GENDER EQUITY IN PHYSICS EDUCATION: FRAMING THE FUTURE OF PHYSICS EDUCATION RESEARCH IN CANADA

by

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Abstract

The overarching purpose of this dissertation is to determine if and how the field of physics education research (PER) in Canada is addressing issues of gender inequity in physics education, and to develop an expert knowledge-based framework to guide Canada’s ongoing PER to increase gender equity in physics education. Three separate but related research phases were designed to achieve this purpose and address specific research questions: What can be learned from PER experts about supporting gender equity in physics education? What is the landscape of PER in Canada; who are our PER experts and what are their areas of research focus? What do Canada’s experts consider to be the most pressing needs and priorities to address the gender equity issue? And what is a framework that could guide and support Canada’s ongoing PER to achieve gender equity in physics education? The research questions were approached with a pragmatic worldview, a feminist and critical theoretical lens, and a qualitative-dominant mixed-methods paradigm, and addressed using qualitative and mixed-methods methodologies—content analysis, interviews, questionnaires, and the Delphi technique.

Phase one describes the sought-after lessons from experts in gender equity PER in the form of three major themes relating to what is currently known and unknown about gender equity in physics education, moving toward gender-equitable physics education, and conducting and using PER as a tool. Phase two describes, for the first time, the landscape of PER in Canada in terms of characteristics of Canadian PER engagers and their areas of research focus, as well as five themes representing this complex field with challenges to its members and progress. Phase three describes resulting consensus levels from the Delphi process concerning what Canada’s physics education researchers consider to be priorities for addressing gender inequity in physics education, as well as six themes representing the commentary during this structured communication process. The data from all three phases of this research are synthesized and integrated into an iterative framework intended to guide, both practically and theoretically, ongoing PER in Canada to increase gender equity in physics education.
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Table of Contents

Abstract.................................................................................................................................................. ii
Acknowledgements................................................................................................................................. iii
List of Figures ....................................................................................................................................... viii
List of Tables .......................................................................................................................................... ix
Chapter 1 Introduction .............................................................................................................................. 1
  The Researcher ....................................................................................................................................... 1
  Introducing the Study ............................................................................................................................ 1
    Format ............................................................................................................................................... 1
    Terminology ....................................................................................................................................... 1
    Research Problem .............................................................................................................................. 4
Literature Review and Map ........................................................................................................................... 5
  Exploring Gender in Physics ................................................................................................................. 5
  Western and North American Historical Context ............................................................................... 6
  Feminist Critique of Science ................................................................................................................. 7
  Feminist Critique of Science (Physics) Education ................................................................................. 9
  History of Physics Education Research in North America ................................................................. 10
  Topics of Physics Education Research ............................................................................................... 12
    Equity a Growing Concern in Physics Education ........................................................................... 13
  Perceptions About Physics Education Research ................................................................................ 13
  Constructing Physics Education Researchers .................................................................................... 14
  Use of Theory in Physics Education Research ................................................................................... 15
  Physics Education Research Paradigms ............................................................................................... 15
  Shifting Priorities in Physics Education Research ............................................................................. 16
  Potential for Physics Education Research to Increase Equity in Physics Education ...................... 19
  Physics Education Research’s Current Limitations and Challenges .................................................. 20
    Summary ........................................................................................................................................... 22
  Purpose .............................................................................................................................................. 25
Research Questions ................................................................................................................................. 25
Conceptual and Theoretical Framing ......................................................................................................... 25
  Conceptual Framework ....................................................................................................................... 25
  Theoretical Framework ........................................................................................................................ 26
Methodological Framework .................................................................................................................... 28
Worldview ........................................................................................................................................................................... 28
Paradigm .................................................................................................................................................................................. 29
Context ..................................................................................................................................................................................... 29
Research Design ....................................................................................................................................................................... 30
Summary of Methodology .......................................................................................................................................................... 31

Chapter 2 Phase One: Learning from Five International Researchers About Supporting Gender Equity in Physics Education .................................................................................................................................................................................. 33
Introduction .................................................................................................................................................................................. 33
Methods ........................................................................................................................................................................................ 34
Identifying and Recruiting the Experts ........................................................................................................................................ 35
The Experts .................................................................................................................................................................................... 35
Interviewing the Experts ............................................................................................................................................................... 36
Analyzing the Interviews ............................................................................................................................................................. 36
Results .......................................................................................................................................................................................... 37
Theme One: What is Known and Unknown About Gender Equity in Physics Education ......................................................... 38
  Gender Equity is a Social Justice, Socio-Historic, and Cultural Issue ...................................................................................... 38
  Current Physics Education Research-Based Knowledge ........................................................................................................ 39
  Lack of Knowledge on How to Support Gender Equity Well .................................................................................................. 40
  Gender Equity-Supportive Practices in Physics Education .................................................................................................... 41
Theme Two: Toward Gender-EQUITABLE Physics Education .................................................................................................. 42
  Address Problematic Physics Education ................................................................................................................................ 42
  Enable Change .............................................................................................................................................................................. 46
  Education-Related Reform and Physics Education Research Group Initiatives ..................................................................... 48
Theme Three: Conducting and Using Physics Education Research as a Tool ............................................................................ 53
  Situating PER and PER People ................................................................................................................................................ 53
  Role of PER Experts, PER Community and PER Researchers .............................................................................................. 55
  PER Approaches and Approach Issues ................................................................................................................................... 56
  Expert Guiding Principles and Goals for Gender Equity PER .................................................................................................... 60
  Current Needs and Priorities for PER ..................................................................................................................................... 61
Discussion .................................................................................................................................................................................... 63
Conclusion .................................................................................................................................................................................... 68

Chapter 3 Phase Two: Characterizing Canadian Physics Education Research and Understanding its Approach to Gender Equity .................................................................................................................................................................................. 69
Introduction .................................................................................................................................................................................. 69
Chapter 4 Phase Three: Defining Current Issues and Priorities for Canadian Physics Education Research to Address Gender Inequity: A Delphi Study

Introduction .................................................................................................................................................. 101

Methods ...................................................................................................................................................... 102

The Delphi Method ..................................................................................................................................... 102

Procedure .................................................................................................................................................. 103

Participants ................................................................................................................................................. 106

Validity Efforts .......................................................................................................................................... 108

Results .......................................................................................................................................................... 108

Questionnaire One ....................................................................................................................................... 109

Questionnaires Two and Three .................................................................................................................. 112

