female students’ changes in beliefs and perceptions. Male response data provide another aspect that probe the coincidental influence of the activity on the male students’ opinions. Unfortunately, long term persistence of post-activity changes to student responses could not be tested for statistical significance because cross tabulations that included the online responses between sex and each question resulted in multiple cells containing fewer than five units, rendering the Pearson Chi-Square analyses unstable. The extensive recoding of variables necessary to combine the cells for a stable analysis including the online survey data rendered the comparisons uninformative. However, constraining the analysis to the pre-activity and post-activity deployments, eliminating the online deployment, retained sufficient data to generate tests of statistical significance.

The sample population comprised a majority of female students in all survey deployments. The results presented in this chapter indicate significant differences between male and female responses for several variables within expectations of courses leading to viable careers, personal goals and ambitions, and the types of careers they intended to pursue (more female respondents prefer professional careers while male respondents also indicate preferences for technical/trades and entertainment/sports careers). Differences exist between pre- and post-survey responses of male and female students to questions about destiny and control, self-efficacy in physics, alienation and independence, and belonging, indicating the possibility of change influenced by the research activity. Chapter 7 includes further investigation into the relevant significant differences in the sample population responses. An assessment of this information diagnoses the challenges and barriers faced by women in Physics 11.
In this dissertation, I use the ten hypotheses to frame the preliminary statistical analysis of the survey responses and the interpretation and final conclusions. However, additional hypotheses arise from the research data. For example, the research question does not directly address the impact of parental occupation or level of education as it does not probe the student motivation for enrolling in Physics 11. However, although beyond the scope of this dissertation, several studies address parental influences on student educational choices (Austen & MacPhail, 2011; Bays, 2016; David et al., 2003) and it may be interesting to similarly assess this data in the future. The personal information questions at the end of the survey will enable correlations with longitudinal studies through later survey deployments. While other potential hypotheses relate to this research, such as whether any changes noted after the activity persist in the longer term, these require further information regarding respondents’ future choices which are not yet available. The next and final chapter includes a discussion of the research limitations and potential future steps for delving more deeply into analyses of this rich dissertation data.
Chapter 7 – Interpretation & Conclusions

The preceding chapters of this dissertation provide foundational information through studies and qualitative reports. They describe the current body of knowledge around gender diversity within the profession of engineering. Comparisons to other professions addressing the barriers women face within the workplace lay the groundwork for this research project. The ensuing theoretical assessment led to the design of the dissertation research project: multiple deployments of a new survey instrument deployed on paper prior to and following an in-class activity and online several months later. The data collected by the surveys and during the activity create opportunities to diagnose the behaviours of students in Physics 11, looking for trends that may explain the low transition of young women from Physics 11 to engineering education. The survey data results presented in Chapter 6 identify apparent and in some cases statistically significant differences in two key comparisons: differences between male and female beliefs and perceptions before the activity and after; and differences between each gender group’s beliefs and perceptions before the activity and after. Differences between male and female responses prior to the activity might indicate systemic gendered beliefs and perceptions; pre-activity differences that cease to exist after the activity may indicate a successful dispelling of stereotype influences. Differences in female (or male) pre- to post-activity responses might serve to quantify the precise change that occurs.

The data interpretation in this chapter seeks to identify potential barriers to pursuing further physics education. Probing significant differences through the lens of each of the hypotheses proposed at the beginning of Chapter 6 simplified the analysis. Earlier in this dissertation, I defined a mixed methods approach to investigate the ten factors. In this chapter, I supplement the
quantitative analysis with descriptions of the research behaviours, photos of the students at work and images of their reports. Including numerical assessments in a qualitative research methodology does not necessarily result in a mixed methods research project (Maxwell, 2010). The discourse analysis, however, of qualitative data augment the quantitative analyses by enlivening the connection between participants and data (Yardley & Bishop, 2008). In the discourse analysis, I identify patterns from the quantitative analysis to theme the student comments and expand on those that align with the theories and goals described in Chapter 4. In the quantitative analysis, I perform preliminary analyses through the use of cross tabulations and identify factors to address the nebulous concepts identified in the hypotheses. Factor analysis is not always a good fit for this data, therefore in some cases I rely on comparison of the means. In this way, the quantitative and qualitative data inform the final research conclusions.

Interpretation of data

The ten major hypotheses introduced in Chapter 6 define the scope of the preliminary quantitative analysis. While it might at first seem over ambitious to use the same data set to analyse so many hypotheses, the survey is in fact very broad and includes sufficient discrete subsets designed to address each hypothesis independently. The analysis is necessarily constrained to ascertaining whether the completion of the pre-activity survey coupled with the exploration inherent in the in-class research activity (the engineering design problem based on their own life experience) influenced the students’ responses in the post-activity survey, within the specific and specified data subset. Hypotheses H1 through H3 resulted in no statistically significant differences in students’ perceptions or interest in pursuing physics following the activity. Upon reflection, although this result is disappointing it is informative nonetheless.
Significant changes were apparent in the quantitative analysis of the more nebulous constructs of control, destiny, self-efficacy, alienation and independence, and belonging, which support observations made during the in-class activity and comments made by teachers throughout the project.

**Testing H₁ – Educational Aspirations**

According to survey results, male and female students in the sample populations agree on their top three future goals: general happiness, having a family and being successful. Male students indicate their fourth goal as education whereas female students indicated theirs to be getting a good job. Students did not change the order of these goals following the activity. I tested for statistical significance (Chapter 6) and the Pearson Chi-Square analysis failed to reject the null hypotheses ($\alpha = 0.25$). Therefore no relationship is shown to exist in the data split by sex, indicating that any changes to the responses after the activity are simply due to chance. In other words, the quantitative survey data analysis rejects hypothesis $H_1$, that the activity influenced changes to students’ educational aspirations towards physics.

**Testing H₂ – Interest in Physics**

I interpret the students’ ranking of physics as a favourite course to indicate their current interest in physics. Male students indicated physics as the second most selected course with a slightly higher ranking following the activity (increase of 3%). Female students’ responses resulted in physics as the seventh favourite course in both survey deployments, although responses increased in favourability by 3% as well. Although male and female students did not change the ranking of physics in their list of favourite courses, they more frequently indicated mathematics as one of the top three courses after the activity. The quantitative survey data
analysis rejects hypothesis H₂, that the activity influenced changes to students’ interest in physics. However, the qualitative analysis indicates an increased participation in the physics classroom that may be indicative of growing interest in applications of physics. Ascertaining the drivers for these results, whether students pragmatically rank mathematics and physics more highly because they see better linkages to good careers such as finance or because they truly enjoy the subjects, requires further research.