1. I Consider the Following to be Current Issues in Physics Education Related to Gender Inequity .............................................................................................................................................. 112

2. I Consider the Following to be Current Research Needs, Priorities, and/or Guiding Principles for PER Aiming to Address Gender Inequity in Physics Education ................................................................................................. 115
3. I Think the Following Guidance, Supports, and/or Developments Could Help the PER Field in Canada Address Gender Inequity in Physics Education

Thematic Analysis of Comments

Discussion

Conclusion

Chapter 5 Conclusion

Addressing the Purpose

Developments in the Field

Key Findings

Phase One

Phase Two

Phase Three

Conclusions

Framework

Components

Utility

Significance and Theoretical Implications

Implications for Practice and Policy

Implications for Methodology

Limitations

Moving Forward

References

Appendix A General Research Ethics Board Clearance Letter

Appendix B Physics Education Research in Canada Questionnaire
List of Figures

Figure 1 Literature Map .......................................................................................................................... 24
Figure 2 Conceptual and Theoretical Framework ......................................................................................... 28
Figure 3 Study Design ................................................................................................................................. 31
Figure 4 Variables of Interest Present in Online Biographies ................................................................. 75
Figure 5 Canadian PER Engagers' Areas of Research by Self-Reported Level of Expertise .................. 79
Figure 6 Canadian PER Engagers’ Areas of Research Focus by Department .............................................. 80
Figure 7 Canadian PER Engagers’ Age by Number of Years Engaged with PER .................................... 81
Figure 8 Expertise Scores of Canadian PER Engagers ............................................................................... 83
Figure 9 Percentage of Participants’ Areas of Research Focus ............................................................... 107
Figure 10 Framework for the Guidance and Support of Canadian PER for Addressing Gender Inequity in Physics Education .................................................................................................................. 149
Figure 11 “If, then...” Statement Structure for Framework Users to Identify and Connect Activities to Desired Outputs and Effects ................................................................................................................. 152
# List of Tables

Table 1 *Summary of Methodology* ........................................................................................................................................32

Table 2 *Summary of Resulting Themes from Thematic Analysis of Experts’ Interviews* ........................................37

Table 3 *Variables of Interest* ........................................................................................................................................71

Table 4 *Response Rate for “PER in Canada” Survey* ........................................................................................................76

Table 5 *Summary Data for “PER in Canada” Survey Results* ..........................................................................................77

Table 6 *Response Rates for Each Delphi Questionnaire* .................................................................................................109

Table 7 *Statements Generated in Response to Three Prompts on Round 1 Questionnaire* ........................................109

Table 8 *Consensus Levels for Prompt 1 Items in Questionnaire 2 and Questionnaire 3* ............................................113

Table 9 *Consensus Levels for Prompt 2 Items in Questionnaire 2 and Questionnaire 3* ............................................115

Table 10 *Consensus Levels for Prompt 3 Items in Questionnaire 2 and Questionnaire 3* ...........................................118

Table 11 *Stability of Consensus Among Questionnaire Items That Reached Consensus* ........................................120

Table 12 *Characterizing Themes with Category Composition and Prominence* ......................................................122

Table 13 *Overall Distribution of Participant Comments Across Themes and Questionnaire Prompts* ................124
Chapter 1

Introduction

The Researcher

I preface this dissertation with a brief statement about my inspiration and dedication to enable women’s progress in physics education. I am compelled by my personal experiences with gender inequities in physics as a young woman, and feel a responsibility rooted in my various privileges, to conduct this research.

Introducing the Study

Format

This study is written in the style of a multiple-manuscript dissertation. Five chapters comprise the dissertation. Chapter 1, the introductory chapter, includes a literature review, the purpose and research questions, conceptual and theoretical frameworks, and a summary of the methodological framework for the study. Chapters 2, 3, and 4 are individual manuscripts that address the research questions separately. Chapter 5, the final chapter, concludes the dissertation by drawing the manuscripts together through a synthesis of each manuscript’s contributions.

Terminology

For clarity of meaning, this section defines the important terms I use throughout the dissertation.

Physics education is the teaching and learning of physics at all levels of education. Encounters with physics in elementary school, grade 9 through 12, post-secondary, and graduate levels are included. Physics education includes the intellectual, socio-emotional, and cultural experiences within the context of physics education, for both teachers and learners. Not included in my definition of physics education are experiences of physics teaching and learning outside of
school and formal physics education because this study focuses on improving experiences within
the formal physics education context.

An education researcher is a scholar who conducts studies in the field of education. 

*Education research*, according to the American Educational Research Association (AERA), is:

> The scientific field of study that examines education and learning processes and the
> human attributes, interactions, organizations, and institutions that shape educational
> outcomes. Scholarship in the field seeks to describe, understand, and explain how
> learning takes place throughout a person’s life and how formal and informal contexts of
> education affect all forms of learning. Education research embraces the full spectrum of
> rigorous methods appropriate to the questions being asked and also drives the
> development of new tools and methods (AERA, n.d.).

I include this definition of education research because it conveys the complexity of aspects that
influence the education process. The definition also identifies research methods as the means to
answer research questions, which aligns well with my pragmatic worldview that focuses on
possible applications to solve problems.

A subfield of education research, *physics education research* (PER) is limited to the
study of teaching and learning of physics. PER originated when post-secondary physics teachers
began recognizing that their students were not learning what they were being taught (Beichner,
2009); however, PER has now expanded to include studies about the teaching and learning of
physics at any level of education (e.g., Hazari, Brewe, Goertzen, & Hodapp, 2017). According to
researchers in the field, “PER is the study of how people learn physics and how to improve the
quality of physics education” (Cornell, n.d.). Similarly, “PER focuses on understanding how
students learn physics at all levels and developing strategies to help students with diverse prior
preparations learn physics more effectively” (Singh, 2014). I do not limit my definition of PER to
specific topics, methodologies, or education levels because part of the study objective is to
understand the entire landscape of PER in Canada. This task requires a broad understanding of
what PER entails. In addition, the study was designed to produce results with maximum
applicability to physics education researchers engaged in any type of PER.
Physics education researchers are individuals who study the teaching and learning of physics. Traditionally, these were physicists situated in post-secondary physics departments when the PER field was established in the 1970s, but researchers from other disciplines began engaging with and conducting PER, increasing the interdisciplinarity of physics education researchers. Now, physics education researchers are not only physicists but researchers of any disciplinary background who find an interest in studying the teaching and learning of physics. Education, psychology (including cognitive science), cultural studies, and gender studies are examples of disciplines from which PER has drawn, as researchers from those areas of study have conducted research about the teaching and learning of physics. Still, most physics education researchers work in Education and Physics disciplines; thus, participants for this study were recruited from these domains.

The study looked closely at if and how gender equity in physics education is studied by physics education researchers. Gender is a term that represents the meanings of masculinity and femininity that our Western culture attaches to the biological sex categories of male and female (Keller, 2001). There is a long Western cultural history of associating physics—as a natural science with a central claim to objectivity—with masculinity and male thought (Keller, 2001). The culture bias of physics perspective explains that physics culture is bound by masculine tendencies and preferences, i.e., it is not a gender-neutral subject and therefore may deter or alienate any individual lacking such tendencies (Hazari & Potvin, 2005). The bias is transmitted socially, academically, and through pedagogy as an enactment of physics culture; therefore, physics education is a context in which gender inequity should be targeted. Gender equity in physics education describes the quality of physics teaching and learning that is unbiased and free of barriers constructed on the basis of gender. It describes physics education that provides for each student what they need to be successful in physics learning. Gender equity does not describe gender equality, where statistically, equal representation of men and women in physics education
is the primary goal, or gender fairness, where all men and women physics students are provided identical support. Equity is “A condition or state of fair, inclusive, and respectful treatment of all people. Equity does not mean treating people the same without regard for individual differences” (Ontario Ministry of Education, 2013, p. 64). My research is driven by the goal for physics education to be *gender-equitable*, meaning that physics education poses no barriers to students on the basis of gender and supports all students in the ways they require to be successful.

Specifically, the study focuses on *women* learners of physics. I am careful to choose *women*, the social construction, rather than *females*, the biological categorization, because I intend for the language I use in the study to be inclusive of all individuals who identify as women. While creating a definition for *women* seems to counter this effort by defining who they are and are not, I offer a definition that aims to include as many women’s identities as possible, including those poorly represented in research: women of colour, with disability, lower in socioeconomic status, of indigenous heritage, and of the LGBTQ+ community, among others.

**Research Problem**

One of the largest and longest-standing issues in the field of physics is the underrepresentation of women (Skibba, 2019; Xu et al., 2015; Strickland, 2017). In Canada, women represent only 24% of physics undergraduate students, 15% of physics master’s students, 23% of physics doctoral students, and 16% of physics faculty (Strickland, 2017). Women participating in physics play an essential role in Canada’s economic and research future by contributing their potential to maximize research excellence and broaden horizons with diverse perspectives (Naylor et al., 2017). It is of major importance to enable women’s participation in physics and mitigate detrimental effects on women’s and the field’s potential.

Women’s participation in physics is strongly dictated by their experiences in physics education (Kanny, Sax, & Riggers-Piehl, 2014). It has been argued that physics education is failing women, as evidenced by their underrepresentation at all levels (Hazari & Potvin, 2005;
McCullough, 2002; McKenna, 2011). Reasons include stereotype threat (Deemer, Thoman, Chase & Smith, 2014), biased assessments (Hofer, 2015), and gendered teacher expectations (Häussler & Hoffmann, 2002), among other barriers related to women’s experiences in physics education such as physics’ image (Mainhood, 2017). Despite nearly 50 years of physics education research and vast initiatives to improve physics education (Preodi-Cross et al., 2013), women remain underrepresented and thus gender equity remains a pressing concern (Hango, 2013).

While the topics, methods, and methodological choices of physics education researchers are increasingly diversifying to include investigations of the problem of women’s underrepresentation (Heron, 2018), the problem remains resistant to progress. The “breadth of research available on the topic of the gender gap in STEM [science, technology, engineering, and mathematics] relative to the modest progress that has been made in women’s STEM participation” is shocking (Kanny et al., 2014, p. 143). I reviewed existing literature to seek out knowledge about how physics education in Canada can better support positive experiences for women; however, I found an absence of literature on this topic in the Canadian context, and the PER experts on gender equity in Canada were not easily identified.

**Literature Review and Map**

Literature about the underrepresentation of women in physics frames and provides the rationale for the educational research problem presented in the previous section. The current section presents a wider review of existing literature to depict the current gaps in knowledge that led to this research. Literature also serves as the basis for comparison to the patterns and themes that emerged from the findings at the end of the study.

**Exploring Gender in Physics**

The relatively young field of PER is situated on the vast backdrop of an unfortunate history of exclusion and discrimination in physics and science as a whole. Understanding the history of women in physics and science is important because it contextualizes not only the
achievements of inclusion and representation of minorities in physics to date, but also the substantial injustices that endure in physics today and confront PER.

**Western and North American Historical Context**

Although women did not receive access or recognition in science academies, or have access granted to universities for more than 700 years, they have participated in science since antiquity (e.g., Hypatia the philosopher, astronomer and mathematician). In the first book that mentions the problem of women in science, *Book of the City of Ladies*, written in 1405, Christine de Pizan questioned if women have made original contributions in the sciences. Yes, she emphasized, given women’s contributions to the invention of writing, calculation, knitting, and making of bread and tapestries (Schiebinger, 1992). Much later than these ancient discoveries, the Church dominated learning throughout the Western world in monasteries and universities; the denial of women’s membership to these institutions set a negative precedent for women’s participation in the following centuries. In fact, women came to be regarded as disruptive or hindrances to serious intellectual pursuits (Schiebinger, 1992).

Tradition and culture trumped the election of women’s participation in such institutions, regardless of whether the woman in question was contributing profoundly to science (e.g., Marie Curie was denied membership to the Académie des Sciences in Paris, even after winning the Nobel Prize in Physics). The traditions and cultures westerners upheld were further crystallized during the eighteenth century around the industrial revolution. Schiebinger (1992) describes a sexual division of labor in which science fell onto the terrain of the male sex. By the 1920’s, the sciences dominated by men were medicine, engineering, and chemistry, whereas women dominated the less prestigious and lower-income fields of botany, zoology, and psychology.

Explanations for the disparities have been suggested throughout history and can be categorized as three major perspectives: a) biological determinism, suggesting women are not innately capable of science as men are; b) social Darwinism, suggesting women are men whose
evolution paused in a primitive stage, or that they have been socialized differently than men (Hazari et al., 2010); and c) a perspective that suggests a woman’s intellectual development can only be maximized at a great cost to her reproductive development—a Harvard doctor once argued that if women exercise their brains their ovaries would shrivel (Schiebinger, 1992).