**Testing H₃ – Perceived Value of Physics**

Question 11 relates directly to the students’ belief that physics leads to a promising career. The cross tabulations and Pearson Chi-Square tests reject the null hypothesis, indicating that no relationship exists between student responses pre- and post-activity. Therefore, the activity appears to have had no influence on students beliefs about careers in physics. However, differences did arise in peripheral courses addressed by the research activity. In particular, belief that social science leads to a promising career increased by 3% (α=0.25) as did belief that art leads to a promising career. This may have been due to the use of drawing and sketching during the research activity (Figure 28). In other words, the quantitative survey data analysis rejects hypothesis H₃, that the activity influenced changes to students’ perceived value of physics but may indicate a trend of increasing recognition of the social relevance of physics. This possibility may be supported by the qualitative discussion provided later in this chapter and warrants further research.

**Testing H₄ – Control**

The variable “control” in this dissertation refers to the beliefs students have about their ability to influence events in their lives. Based on the theory of precluded interest, one would
expect that female students have differing opinions about their control over future events than male students because of stereotypes that constrain girls’ decision-making to socially determined feminine roles such as home life and child-care (Cheryan & Plaut, 2010; Clark, 2005; Forsman & Barth, 2016).

Although this concept cannot be questioned directly, survey questions 47 through 61 asked students to respond to scenarios that reflect control by indicating their agreement with the statements. In anticipation of building a complex variable from the set of statements, I ran factor analysis to construct this concept (I also ran factor analyses on the concepts that address Hypotheses 6-10) and include the output data in Appendix M.

The unrotated exploratory factor analysis determined a maximum of four of the eleven destiny and control variables to be significantly related, while the Varimax rotation matrix with Kaiser normalization determined a significant relationship between a maximum of three variables. None of these resulting significant relationships persisted through the survey deployments such that factor analysis failed to construct any useful conceptual variables. Since factor analysis proved to be a poor fit for this data, the analysis relies on cross tabulations on

Figure 28: Most samples of student work included intricate and detailed drawings.
each original variable or its necessary recoding (Chapter 6). Future analysis of these factors may identify informative behaviours within each deployment group.

Significant differences in the individual male and female survey responses prior to the research activity ceased to exist for all but one question in the survey deployed after the activity. This trend aligns with the social role theory work of Steinmetz et al. (2014) that individual opinions that reflect stereotypes can be easily dispelled through role information and education. As predicted by the theory of precluded interest, the activity in the classroom may sufficiently demonstrate the relevance of physics to both male and female students. The activity allows deep-seated gender role beliefs to persist unchallenged while apparently mitigating experiences of sex discrimination within the masculine-dominated field of careers the apply physics. The expectancy violation theory predictions, that society expects women who resist social expected behaviours to exceed masculine skill levels, also seem to be mitigated: in this research activity, no such expectations of over-achieving apparently exist. The lack of over-compensation in female student responses to questions about destiny may indicate a realignment of their opinions to those more indicative of self-confidence and self-actualization (Acker & Oatley, 1993; Eccles, 2011; Sunny et al., 2017).

One question resulted in a significant difference in the survey deployment that followed the activity, question 47 “I feel that the future holds nothing for me to fear.” Female students (M = 113, SD = 0.964) agree with this statement at a significantly higher rate than male students (M = 105, SD = 1.154), t(216) = 3.2023, p ≤ .0016, CI.95 -0.74313, -0.17687. Therefore, we reject the null hypothesis that there is no difference in responses for male and female students after the activity. Significance testing on data comparisons between male and female results prior to the
activity, male results before and after, and female results before and after all resulted in failing to reject the null hypothesis, indicating there were no differences in these responses (all t-test data is available in Appendix N).

In all responses other than question 47, within the control question set, the null hypothesis is not rejected. Yet the increase in female students’ relative agreement with the statement for question 47 may reflect a trend of increased confidence achieved by female students through the research activity. As per the qualitative discussion below, female students apparently exhibited greater control over their work than previously noted by teachers. Therefore, the null hypothesis, $H_{40}$, is partially rejected and one form of student perception of control is increased following the activity. These apparent trends warrant further targeted research.

**Testing $H_5$ – Destiny**

As mentioned in the preceding section, factor analysis failed to created a single construct to test the concept of perceptions of destiny. However, the cross tabulations provide insight into differences in the beliefs and perceptions of male and female students with regards to their agreements to the statements relating to destiny included in questions 62-70. In alignment with social cognitive theory, hypothesis $H_5$ predicts the activity may induce an increase in female students’ perceptions of their power over their own destiny. By reflecting on the research activity, students build mental linkages between applications of physics and their own world view or personal experiences. In this way, students may change convictions about their autonomy to dispel stereotypical response behaviours (Hafen et al., 2012; Lent et al., 2008; Luthans & Stajkovic, 1998).
As occurred for beliefs about destiny and control, in the destiny tests above, any differences that exist between female and male student responses prior to the activity apparently cease to exist afterwards, with the exception of one question for which student disagreement increased with the statement “I have often found that what is going to happen will happen no matter what.” Male and female responses continue to be significantly different before and after the activity. Although all students generally disagreed more with the statement after the activity, that change is not statistically significant and, instead, due to chance (Appendix N), failing to reject the null hypothesis, $H_{05}$.

In the pre-survey responses, male students ($N = 104$, $SD = 0.797$) agreed with this statement 10% more than female students ($N = 122$, $SD = 0.795$), with unpaired t-test results of $t(224) = 4.7070$, $p \leq .0001$, CI$_{95}$ 0.29067, 0.70933, rejecting the null hypothesis that there is no difference in responses for male and female students before the activity. The post-survey responses, male students ($N = 105$, $SD = 0.815$) agreed with this statement only 7% more than female students ($N = 113$, $SD = 0.804$), with unpaired t-test results of $t(216) = 3.1905$, $p \leq .0016$, CI$_{95}$ 0.13378, 0.56622, rejecting the null hypothesis that there is no difference in responses for male and female students after the activity.

The elimination of response differences in all but one question may indicate a trend that warrants further exploration, that the activity results in a shift in female students towards similar perceptions of destiny and control held by male students, in essence supporting $H_5$. The activity provides an opportunity for students to reflect on their ability to create knowledge about physics through applications related to their current, everyday experiences. Students in the classroom exhibited very similar behaviours with respect to all aspects of the research activity. This may
lead to an apparent alignment with the hypothesized application of social cognitive theory regarding physics applications and the students’ ultimate perceptions of controlling their destiny. Whether this translates to long term decisions about their future course of study can only be determined with future longitudinal survey deployments (Woodington, 2010).