**Feminist Critique of Science**

Evelyn Fox Keller, physicist and feminist philosopher, describes the intricate relationship between gender and science (1983; 2001). Specifically, she describes the association of *masculinity* with *scientific* as a topic that seems to have a myth-like status among academic critics who avoid taking the topic seriously in formal philosophical and sociological criticism. Myths surviving in science, of all fields—the “archetype of anti-myth” (1983, p. 187)—seem most in need of investigation. However, “unexamined myths . . . affect our thinking in ways we are not aware of, and to the extent that we lack awareness, our capacity to resist their influence is undermined” (Keller, 1983, p. 187). While the myth may survive, exposing the truth is crucial. The fact that the make-up of the scientific community is overwhelmingly male does not by itself explain the attribution of masculinity to science as an intellectual domain. Rather, the fact and reality that the majority of people participating in science are male is actually “a consequence rather than a cause of the attribution of masculinity to scientific thought” (Keller, 1983, p. 188).

The association of masculinity with scientific thought began with the belief that women were innately inferior to men and as a result they did not possess the strength, rigor and clarity of mind to do science. While this idea has become less popular and offensive when openly broadcast, society and science are far from free of this long-held belief. Our daily language continues to express stereotypical associations of masculinity with science and objectivity. For example, when we refer to the natural sciences as “hard” and the more subjective branches of science as “soft,” Keller argues, we implicitly suggest a gendered metaphor in which hard is
masculine and soft is feminine. Scientific thinking is synonymous with masculine and objective, while feminization is synonymous with sentimentality and feelings.

Our social and cultural association of science and objectivity with masculinity has consequences (i.e., underrepresentation of women) and secondary implications. “Not only does our characterization of science thereby become coloured by the biases of patriarchy and sexism, but simultaneously our evaluation of masculine and feminine becomes affected by the prestige of science” (Keller, 1983, p. 202). What we know as scientific receives extra value from the cultural preference for what we know as masculine. At the same time—in this mutually reinforcing process—what we know as feminine is devalued because it is excluded from the social and intellectual value placed on science. However, these dichotomies are not necessarily inevitable. Analysis of the topic makes room for and emphasizes the possibility of alternative realities. In challenging the association between scientific and masculine, their interaction with one another and other constructs may be freed from such rigid definitions. The ramifications of this could include a higher level of accessibility in science for women, removing constraints on the definitions of scientific and objective, expanding what these ideas mean, and challenging old dogma within and outside of science.

In her modern feminist critique of science, Inferior: How Science Got Women Wrong—and the New Research That’s Rewriting the Story, Angela Saini (2017) argues, through critical analysis, how the field of science was born from a patriarchal system of valuing and giving power to what we know as masculine. During the Enlightenment Era, when reason and rationalism prevailed, science was granted the privilege of constructing knowledge about nature, including human nature. Darwin and other early biologists believed women to be naturally inferior to men, yet the reality is that women were systematically suppressed throughout history and were not permitted to develop their talents. Such realities can be revealed through feminist science studies,
which “illuminate practices of devaluation, marginalization, and exclusion linked to gender, race, class, sexuality, disability, and colonialism” (Roy, 2016, p. 832).

**Feminist Critique of Science (Physics) Education**

Physics education is not immune to the above practices as a derivative of the broader domain of science. Physics education, like science—with its authority of knowledge production and social value—has played a role in producing, sustaining, and justifying social inequalities and power systems (Roy, 2016, p. 832). Studies in science education have tended to ignore the interplay of sex, the body, and biology in the social construction of gender (Gilbert, 2001). They also tend to obsess over finding differences between females and males, despite no counter evidence to the fact that girls and boys overlap on nearly every behavioural and cognitive gap measured—there are no “general intelligence” gaps between men and women as far as measures for intelligence, cognitive ability, and mental ability go (Saini, 2017). In these cases, gender has been viewed as a fixed construct, which establishes a nonexistent dichotomy between feminine and masculine: a stance that limits theoretical and empirical explorations of gender in science education.

However, when we understand gender as a social construction, we understand the important role for education to support all students’ constructions and enactments of their gender. For physics education, this means that it examines its construction of *physics student*, supports the needs of girls and women, and mitigates barriers to their participation and success.

The curriculum reforms that happened in Canada and the United Kingdom in the 1970s and 1980s began to address the fact that science curriculum was ignoring the needs of girls. Eventually, guidelines for nonsexist curriculum materials were created, sexist guidance materials were eliminated, and the efforts to increase girls’ interest in science began (Blair, 1998). However, the prevailing approach to improving gender parity in science and research on this topic was to “add women and stir,” which fails to question the crux of the problem, which lies in
the education (Roy, 2016, p. 835). Research focused on how girls should fit science, rather than how science should fit girls. Blame was and is still often placed on girls for their differences. Early science education research showed reluctance to consider the masculine nature of science as an explanation for the gender gap.

In the next section, physics education research, specifically, is examined from its beginnings to its current approaches to the gender inequities persisting today.

**History of Physics Education Research in North America**

Physics education research as a field in North America has a rich history, and has been described by a number of American physics education researchers (American Association of Physics Teachers, n.d.; Beichner, 2009; Cummings, 2011). The beginnings of the field can be argued to have stirred in the 1960s with the research of Robert Karplus and Fredrick Reif at Berkeley or Arnold Arons at the University of Washington. These pioneers and other early physics education researchers agree that the discipline began in the 1970s. At this time, U.S. PER publications began appearing (Cummings, 2011). The major impetus for the birth of the discipline was physics faculty’s realization that students were not learning what was being taught. Additionally, there were federally funded science curriculum improvement projects around the same time. In her developmental history of physics education research, Cummings (2011) suggests that the Sputnik era prompted the government and education officials to shift physics education from a *gatekeeper* course to a *gateway* course; the country could not afford to leave it up to chance that enough students would “have what it takes” to succeed in physics courses as they were. Hence, funding and early research for physics education provided a foundation for growth.

The first PhD in physics education was granted to Pat Heller in 1977 from the School of Education while she was a Teaching Assistant at the University of Michigan. The first organized PER group in a department of physics was at The University of Washington initiated by Lillian
McDermott, from which the first physics PhD in physics education was granted to David Trowbridge in 1979. Trowbridge and McDermott’s Piagetian-based papers on velocity and acceleration are recognized as the first “modern” physics education research publications (Beichner, 2009). The major research focus on physics education at this time was on student understanding of concepts taught in physics.

The history of PER in Canada, specifically, remains undocumented. The Canadian field of PER is young and less well-developed than that in the US where the majority of the literature has emerged from physics education researchers and/or their established PER groups. However, that is not to say the Canadian PER field is negligible; in fact, the opposite is true. Among Canadian physicists there is a growing interest in PER. Doctoral programs in PER are offered at the University of British Columbia, the University of Calgary, and Concordia University, and while the overall membership in the Canadian Association of Physicists (CAP) has remained constant, membership in the Division of Physics Education (DPE) has increased by more than 50% in less than ten years (Antimirova, Kalman, & Lasry, 2014). Compared to 2005, when only two DPE sessions were held at CAP, there were five sessions and a joint session with the Committee to Encourage Women in Physics (CEWIP) in 2013 (Antimirova et al., 2014).

While still not boasting as long a history nor extensive reach as PER in the US, Canadian PER is growing and shares the same philosophy and goal regarding gender equity: paying more attention to improving physics education will help mitigate the loss of learners who reject physics due to various inequities (Antimirova et al., 2014). The existing literature on the Canadian PER field indicates the following are PER subfields: cognitive mechanism, curriculum and instruction, epistemology and attitudes, institutional change, problem solving and reasoning, research methods, socio-cultural mechanisms, student conceptions, teacher education and teaching assistant training, and effective use of technology in teaching (Antimirova & Goldman, 2008).
Topics of Physics Education Research

Ding (2019) refers to what PER investigates as “abstract, socially constructed, and often elusive entities in teaching and learning processes” (p. 3). Physics education researchers seek to investigate what Ding calls a second order construction; the first order construction is the students making sense of the world, and the second order construction is the researchers making sense of the first order construction (Schutz, 1967). As there are vast constructions which are part of the processes of teaching and learning physics, Heron (2018) helpfully categorizes PER topics into three domains: intellectual, affective and personal, and social and cultural.

The intellectual domain of PER is defined as research on how learners develop and apply their understanding of physics and the natural world. Examples include conceptual understanding, “thinking like a physicist,” reasoning (including spatial-visual reasoning), quantitative problem solving, measurement and experimentation, mathematical thinking in physics contexts, the epistemology of physics, and ideas about the nature of teaching and learning (Heron, 2018). Other topics in this domain include the examination of popular PER assessment instruments (Ding, 2014; Henderson, Miller, Stewart, Traxler, & Lindell, 2018; Traxler et al., 2018), and focusing on students’ learning difficulties (Meltzer, 2003).

The affective and personal domain of PER is defined as research on learners’ emotional experiences and how they view themselves in relation to physics. Self-efficacy, identity, attitudes, expectations, and personal epistemology are examples of topics in this domain (Heron, 2018). More specific examples include student persistence in physics, changes in student career-related beliefs (e.g., interest) and academic success (Dou & Zwolak, 2019).

The social and cultural domain of PER is defined as “research on the classroom environment, the culture of physics, and the influence of the broader culture in which learners operate” (Heron, 2018, p. 5). Examples include classroom and school/institutional environments, social networks, group dynamics, and participation of underrepresented groups, which includes
women, people of colour, people who have a disability, and people who identify as LGBTQ (Heron, 2018). The topics of equity and gender form a subdomain of this type of research.

**Equity a Growing Concern in Physics Education**

On equity, Kanim and Cid (2020) note the growing awareness of the issues in PER: “The relative racial, gender, and socio-economic homogeneity of the overall physics community is an issue that in recent years is an increasing focus of the physics education research community” (p. 22). Questions of equity examined through PER relate to social justice, gender, race, ethnicity, socioeconomic status, equality of education, quality of education, and fairness, among others (Rodriguez et al., 2012). PER’s increasing focus on equity has “pushed the boundaries beyond focusing on performance gaps and curricular issues, looking into bias, attitudes, affirmation and sense of belonging, and other people-focused issues” (McCullough, 2018, p. 8). The ways in which the intersection of people’s gender with additional identities is an example of further boundary-pushing which the field of PER is broaching (Blue, Traxler, & Cochran, 2019).

**Perceptions About Physics Education Research**

Boundary-pushing is rarely welcome without pushback. Initially, PER was viewed by physicists skeptically, even with hostility, or was dismissed altogether because it was not seen as worthy physics research (Cummings, 2011). As acceptance grew, it was widely argued that for PER to be influential, valid, and useful, it is necessary that PER be conducted by physicists in physics departments (Heron & Meltzer, 2005). PER was not acceptable if conducted by individuals who merely had strong subject knowledge; such research would not represent the strength of PER, which was argued to be a “unique enterprise in which the techniques are strongly coloured by the discipline in which it is embedded” (Heron & Meltzer, 2005, p. 391). While social scientists gave physics education researchers little respect for they did not rely on established research methodologies in the humanities, educators tended to favour physics education researchers since their work was consistent with the experience of good teachers
(Cummings, 2011). In his history of PER, Beichner (2009) commented on this sometimes problematic dynamic between physics education researchers and education researchers: “An unfortunate truth is that some physics faculty will only listen to other physicists, and not regard the work of science education researchers as valid” (p. 4). This is problematic, indeed, since PER and education researchers can benefit from each other’s knowledge and background, and as Beichner (2009) notes, education researchers often have training in complicated methodologies useful in PER.

**Constructing Physics Education Researchers**

“Who are physics education researchers?” asks Beichner (2009) in his history of PER. Before physics education was accepted as a legitimate subfield of physics, physics faculty members whose roles were described as focused on “physics education” were solely focused on teaching. As PER became increasingly accepted, so too did the role of physics education faculty as those who conduct rigorous research on how students learn physics. Much research on university-level students is conducted in physics departments by faculty because they are familiar with the “complex and often subtle aspects of physics as covered in college-level coursework and they appreciate the peculiar culture of physics” (Beichner, 2009, p. 4). Conversely, pre-university physics education research is often conducted by faculty in education departments. Beichner suggests both physics and education faculty could benefit from one another’s knowledge. I suggest that such interdisciplinary research is necessary, specifically in light of the *peculiar culture* of physics, to which Beichner refers. If students experience what physicists recognize as a “peculiar culture,” marked by strong associations with objectivity and masculinity, then an interdisciplinary research approach involving diverse researchers’ perspectives may be useful for understanding the learning experiences in such a context.
Use of Theory in Physics Education Research

Prominent physics education researchers have argued over the need for a theoretical framework in physics education research. For example, Fred Reif regards the absence of a coherent framework for PER as a limitation to significant progress, while Lillian McDermott argues a theoretical framework is not necessary for productive research to continue (Cummings, 2011). The culture of physics that physics education researchers share with their physics department colleagues offers some explanation for the cause of resistance to framing PER in theoretical terms: “For traditionally trained physicists, many education theories seem more like prescriptions of best practices or summaries of patterns in observations, rather than precise, broad, and powerful explanations invoking unseen entities, interactions and processes” (Heron, 2018, p. 12). Compounded with skepticism and discomfort, the nonuse of theory by many physics-based physics education researchers may be unsurprising. Other reasons include the perception that broader conceptual frameworks are easier to use than theoretical frameworks in guiding PER research, or the perception that very detailed educational theories may constrain the spectrum of intellectual challenges that can be addressed while researching physics education (Heron, 2018).