Testing $H_6$ – Self-efficacy

Questions 82-91 consist of statements relating to the concept of self-efficacy, an aspect of social cognitive theory related to academic interests, choices and educational performance (Lent et al., 2008; Luthans & Stajkovic, 1998; Sawtelle et al., 2012). The resulting data from this set of equations appeared to be a good fit for conducting factor analysis.

I began the process of factor analysis on this concept by using the full dataset, including all students over all deployments. The component matrix seemed promising with seven responses aligning, indicating the possibility of creating a single self-efficacy construct, leaving four responses to describe two additional constructs. The rotated component matrix created three components that defined logical constructs, based on the combined responses. However, the full dataset pools information from the subgroup comparators, eliminating possibilities for retrieving information about the subgroups. After splitting the dataset by deployment and by sex, factor analysis did not create common components. Regardless, I created three factors for comparison from the full-data analysis: Comfort doing physics, Comfort talking physics and Comfort using computers (Appendix M). In all cases, the t-test fails to reject the null hypotheses indicating that any differences existing between male results before and after the activity and female results before and after the activity for these physics self-efficacy constructs are due to chance. The failure to reject the null hypothesis is likely due to the constructs and the poor fit of this data to
factor analysis. This being said, future factor analysis oaf each data subset within survey deployment groups may generate informative knowledge about the population albeit non-comparative.

Returning to the cross-tabulations by sex and deployment on individual questions within this set, the Pearson Chi-Square test indicated statistically significant differences pre- and post-activity resulted in three cases for female students (questions 72, 74 and 78) and three cases for male students (questions 73, 78, 81). In all cases, student responses to the physics self-efficacy set of questions indicated increased agreement with the Student’s t-test comparison of means on the female responses to the relevant questions before and after the activity failed to reject the null hypothesis that any change in response to these questions is due to chance. In other words, female students did not respond to the survey questions on physics self-efficacy significantly differently after the activity for the quantitative analysis to support the hypothesis.

Two sets of the male response t-tests, however, rejected the null hypothesis that differences in their responses were due to chance: question 78, “I can easily relate sketches to the object in the sketch”, and question 81, “I prefer solving problems with paper and pencil.” For question 78, male students’ post-activity responses (N = 105, SD = 0.781) indicated their disagreement with this statement 9.9% more than in the post-activity survey (N = 104, SD = 0.822), with unpaired t-test results of t(207) = 2.1640, p ≤ .0316, CI$_{95}$ -0.45865, -0.02135, rejecting the null hypothesis that there is no difference in male student responses before and after the activity. In other words, male students perceived greater difficulty in relating sketches to objects in the sketch after the activity.
For question 81, male students’ post-activity responses \((N = 105, \text{SD} = 0.713)\) indicated their agreement with this statement 10.4% more than in the post-activity survey \((N = 104, \text{SD} = 0.744)\), with unpaired t-test results of \(t(207) = 2.0834, p \leq 0.0384, C1_{95} 0.01128, 0.40872\), rejecting the null hypothesis that there is no difference in male student responses before and after the activity. In other words, male students perceived greater preference for solving problems by hand after the activity.

The quantitative analysis rejects the null hypothesis \(H_{06}\) for male students, supporting hypothesis \(H_6\). However, this analysis fails to reject the null hypothesis \(H_{06}\) for female students. I consider possible factors contributing to these unchanging perceptions and behaviours regarding physics self-efficacy before and after the in-class activity in a section on confounding factors later in this chapter.

**Testing \(H_7 – \) Alienation & Independence at home**

Questions 82-91 probed the students’ sense of alienation and independence through statements about home or community life outside of school. The intent of this set of questions is to isolate negative or positive experiences in the physics classroom from those in the student’s home or community. Changes in behaviour seen here but not in the physics classroom indicate that confounding factors influence the data results. Cross tabulations between these variables at each deployment demonstrate that significant differences existed prior to but not following the activity. In general, students responded with agreement to statements about enjoying home life and their friends. Student’s t-tests fail to reject the null hypotheses that differences by gender are due to chance. In other words, the quantitative survey data analysis fails to reject the null
hypothesis $H_{07}$, that the activity influenced changes to students’ sense of alienation and independence at home.

**Testing $H_8$ – Alienation & Independence at school**

Students responded to questions 92-99 with general agreement of feelings of safety in school to speak opinions and that teachers in general treat students fairly. Statistical analysis of changes to female student responses consistently **failed to reject** the null hypothesis that any differences were due to chance. For male students responses, however, both Pearson Chi-Squared and t-test analysis indicated statistically significant increases in dissatisfaction for three variables: decreased disagreement with question 94, “My teachers are mean to me”, and increased agreement with both question 97, “I feel safe to speak my opinion in the classroom”, and question 99, “I enjoy being at school.”

Hypothesis 8, $H_8$, proposes that students will exhibit reduces alienation in their school life. The changes in male students’ responses and no change in female students’ responses to statements about alienation and independence at school indicate the possibility that teachers in these classrooms already provide greater support for female student learning, perhaps focusing less on male students. Subsequently, as male students perceive the validity of applications physics in their own lives, they appreciate and recognize the validity of others studies as well (Biernat & Sesko, 2013; Forsman & Barth, 2016). In other words, the quantitative survey data analysis **rejects** the null hypothesis, $H_{08}$, for male students but **fails to reject** the null hypothesis, $H_{08}$, for female students that the activity influenced changes to students’ sense of alienation and independence at school.
Testing $H_0$ – Alienation & Independence in the physics classroom

Attempts to isolate perceptions and beliefs in the physics classroom from those related to school or home and community life appear to be unsuccessful in this study. Pearson Chi-Square analyses indicated that male students responses to four questions within this set (questions 100-108) demonstrated statistically significant increases in satisfaction in the classroom except for question 101, “My physics teacher will help me if I need it”, for which the response after the activity was slightly less in agreement. However, the t-test comparison of means failed to reject the null hypothesis in all cases, indicating that these differences were due to chance.