Although there is a lack of established theoretical or conceptual frameworks used to study physics education that are specific to PER, theories present in PER are adopted from social science fields such as education or psychology: for example, the educational theory of learning, the zone of proximal development by Vygotsky (e.g., Meltzer, 2003), or social cognitive career theory (e.g., Kelly, 2016; Mainhood, 2017) rooted in Bandura’s social cognitive theory (Bandura, 2001).

Physics Education Research Paradigms

In a content analysis study of PER published globally between 2008 and 2013, it was found that researchers mostly use quantitative methods (55.24%), secondarily use qualitative
methods (37.14%) and least frequently use mixed methods (7.62%) (Uzunboylu & Aşıksoy, 2014). Standard quantitative and qualitative PER data collection methods include surveys, assessment instruments, interviews, and participant observation. Standard data analysis methods include basic statistical techniques, coding analyses of written or video data, large-N summary/frequency analyses, discourse analysis, and case-study analysis (Russ & Odden, 2018).

Although physics education researchers’ method choices are primarily quantitative, methods are becoming increasingly diverse, especially as more PER overlaps topics and is interdisciplinary. The growth of rigorous qualitative methods has “significantly changed the face of PER” as more methods from different paradigms (e.g., qualitative and mixed methods) are being employed (Heron, 2018, p. 6). Diversifying methods is important for addressing non-traditional physics education research issues such as gender equity. PER is increasingly having philosophical discussions about quantitative methodologies (Ding, 2019), producing models for PER paradigms (Robertson, McKagan, & Scherr, 2018), and reviewing theoretical perspectives for use in qualitative PER (Otero & Harlow, 2009).

**Shifting Priorities in Physics Education Research**

Cummings (2011) posited that a wide diversity of research interest in a small field makes the PER community seem unfocused. A young American physics education researcher was quoted as saying, “[PER research] seems to have become more and more fragmented, quite divergent. This may be a natural consequence of the increasing number of researchers, but there seems to be a lack of consensus on priorities and goals of the field.” (Cummings, 2011, p. 10). Beichner (2009) also noted “Many US PER specialists are embarrassingly illiterate when it comes to knowing of relevant studies conducted in other countries” (p. 9). Considering how fragmented the physics education research community seems to be, another argument is introduced: the need for networking and collaboration among PER groups in order for their research to serve as the foundation for improved physics education.
As stated earlier, the focus of the PER field at its genesis was identifying student misunderstandings, which was researched thoroughly by systematically studying students’ difficulties in different areas of physics. The focus of the field has shifted over time, and its trajectory has moved from the early, applied research that sought to identify misconceptions, toward research on the impact of instruction on factors such as attitudes toward science and structures of knowledge, and then toward applying cognitive science methodologies (Cummings, 2011). The specific research priorities of PER have included topics such as problem solving, epistemology, student attitudes, social aspects, technology, and evaluation of interventions and instructional materials (Beichner, 2009).

Recently, gender in physics has become a major political and research priority, as evidenced by increasing publications on the issue of underrepresentation. While the definition of gender has been seen to shift throughout time as a culturally constructed idea, the issue of gender equity in physics stands unimproved. In 2019, the American Association of Physics Teachers published a resource letter, *Gender and Physics*, for researchers tackling the subject (Blue et al., 2019). In 2016, the *Focused Issue: Gender in Physics*, was published in *Physical Review Physics Education Research*. As part of the National Research Council’s report *Adapting to a Changing World: Challenges and Opportunities in Undergraduate Physics Education*, gender and underrepresentation is a key issue explored, among other contemporary needs outside the traditional physics education paradigm (NRC, 2013). Most recently, the Canadian Association of Physicists conducted a national survey focused on equity, diversity, and inclusion (EDI) in physics in Canada, for which they released preliminary results (Smolina et al., 2021). Expanded results will be published in a special issue of their publication *Physics in Canada* that will feature EDI-related contributions from authors across the country.

As the demographics of physics classrooms and laboratories are changing, along with the shifting needs for learning and skills in the 21st century, the traditional physics education
paradigm requires shifting as well. Overall, the enrollment of students in post-secondary education is increasing, as is the fraction of part-time students, students over 25 years old, students who represent an ethnic minority, and those taking online courses or dual degree courses (NRC, 2013). Interestingly, the growth of students majoring in general STEM fields has grown 200% between 1965 and 2005, but the growth in physics majors is only 20% in comparison (NRC, 2013). The National Research Council (2013) also noted, according to data from the National Centre for Education Statistics, that only 3% of all undergraduate students are enrolled in a physics course at a given point in time, and of these students only slightly more than 1% will go on to earn a physics degree. While this dictates that most students do not take a physics course, most of those who do stop once they fulfill their program requirements. Another possible (and well-documented) explanation, however, is that there are barriers to students’ election and persistence in physics, and certain students are most susceptible to threats posed by such barriers (Chen and Thomas, 2009; Mainhood, 2017). Both women and underrepresented minorities are less likely to elect physics, and if they do, they are less likely to persist in that program (Chen and Thomas, 2009). “Physics majors have the lowest percentile representation of African American, Hispanic, Native American, and female students in the liberal arts and science disciplines” (NRC, 2013, p. 29).

Physics education is failing to support young women, which is evidenced by the unfortunate reality that increased enrollment in high school or university physics does not translate to more women graduating with physics degrees. In fact, as can be observed in Canada, the numbers of women in physics decrease as the level of academia increases. That is, while there is almost gender parity at the high school level across Canada, women represent only 24% of physics undergraduate students, 15% of physics masters students, and 23% of physics doctoral students (Strickland, 2017). These figures and barely-improving trends are reflected at the professional level, where the number of women working in STEM has increased, but only from
20% in 1987 to 21% in 2004, a mere 1% increase in almost two decades (Statistics Canada, 2011). The number of women entering and persisting in the physics field cannot be expected to increase unless physics education is gender-equitable, meaning that it not include barriers to young women’s participation and persistence.