The female students’ responses indicated a slight decrease in satisfaction within the physics classroom. For almost all statements, however, the t-test analysis failed to reject the null hypothesis, indicating that most differences were due to chance, except for question 104, “The [my physics] teachers treat all students equally.” For question 104, female students’ post-activity responses ($N = 112, SD = 0.871$) indicated their agreement with this statement 7% less than in the pre-activity survey ($N = 121, SD = 0.930$), with unpaired t-test results of $t(231) = 1.6908, p \leq .0922, CI_{95\%} -0.03306, 0.43306$, marginally rejecting the null hypothesis that there is no difference in male student responses before and after the activity. In other words, a trend may exist indicating that female students believed less strongly that their physics teachers treat all students equally. It is interesting to consider that, although not statistically significant, male students appeared to believe more strongly that physics teachers treat all students equally. Again, the quantitative survey data analysis almost rejects the null hypothesis, $H_{09}$, for male students but fails to reject the null hypothesis, $H_{09}$, for female students that the activity influenced changes to students’ sense of alienation and independence within the physics classroom. This
potential trend may indicate growing awareness of bias in the classroom and may make an interesting future study.

**Testing H$_{10}$ – Belonging**

Several questions near the end of the survey addressed the students’ connections to society and to the classroom. The questions focus on community connections, like belonging to sports teams or community groups, friend connections, such as the declared number of close friends, and satisfaction with community and school life. Interactional theory suggests that working in new groups can foster an increased sense of belonging regardless of the composition of that group (Gallagher, 2008; Thornberry, 1987). I defined confidants in the survey to be someone in whom the student can confide and gave suggestions including friends, family, coaches and spiritual leaders. In this way, the responses focus on any affiliation as a contributor to the sense of belonging instead of requiring an interpretation of friendships or intimate relationships (Csikszentmihalyi, 2014). All female students declared they had at least one confidant, indicating an existing connection to others. The majority of male students, 89.5% pre-activity and 94.5% post activity, also declared they had at least one confidant. No statistically significant changes between responses to the pre- and post-activity surveys resulted from the analyses of these questions, **failing to reject** the null hypothesis that changes in male or female responses to these questions are due to chance. However, differences between the number of confidants declared by female students and the number declared by male students remain statistically significant before the activity and after the activity.

For the recalculated confidants variable, female students’ pre-activity responses ($N = 123$, $SD = 1.296$) indicated on average 0.46 more than demonstrated by male students’ pre-activity
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responses (N = 106, SD = 1.386), with unpaired t-test results of t(227) = 2.5934, p ≤ 0.0101, CI.95 0.11049, 0.80951, rejecting the null hypothesis that there is no difference in the number of confidants declared by male and female student prior to the activity (Appendix J). The impact of belonging, using number of confidants, on physics interest may become apparent through further analysis of this data. Female students’ post-activity responses to this variable (N = 113, SD = 1.394) indicated on average 0.46 more than demonstrated by male students’ pre-activity responses (N = 105, SD = 1.366), with unpaired t-test results of t(216) = 2.084, p ≤ 0.0383, CI.95 0.02115, 0.75885, rejecting the null hypothesis that there is no difference in the number of confidants declared by male and female student following the activity. The quantitative survey data analysis fails to reject the null hypothesis, H.010, for all students that the activity influenced changes to students’ general sense of belonging.

Interpretation of qualitative data

Throughout the research activity, I recorded observations and conversations with students and teachers using notebooks and video cameras. The survey data analysis attempts to quantify existing changes to student beliefs and perceptions about their learning and their satisfaction with the physics environment. The qualitative analysis serves to provide a perspective of the classroom environment independent of judgement and bias, often indiscernible from the quantitative analysis of survey responses (Bick, Müller, & Reinke, 1977).

Using the ten hypotheses as a frame and the factor analysis constructs for physics efficacy as a lens, I theme the observations into two major categories: comfort with physics and comfort in the classroom (belonging). Observations within these categories address each of the hypotheses through the proposed theories. Within the classroom, observations reflecting (or
contradicting) comfort with physics align with social cognitive theory in that demonstrations of comfort with context-based applications of physics and increased capacity to do so may alter the students’ educational aspirations, addressing $H_1$, their overall interest in physics as a possible pathway, $H_2$ and their belief that physics leads to a viable career path, $H_3$. Applications of physics to their own life experience may enhance the students perception of physics as a possible career path for themselves, $H_6$, increasing their sense of agency and influencing their beliefs, $H_4$, and perceptions, $H_5$, of destiny and control. This acquisition of an ability to directly improve their personal lives through engineering design in group settings may increase their sense of belonging within the classroom, $H_9$, school, $H_8$, and community, $H_7$, as they perceive greater opportunities for contributing to society, $H_{10}$.

The teachers came to know the students in their classrooms during the months between the teacher workshop in September and the research activity conducted in November, December or even January of the following year. Therefore, their observations effectively identified behavioural differences most likely resulting from the research activity rather than from other factors, such as presentations elsewhere in the school, global events or the novelty of having a guest in the classroom.

**Comfort with physics**

When I first entered the physics classrooms to deploy the pre-activity survey, students appeared to be open to the experience of participating in this research project. With support from their parents, guardians and teachers, and the clearly outlined description of the research project (communicated through the written permission forms and verbally explained prior to the opening of the survey booklets) all students but one agreed to participate. That one student withdrew after
the first survey deployment but prior to the data anonymization, therefore her booklet was destroyed and all recordings of her participation deleted.

As the activity itself requires the discussion and synthesis of content contained within the Physics 11 curriculum objectives, students who did not complete the survey or declined to be part of the research project continued to join in the activity (with their comments and images removed). The teachers remained in attendance at all times to verify curriculum objects would in fact be met. To protect student anonymity, this section of the dissertation includes no direct reference to students, teachers, schools or districts.

The introductory phase of the research activity consisted of a full class discussion during which I invited students to identify and share situations in their lives where they may have experienced sliding. I deliberately made eye contact with as many individuals as possible during this phase. Participation was low until I prompted students to consider possible applications of sliding at work, home or while playing sports by asking a form of the following questions: “Did you ever need to slide something at work? At home? Do you play a sport where sliding may make things more difficult or where you may want to slide more?” Almost immediately, male and female students made connections and demonstrated their increased interest in the topic by sitting up straighter, looking to each other, smiling or even blurting out their examples right away. This reaction was consistent across all 13 classrooms and addresses the theory of precluded interest by demonstrating how all students, male and female, readily found examples from their personal experience in which physics is applied, potentially dispelling gender stereotypes (Barth, Guadagno, Rice, Eno, & Minney, 2015).
Student examples of sliding scenarios included moving boxes of inventory at work or furniture around at home, playing rugby or playing sliding sports that require skating or sledding. I reinforced each scenario by repeating it back to the class, adding emphasis to the sliding aspect and whether increasing or decreasing the sliding of the person or object might be of benefit. Once ideas began to flow more swiftly, I introduced the documentation phase of the activity, describing how the original scenario must be kept in mind throughout the design of improvements, prototypes and verification tests. I invited students to form groups of 3-5 members at the side tables to begin their design phase of the activity and draw a sketch of their chosen scenario (Figure 29).