Recently, the five most prevalent themes in literature related to the gender gap were identified as background characteristics, familial expectations and beliefs, kindergarten to Grade 12 experiences, psychological factors, and perceptions of the field (Kanny et al., 2014). Experiences relating to the affective domain, namely student motivation, attitudes, perceptions and values, can either enhance or inhibit student physics learning (NRC, 2013). Such factors are influenced by the educational environment in which students learn, which is the foundational rationale for demanding that physics education be gender-equitable. Stereotype threat (Steele, 1997) and self-efficacy (Bandura, 1986) are two early-studied examples of the relationship between affective domain characteristics and women’s performance in physics that can be hindered.

**Potential for Physics Education Research to Increase Equity in Physics Education**

The current approach to solving the gender inequity problem in physics education in the U.S. involves PER. Physics education research is cited as a foundation for improving physics education (NRC, 2013). There are six suggested priority areas for PER: (a) student conceptual understanding, reasoning and problem solving, and learning processes in physics; (b) role of physical and social environment in physics learning; (c) participation and achievement of students from underrepresented groups; (d) preparation of future physics teachers; (e) assessment of student progress; and (f) sustainable research-informed pedagogy (NRC, 2013). Specifically, the National Research Council committee urges that,

The community must undertake a systematic process that draws on discipline-based research on student learning and on rigorous assessment of the degree to which students are acquiring the knowledge, skills, and attitudes that are needed to solve 21st-century
problems. Change in the academic culture is required in order to encourage, enact, spread, and sustain these improvements (2013, p. 82).

The 2019 *Gender and Physics* academic resource letter for researchers questioning gender and physics supports PER in efforts to achieve gender equity in physics education. First, statistics, reports and reviews of the literature help orient researchers to what is currently known about gender and physics. Theoretical resources in gender theory, feminist science studies, and education theory help situate gender in light of powerful Western cultural norms and also help in “unearthing and questioning assumptions about what gender means” (Blue et al., 2019, p. 618). Resources on intersectionality help researchers studying gender in physics understand the complex intersections of gender, as only one socio-demographic identity, with multiple others, such as race. Resources addressing the impact on participation and experiences for women at all levels of education and workplace are offered—by theme—since there are so many impacts: implicit bias and stereotype threat; micro and macroaggressions; belongingness and identity; and socialization, cultural impacts, and social capital. This large group of resources helps researchers make methodological decisions about gender with research on how society and culture influences who participates in physics and what they experience. Finally, resources on women’s career choice and sexism in physics careers offer further perspectives on how women are inhibited or supported in pursuing a physics career.

**Physics Education Research’s Current Limitations and Challenges**

A limitation of equity-related PER is the predominant trend to focus on gaps, and on closing gaps, which means comparing students and searching for equal outcomes. This type of research mistakes equity to be equality. Rodriguez et al. (2012) urge, “it is important to realize that equity goes beyond quantitative differences in achievement and can be concerned with the individual, with excellence, and with fairness and justice” (p. 4). Similarly, Kanim and Cid (2020) found that PER studies tend to: rarely focus on high school students; focus on students in calculus-based introductory physics courses; focus on institutions whose students have strong
math preparation; focus on institutions with wealthier students and a small fraction of underrepresented students compared to the overall post-secondary-bound student population; and have highly homogenized sampling in upper-year physics courses. These limitations are recognized as population bias, or “cherry-picking” of data that does not represent the population of students outside the bounds of the selective universities and courses from which the data were collected.

The consequence of population bias is underrepresenting students of diverse gender, race and ethnicity in PER, all of whom are part of the overall physics student population. With the evidence that suggests narrow and non-representative PER samples, researchers are beginning to question whether our knowledge about physics education could be replicated reliably in various institutional and demographic contexts (Conlin et al., 2019). While the answer is likely, “perhaps not,” framing differences among students in an equitable way may help. This means moving away from the deficit model in which underrepresented students are compared to white, male students and are considered to be lacking in comparison to a reinforced “norm.” Moving toward a methodology that approaches differences among students more equitably (simply as a function of population) could help prevent PER from framing differences as deficiencies (Kanim & Cid, 2020).

A current challenge specific to PER is that quantitative methods are often misjudged; they are sometimes demonized for being strictly positivist or postpositivist (pursuing absolute truth of reality) or they are sometimes idolized and thought to be the ultimate scientific method for research in education (Ding, 2019). Another challenge of PER is that it struggles through its ties to quantitative methods to quantify the human cognitive and affective experience (i.e., learning). Similarly, within the data mining genre of PER methods, the knowledge gained about a classroom environment may not align with the knowledge gained at the institutional level. Also,
combining large data sets with differing standards or definitions (e.g., what defines gender) can become problematic (Ding, 2019).

In Canada, a major challenge for PER is the lack of funding on a national and provincial level meaning that PER is often initiated and completed by an individual or a small group without PER funding (Antimirova & Goldman, 2008). Only as recently as 2008, there was lobbying effort put forth by Canadian physics education researchers to the Canadian governmental funding agencies to review PER proposals.

Finally, a challenge that PER faces is the lack of collaboration among researchers in the field. This challenge is of particular concern in Canada, where there are fewer physics education researchers and groups available with whom to collaborate than in the United States. Yeung et al. (2005) used social network analysis to examine the sociological characteristics of collaboration between physics teachers/researchers. It was found that the publications of physics education researchers and the degree of collaboration between physics education researchers are much less than those found in other science fields. Moreover, PER communities form small clusters with strong internal collaboration. “These collaboration networks are highly fragmented on a global scale and the individuals writing on physics teaching are not so easily or directly connected through research collaborations” (Yeung et al., 2005, p. 150). In my effort to frame the limitations and challenges associated with PER in a forward-looking lens, there is much opportunity for growth in PER as more researchers take interest in physics education, including those from disciplines outside of physics who bring an interdisciplinary connection and potential for collaboration.