The teachers expressed interest in the “flipped” way of teaching, couching the concept within the context instead of offering contextual examples after the activity. They liked and would use again the open-ended questions and the method I employed to prompt the students to come up with their own experiences as examples.

Figure 29: Students drawing their chosen scenario.
During the documentation phase, the teachers tended to direct students in solving their design challenges. In some cases, I had to quickly follow up with mitigating statements to the students, such as “…if you would like to” or “…if that makes sense to you.” Once the students were again on their way, I pulled the teacher gently aside to remind them that the students were to come up with the ideas for design changes and prototypes. I observed that in cases when the teacher intervened and suggested methods, the students visibly withdrew from the activity by sitting back from their work space and becoming more serious in their demeanour, where prior to the intervention they were laughing and working with enthusiasm. For example, I observed one group of female students conducting an energetic discussion about their prototype design. They scanned the classroom in search of materials they could use when the teacher walked up and said to use the blocks and spring scales we had set up on a side table ahead of the class time (Figure 30). After suggesting the students “could” use these materials “if they wanted”, I reminded the teacher that the prototype designs were to come from the students’ imagination.

Some students at first complained about the lack of structure, however these students then referred to the Student Guide, read the expectations over, and could create and perform a more

Figure 30: Typical apparatus available for creating prototypes included wooden blocks, mass sets, spring scales and textiles to vary surface roughness.
constrained experiment (Appendix C). Students comfortable with discovery-based learning could use a more fluid and self-defined procedure. However, the activity required a basic minimum level of documentation that included a scenario sketch exhibiting two cases in which the sliding may increase or decrease, a verification test to assess whether the proposed changes achieve the anticipated improvements, and quantitative experimental data to support their outcome.

**Comfort using paper and pencil for problem analysis**

The activity describes the documentation procedure as parallel to the engineering log book in that all notes, ideas, sketches, theory, perceptions and observations must be contained within single document for ease of retrieval. In the activity, students recorded all ideation and data in the forms just described: graphically, through sketches, numerically, through theory and data recording, and descriptively, through writing out observations, limitations, recommendations and conclusions. Previously, physics data are typically entered directly into spreadsheets created by the teacher in advance. The practical experience of creating the data tables and designing the experiment to verify theory increased their comfort with using paper and pencil for solving physics problems (Little & León de la Barra, 2009). Interestingly, the quantitative data analysis in Chapter 6 indicates that male students experienced more of a positive improvement in their perceptions of this quality than female students, indicative of boys interest in taking on more active roles (Vingilis-Jaremko, 2010). Similarly, the encouragement for female students to take on more active role increased their engagement in the physics experiment (Shapka & Keating, 2003).
Comfort in the classroom -- belonging

The comfort experienced by female students in the classroom appears to support various studies on STEM (science, technology, engineering and math) education, which conclude that girls prefer to work in small groups on activities that are “hands on”, practical in application (Little & León de la Barra, 2009). In this research activity, female students engaged equally with their male colleagues. Most of the self-selected groups ended up single-sex. In all cases, all members of the group participated in the activity. All teachers commented on the high level of involvement of all students in the classroom.

As an example, one student group insisted they would include six members: two males and four females. One female student seemed to be taking lead of the group and two students appeared to be disengaged from the process. After a few minutes, I insisted that the group member split and form two groups. When I returned, the lead female student joined up with two other female students and one male student while the other male student formed a group of two with the last female student. I checked with both groups to ensure they understood the activity and left them to their work. The second time I returned, it appeared to me that the group of two were just chatting. When I asked how things were going, the female student in this group of two launched into an energetic description of the scenario, the proposed change to reduce friction and the verification test they had designed. I took the opportunity a few moments later to chat with the teacher about the newly split groups and the scenario under investigation by the group of two. The teacher said that this was the first time that this student had become comfortable enough to actively participate in a physics experiment (Little & León de la Barra, 2009; Shapka & Keating, 2003).
In another example, a group of male students who typically ignored physics class proceedings, laughing and joking in the background, became fully engaged in the research activity. These students were playing with their rubber erasers and their mobile phones until I came over to them, intending to redirect their energy back to the activity. Contrary to the teacher’s and my expectations, they were already engaged in the activity, using their eraser to simulate a rougher surface than that on their phones and study the effect of phone surface on how slippery it is. With minimal coaching, the students developed a more consistent experiment using different phone covers instead of completely different items.

Each teacher made similar observations that a higher number of students contributed to the conversation about physics concepts and became involved in the research activity than had previously occurred in each classroom. Sometimes the comment related to female students, other times to male students who previously refrained from participating. The theory of precluded interest suggest that women would participate less frequently than men in these activities because of preconceived sex-oriented stereotypes (Cheryan & Plaut, 2010; Forsman & Barth, 2016), however this research seems to indicate that such stereotypes did not prevail prior to entry into Physics 11 classrooms.

Confounding Factors

Isolating external influences from research subjects is a major challenge for measuring and assessing the drivers for social change. Were the changes noted in previous chapters and sections a result of the research activity or were they due, perhaps, to a school-wide presentation by a visiting scholar? During August, 2015, I discovered that an engineering student in Victoria coincidentally and concurrently contacted St. Margaret’s School to give presentations to high
school students about engineering. The principal of St. Margaret’s connected us and the we met to discuss our work. Fortunately, her presentation would be delivered to grade 12 students while my work was with grade 11 students. Unfortunately, the risk of confounding my data existed because some grade 12 students had registered in Physics 11. In general, however, this risk is assumed to be low especially in consideration of the alignment of this data with the public schools who did not experience the engineering student’s presentation.

I noticed in some cases that the students discussed their responses during survey. Although I tried to limit this and encourage students to complete the surveys as honest representations of their personal opinions, I did not wish to disrupt other students. Between deployments, however, I could not constrain such discussions, which may have influenced the outcomes of the surveys post-activity. In addition, student discussions with their parents and others may have a greater influence on student outcomes as the majority of male students’ parents are engineers. This results in a moderate risk to the integrity of the data, as the survey included so many questions that the students could not possibly remember them all.

When asked, the PAR Team teachers indicated that students always seemed to exhibit greater interest in their classrooms when external visitors attended to discuss their work or their research. However, the teachers clarified that these visits typically do not include an activity that comprises part of the physics curriculum. The engagement and focus exhibited by the students during the research activity appeared to be greater than that witnessed during or following presentations by guest speakers.

The data may have been skewed before the first survey deployment occurred. The possibility exists that some of the insignificant results were due to the teachers’ changed
behaviour prior to the first survey. The introductory workshops presented evidence-based information that perceptively changed the beliefs and perceptions of the teachers. It is likely that these changes influenced students' beliefs and perceptions about some of the key factors I attempted to measure during this dissertation research project. To mitigate this high risk, future studies should have the first survey deployment occur prior to classes beginning or prior to first contact with the Physics teachers. Similarly, the teachers self-selected their participation in this research, which may indicate their predisposition to explore and eliminate classroom bias. Future studies should attempt to include a broad representation of backgrounds, education and interests to provide more generalizable data. Additionally, the independent school data may have skewed the results by including responses by female students who typically have greater inclination to attend university and pursue atypical educational pathways. They may also be more resistant to gender bias, which could be tested using comparative analysis with a larger data set.

Finally, as described in Chapter 3, the WITS bullying awareness program piloted in the Greater Victoria school systems may serve to limit the generalizability of this data. Although widely disseminated at this time across the province, the outcomes of enhanced inclusivity and social responsibility imbued by the WITS program may be more entrenched in the social fabric of Victoria at the time of this research activity. The potential generalizability can be tested through comparisons with populations outside of British Columbia.

**Future Research**

I used ten hypotheses to frame the process of organizing the preliminary statistical analysis of the survey responses. Additional hypotheses arise from the research data. For example, the
research question does not directly address the impact of parental occupation or level of
education as it does not probe the student motivation for enrolling in Physics 11. Several studies
attempt to identify parental influences on student educational choices (Austen & MacPhail,
2011; Bays, 2016; David et al., 2003) and it may be interesting to similarly assess this data as
potential verification for the theories presented.

**Longitudinal analysis – emerging change**

The personal information questions at the end of the survey could enable correlations with
longitudinal studies through later survey deployments. While other potential hypotheses relate to
this research, such as whether any changes noted after the activity persist in the longer term,
these require further information regarding respondents’ future choices which are not yet
available. In some cases, change takes time and statistically significant changes may emerge
from future survey deployments.

**Discourse analysis – gendered language**

Engineers and Geoscientists of British Columbia (formerly APEGBC, the Association of
Professional Engineers and Geoscientists of BC referenced in earlier chapters) and Engineers
Canada assembled the results of studies exploring the influence of gendered language in job
postings on the recruitment and retention of women in engineering. Transcriptions of the video
data collected through this project may yield interesting information about gendered language
that may or may not exist in Victoria Physics 11 classrooms.

**Activity analysis – precluded interest**

An analysis of the activity documentation generated by the students may yield interesting
information. For example, do students choose stereotypical examples based on theory of
precluded interest? Do female students use specific turns of phrase when they write or do they draw people pursuing in specific activities?

**Longitudinal analysis – teacher behaviour/student behaviour**

The PAR Team teachers indicated interest in following up with this research project. Follow-up surveys may indicate the lasting influence on teachers of participation in the workshops and activities, whether they persist in using techniques introduced through this research. It would be good to regularly check in with teachers, through structured or open-ended interviews and surveys, to keep the experience fresh in their minds.

**Teacher workshops**

The teachers indicated their belief that the introductory workshop would be beneficial for other teachers. They found the Teacher Guide and Students Guide helpful but training would be required prior to implementing this in the classroom. The teachers expressed surprize at the study data presented during the first workshop but, upon reflection, realized parallels with their own past behaviour that changed because of this research project. Future deployments of the Teacher survey would generate interesting quantitative data about the beliefs and perceptions of teachers in British Columbia and further afield.

**Regression Analysis**

The survey data analysis of this research project focused on potential changes in the beliefs and perceptions of students that could indicate an influence on future career choices. Future multivariable regression analysis may generate predictor equations, using the ordinary least squares method for pairs of correlated variables, to predict population behaviours based on this data.
Conclusions

Students in the physics classrooms included in this research study increased their sense of destiny. Following the in-class activity, more students agreed with statements about one’s control over the future. The most notable changes in beliefs and perceptions centred on female student responses becoming more similar to male students’ responses. This change implies that the research activity dispelled differences of opinion between the two main genders. Barring the influence of confounding factors identified above, the changes may be due to dispelling stereotypically female assumptions about destiny and control in alignment with the theory of precluded interest.

Other notable outcomes of the activity include identifying trends of increased comfort in participating within the physics classroom, for using physics and for solving problems with paper and pencil (Table 15). The practical aspect of the physics activity allowed students to use their creativity in drawing the sketches, to find context from their personal experiences and to build relationship with others in the classroom that enhance their sense of belonging. That quantitative changes occurred more notably with male students suggests that the PAR Team teachers may already focus more attention on female students. This focus is contrary to our earliest workshop discussions and contrary to earlier studies showing this not to be the case. Some confounding factors may be at play that skewed the data.

The combination of qualitative and quantitative methods serves to expand on the preliminary numerical analysis, providing more insight into the outcomes and suggesting further analysis is necessary. Some results not supported by the data formed key discussion points.
among the action research team members. This highlights the need for qualitative assessments when investigating social effects and diagnosing undesirable behaviours.

The results of this dissertation research have important implications for the understanding of the influence of in-class activities on the engagement of female and male students in Physics 11 classrooms. As this study has demonstrated, stereotypical beliefs and expectations of behaviour for high school students exist yet may be quickly dispelled through context-based experiential learning. Therefore, the main implication of my research is that students’ own life experiences should be encouraged for examples of the application of physics principles in order to create meaning in high school physics curricula.

Table 15: Summary of results.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Description</th>
<th>Quantitative Result</th>
<th>Qualitative Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₁</td>
<td>Educational Aspirations</td>
<td>Rejected</td>
<td>Comfort with physics: students exhibited greater engagement with in-class activity than previously noted, high energy, positive feedback from teachers</td>
</tr>
<tr>
<td>H₂</td>
<td>Interest in Physics</td>
<td>Rejected</td>
<td></td>
</tr>
<tr>
<td>H₃</td>
<td>Perceived Value of Physics</td>
<td>Rejected - however, increased interest in Social Science and Art</td>
<td>Male-female differences dispelled; greater belief in female students that future holds nothing to fear</td>
</tr>
<tr>
<td>H₄</td>
<td>Control - ability to influence events in their lives</td>
<td>Male-female differences dispelled</td>
<td>High rate of documentation performance and prototype development, male &amp; female students</td>
</tr>
<tr>
<td>H₅</td>
<td>Destiny - feelings of empowerment</td>
<td>Male-female differences dispelled</td>
<td></td>
</tr>
<tr>
<td>H₆</td>
<td>Self-efficacy</td>
<td>Rejected - Increased comfort in male students re: solving problem by hand</td>
<td></td>
</tr>
<tr>
<td>H₇</td>
<td>Alienation &amp; Independence - home</td>
<td>Rejected</td>
<td>Comfort in the physics classroom (belonging): High level of engagement, high rate of participation, low incidence of stereotypical performance behaviours (girls as note-takers)</td>
</tr>
<tr>
<td>H₈</td>
<td>Alienation &amp; Independence - school</td>
<td>Rejected - Increased satisfaction at school by male students</td>
<td></td>
</tr>
<tr>
<td>H₉</td>
<td>Alienation &amp; Independence - physics class</td>
<td>Rejected - all students belief in teachers improved</td>
<td></td>
</tr>
<tr>
<td>H₁₀</td>
<td>Belonging</td>
<td>Rejected</td>
<td>Rejected - female students have greater social connections</td>
</tr>
</tbody>
</table>

Table 15: Summary of results
Chapter 8 – Conclusions

This doctoral research emerged from a desire to dispel stereotype influences within the field of engineering and work towards increasing the number of women in the profession. At the time this project began in 2013, women made up 11% of Professional Engineers and Professional Geoscientists in British Columbia (Why We Matter: APEGBC 2012/2013 Annual Report, 2013). As of 2017, women make up 14% of the BC professions and 17.6% of new members to the association, including student members, recent university graduates and immigrants working towards professional registration (2016/2017 Annual Report, 2017). The gender parity of Physics 11 supports its identification as a key course in the educational pipeline to engineering, a period in which little direct feminist research has been conducted yet in which barriers to the progression of women along the pipeline appear to persist.

This chapter provides a discursive review of the doctoral research project. Beginning with a reminder of the current state of engineering, this chapter touches on aspects of the deep immersion into the historical influences on gendered education that led to the development of the research activity. It then highlights exciting findings within the results and ends with a discussion of limitations to the research, challenges to conducting this research in today’s # feminist climate, and why this research is still important within the current context. With the added complexities of social change, this is an exciting time to conduct feminist research in engineering.

Goals, hypotheses and objectives

The focus of this research project became clear as soon as I identified Physics 11 as a key course: diagnose and attempt to mitigate the barriers arising in Physics 11 that appear to deter
young women from pursuing further studies in physics or engineering. The deep dive into British Columbia’s curricula over the last 100 years revealed the systemic social stereotypes reinforced daily throughout a child’s life. Social Studies, a required topic in each of the twelve years of grade school education, depicts women in secondary roles to men since before the founding of Canada in 1867. Men produced the vast majority of textbooks in use by schools, so the focus of these books was unsurprisingly biased towards activities that featured men and of a style that appeals to men (Gaskell, 1973). Women’s issues written as afterthoughts or in text boxes separate from the main dialogue generate stereotypical beliefs about gender roles that resonate in workplaces today.

Most scientific textbooks in publication continue to be written by men. This in itself is not a deterrent to girls studying physics but it does raise the question about how science knowledge is constructed and whether this lack of feminist modes for creating knowledge reinforces the gender stereotype in students and teachers (Kelly, 1985; Lemke, 2011). Interestingly, the engineering design process aligns well with feminist knowledge creation, which posits that women are well suited to the process: it is only after considering the needs of society and the environment, after consulting with communities and influencers and after developing cohesive plans for sustainable solutions that construction proceeds. The engineering design process is well suited for knowledge creation in science and informs research into a new teaching paradigm.

The goal of the doctoral project is to add to the existing knowledge structures in ways that include both male and female students by breaking down gender stereotypes in physics and building connections between physics and society. This activity is embedded into the curriculum using techniques shown to support how girls like to learn, presenting the new knowledge within
the students’ life experiences while maintaining a safe, risk-tolerant learning environment (Raby & Pomerantz, 2013; Shapka et al., 2012). While additive activities such as Science Venture and GoEngGirl have been shown to increase the participation of girls in high school physics, they are elective in nature and cannot reach all students. Therefore, in order to maximize the impact of the activity, the research project development constraints included minimizing teacher impact, minimizing resource requirements and maximizing usability. The mixed methodologies of action research and quantitative survey analysis addressed the dual drivers of the social construction of knowledge and future dissemination to pragmatic engineers and physicists.

**Workshop and in-class activities**

The teacher workshops presented an opportunity to introduce the participatory action team to feminist history, curriculum and epistemology, and to discuss studies identifying female students’ issues with physics: that they felt they did not belong in physics, there was nothing new to learn in physics and that they could not see how to use physics to make the world a better place (Layzer, 1992; Levin et al., 2005). This was the third occasion to share this topic with physicists, the second being at an engineering educators’ conference in Georgia (Tarnai-Lokhorst, 2015) and the first at the Camosun College Walls Optional Conference in Victoria (Tarnai-Lokhorst & Hodgson, 2015). On each occasion, reactions were astonishment followed swiftly by understanding and chagrin. Astonishment that anyone could think there was nothing new to learn in physics, understanding why some might not see the connection between physics and making the world a better place, but then chagrin that each teacher, male and female, recognized their behaviours in the classroom supported male students at the expense of female students, thereby contributing to their feelings of belonging in physics. In my presentations and
in the workshop, when I asked why teachers spent more time with male students, they replied with a variant of: “more boys go into physics and engineering, so I wanted to make sure they understood the concepts well.” The irony was also always acknowledged.

The visible transformation in teachers was immediate and potentially contributed a substantial confounding factor to the survey results. Changes in teacher classroom behaviours may have begun immediately after the workshop, while I measured baseline student beliefs and perceptions months later, just before facilitating the in-class activity.

The in-class activity design followed an unanticipated process. The teachers could not at first understand the recommended paradigm shift to introduce student-selected contexts prior to teaching the concept theory. In a classic case of preconceived ideas reducing listening ability, our humorous circular conversations cycled between the process for which I advocated and the process teachers typically followed until one teacher’s realization broke the circle. “You want us to teach it your way?” Once we figured out a common objective of changing behaviour, we were able to move forward and develop a lesson plan that reflects the engineering design process: start with the situation, hypothesize a solution, test the solution and discuss how this verifies or discounts the theory behind the hypothesis.

Results

The level of student engagement during the activity excited the teachers in some classrooms. Male and female students who previously rarely participated in physics experiments or discussions joined in the conversation in substantive ways. The students introduced creative scenarios and innovative solutions that reflected an intuitive comprehension of the concept they explored. By incorporating scenario drawings into the activity, students with an affinity for art
found enjoyment in the new procedure. By using scenarios from their personal experiences, students formed connections about applying physics to the real world. By restraining teacher input, students felt free to come up with random ideas for solutions in a risk-tolerant atmosphere.

The student behaviour demonstrated comfort in the classroom through their willingness to try new things. They demonstrated belonging by working effectively in small groups and having fun while doing so. Male and female students participated equally in the activities and in the ensuing discussions, and, with near gender parity in most classrooms, students were able to form all-male, all-female or mixed gender groups as they desired.

Exciting results also arose from qualitative assessments. Although many of the statistical tests failed to reject the null hypotheses, two unexpected outcomes surfaced. The first was that male students’ self-efficacy in physics improved following the activity including their comfort with solving problems by hand, with pencil and paper. I found this surprising because I expected the male students to have no change and the female students self-efficacy to increase. However, the teachers may have unconsciously changed their behaviour immediately after the workshop, months prior to the first student survey, and began to support female students in their classrooms at a higher rate, possibly to the detriment of male students. If this is the case, the activity may have benefited male students more than female students in balancing teacher support.

The second interesting quantitative result relates to student beliefs in their ability to control their destiny by influencing events in their lives: that statistically significant differences between male and female responses ceased to exist after the activity. This change in empowerment is undetectable as a before and after comparison for male students or for female students. However, the activity successfully dispelled any differences in these beliefs as evidenced by the results
presented in Chapter 7. Determining the root cause for this requires further analysis of the data set and additional targeted research.

**Limitations, modifications and context**

Some of the lackluster differences, which may at first appear to be discouraging, in fact point to future refinements of the social experiment that may produce more informative results. For example, one limitation to the current experiment is a failure to account for potential changes to teacher behaviours resulting from the September workshops. These behavioural changes could skew the preliminary, pre-activity survey data. In order to minimize this impact, two additional procedures should have been implemented: first, the students in the teachers’ classes should have been surveyed immediately prior to the workshop. Should the workshop be scheduled just prior to the activity, students’ original beliefs and perceptions of the physics classroom could be reported before any change took place. I believe this research might have been more effective with fewer confounding variables if the workshops were distinct from the survey deployments.

A second limitation is in the survey tool itself. Some questions were redundant in the second and third deployments, such as the personal information questions, and the favourite courses questions. Some students found the exact same questions to be annoying and may not have answered as truthfully. With online surveys, these questions could have been reordered for interest, tailored to the individual students, specifically looking for changes in behaviour or have more text responses to give students the opportunity to share their thoughts. Other questions could have been more specific regarding the students chosen career path, as in “do you intend to attend college or university” or “what job do you hope to have when you finish your education”
and then give a list of career options, including doctor, lawyer, nurse, dental hygienist, electrician, et cetera.

External factors will always influence social experiments and social science research projects. During the survey deployments and in-class activities, the Victoria Branch of Engineers and Geoscientists of British Columbia, formerly APEGBC, coincidentally began conducting outreach presentations in middle and high schools in the Victoria region. These presentations, also designed to break gender stereotypes in engineering, likely confounded the research data by introducing similar information to students prior to the in-class activity, thereby potentially influencing the pre-activity survey sufficiently to skew the research results.

In 2015, the Government of British Columbia introduced new curricula for all grades, Kindergarten through Grade 12. This new curricula is based on a paradigm of discovery and inquiry-based learning similar to that of this research activity. Although not yet fully implemented at the time of this dissertation – K-9 implementation was set for August, 2016, Grade 10 for September 2018, and the Grades 11-12 implementation will remain optional until September 2019 (“B.C.’s Redesigned Curriculum,” 2018) – training on the new curricula likely influences teacher behaviour in the classroom. Curricula training is designed to incorporate new teaching methods into all classrooms. How the new methods impact learning is yet to be seen. However, this doctoral research begins the process of measuring educational influences on more than a student’s level of subject matter knowledge. According to this research, education and teaching methods effect the construction of knowledge, the creation or reinforcement of stereotypes and the development of students perceptions and beliefs about destiny and control.
Finally, current events will effect future deployments of the survey and future assessments of the influence of the in-class activity but in no way negate the relevance of further study. With the ongoing exposure of sexual harassment in the Royal Canadian Mounted Police, multiple cases of widely publicized sexual misconduct in the entertainment industry, the rise of movements such as #MeToo and #TimesUp that actively support female victims in all workplaces, research into gender stereotypes in education become increasingly meaningful. While the social movements highlight sexual misconduct through the public disclosures of wealthy and relatively powerful women, this research seeks to proffer solutions for all by embedding them in standard curriculum. The timing seems right for change in heretofore culturally acceptable behaviours, which can only improve the environment for women in engineering and, hopefully, encourage more female students to pursue their interests and aptitudes in math and physics.

**Future investigations arising from this research**

Future explorations into the effectiveness of this research would require better isolation of confounding factors. Separating the teacher workshop from the in-class deployment would be one step, as both activities appear to influence students’ gendered beliefs and perceptions. Conducting the workshop with physics teachers may be sufficient to inspire the necessary changes to behaviour and to their students comfort in the classroom and sense of belonging.

The effectiveness of the activity itself may best be measured by establishing control groups of similar socio-economic background to eliminate the confounding factors of parent income and parent education. Perhaps two similarly performing classes from the same school could both complete the surveys but one would run the new activity while the other class experiences the
teacher’s traditional presentation of the concept. This might present a better closed case analysis. Alternatively, running same process concurrently at two schools from different cities might more fully minimize the possibility of cross-contamination through the sharing of information.

Longitudinal studies on the sample population will close the loop on this research sample population by determining the ultimate career path students choose. Rates of conversion to engineering education compared against the provincial population may identify the long term success of this research activity, in spite of the confounding factors noted above.

Chapter Conclusions

This research created a solid foundation for further work into dispelling gender stereotypes in high school physics classes. It builds on research that identifies the influence of education on building and reinforcing cultural stereotypes and expands the work of feminists through later decades to identify inequities and gender workplace needs. The results demonstrate the successful testing of the impact of an inquiry-based in-class activity on dispelling gender differences in destiny and control, increasing student comfort in studying physics, building connections between applications of physics and students’ life experience, and strengthening students’ feelings of belonging. These factors contribute to self-efficacy and interest in physics, which may translate into increasing the participation of women in engineering education. Whether the observed changes persist and influence students’ post-secondary educational choices can only be determined through future longitudinal research.
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women-experts/


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