**Summary**

My review of the literature related to gender equity in physics education revealed that PER is currently conducted by researchers in education, physics, and other domains, increasingly diverse methodologies are used, and the ever-present issue of gender inequity is a concern in the
field. While the problem is resistant to progress, feminist critiques of physics education and the latest resources on gender and physics challenge PER to confront the gender-based barriers in physics education rooted in historical exclusion and discrimination of women from physics. Considering this, and the current challenges facing PER in Canada, this study’s aim is to fill a gap in our current knowledge, which is how PER can improve gender equity in physics education in Canada.
Note. Literature map providing a visual summary of the literature review. The map depicts how this study adds to and fills a knowledge gap in the existing literature related to gender equity in physics education.
Purpose

Careful consideration of the research problem and current knowledge gaps supported the development of the study’s purpose: To determine if and how Canada’s physics education researchers are working to address gender inequities in physics education, and to develop an expert knowledge-based framework to guide Canada’s ongoing PER to increase gender equity in physics education.

Research Questions

1. What can be learned from PER experts about supporting gender equity in physics education?
2. What is the landscape of PER in Canada; who are our PER experts and what are their areas of research focus?
3. What do Canada’s PER experts consider to be the most pressing needs and priorities to address the gender equity issue?
4. What is a framework that could guide and support Canada’s ongoing PER to achieve gender equity in physics education?

Conceptual and Theoretical Framing

Conceptual Framework

The concept of culture has been defined in many ways in the following classifications: 1) subjective culture, invisible and within individuals’ minds, 2) objective culture, the institutions and artefacts objectively existing and created by individuals, 3) culture as a system of behaviours, norms in thought, activity, and artefact, 4) culture as a set of meanings encoded in the norms that comprise it, 5) culture as an independently existing phenomenon apart from humans, and 6) culture as a subjective human construct (Minkov, 2013). In all cases, culture is a construct, not reality itself, but the abstract models we build to make sense of that reality. The myriad ways culture can be defined is telling of the complexity of human patterns and situations. Maintaining
this view is important in this study since I believe there to be complex interactions at play; namely, between three derivatives of culture which are central to the proposed study: gender, culture of physics, and physics education.

Gender is a construct that represents the meanings of masculinity and femininity that our Western culture attaches to the biological sex categories of male and female (Keller, 2001). Western culture has a long history of associating physics–as a natural science with a central claim to objectivity–with masculinity and male thought (Keller, 2001). The culture of physics includes the institutions, norms, meanings, and people who constitute it; largely, research and post-secondary education institutions, physicists, and physics education researchers. These are important stakeholders interacting with the construction of physics culture, and with physics education, by extension. Physics education is the teaching and learning of physics, including the intellectual, affective/personal, social, and cultural experiences within this context.

The four concepts, culture, the culture of physics, physics education, and gender together form the conceptual framework that broadly explains the important constructs in this study. These are shown in circles with dotted outlines in Figure 2.

**Theoretical Framework**

The accompanying theoretical framework serves to 1) provide the orienting lens for studying issues related to the concepts, 2) shape the research questions asked and how the data are collected and analyzed, and 3) make a call for change. Three theories comprise the theoretical framework for this study: feminist theory, critical theory, and culture bias of physics.

Feminist theory supports problematizing women’s situations and the institutions that frame their situations (Olesen, 2000). Feminist theory enables my questioning of the constraining gender constructs manifested in the culture of physics that have excluded and discriminated against women throughout history and presently. Specifically, I question the aspects of the culture of physics described as the culture bias of physics. This perspective centres on the crux of the
research problem where the culture of physics and gender meet. *Culture bias of physics* explains how physics is bound by masculine tendencies and preferences, i.e., it is not a gender-neutral subject and may discriminate against people who lack masculine tendencies (Hazari & Potvin, 2005). The bias is transmitted socially, academically, and through pedagogy as an enactment of physics culture; therefore, physics education is the context in which gender inequity is targeted in this study. Lastly, *critical theory* supports empowering people to transcend constraints placed on them by race, class, and gender (Fay, 1987). Critical theory therefore supports this research’s call to improve physics education so that it poses no barriers to any student on the basis of gender and supports all students in the ways they require to be successful.

Together, *feminist theory*, *critical theory*, and *culture bias of physics* relate the central concepts of this study and provide the orienting theoretical framework. The theories are shown in rectangles with solid outlines in Figure 2.

Figure 2 visually represents the conceptual and theoretical framing for this study. The culture of physics and cultural construction of gender are two derivatives of the overarching culture. Between these two concepts, culture of physics and cultural construction of gender, a discord exists and can be explained by the culture bias of physics perspective: The culture of physics is biased toward the masculine cultural construction of gender, which is transmitted socially, academically, and pedagogically in physics education. Feminist and critical theories orient this study to view these interactions as problematic for women and call for improvement to physics education for women’s transcendence of gender-based bias in physics education.
Figure 2

Conceptual and Theoretical Framework

Note. Conceptual and theoretical framing for the study. Concepts are shown in ovals with dotted outlines and theories are shown in rectangles with solid outlines.

Methodological Framework

This section outlines this study’s system of addressing the research questions, including my worldview, research paradigm, the context and research design of the study, and a summary of the methodology of this study by phase.

Worldview

A worldview is “a basic set of beliefs that guide action” (Guba, 1990, p. 7). The worldview which represents the values and beliefs that I hold and which guides my actions in this study is pragmatism: a practical worldview that is concerned with possible applications to solve problems (Patton, 1990). The philosophical basis or set of beliefs that constitutes pragmatism includes: acceptance that research problems exist in a world with historical, social, political and
other contexts; the potential use of a theoretical framework supporting, for example, a social justice aim; strong focus on a research problem, using all available approaches to gain knowledge about a problem; asking what and how to approach a problem to have intended consequences; and no commitment to one research paradigm (Creswell, 2014). My pragmatic worldview shapes my desire to approach the problem of gender equity in physics education, forms the philosophical underpinning to the mixed methods research paradigm of this study, and allows for choice of multiple methods that best derive knowledge about the problem.

Paradigm

More specifically describing how I seek to acquire knowledge and what I believe to be knowledge in research, is the research paradigm (Johnson & Onwuegbuzie, 2004), also known as the research approach (Johnson et al., 2007). The paradigm is “a set of beliefs, values, and assumptions that a community of researchers has in common regarding the nature and conduct of research” (Johnson & Onwuegbuzie, 2004, p. 24).

Three paradigms exist and are widely known as qualitative research, quantitative research, and mixed methods research. Johnson et al. (2007) illustrate a continuum of these three research paradigms, with the pure qualitative paradigm on the left, pure mixed in the center, and pure quantitative on the right. I am a researcher whose paradigm falls to the left side of the central “pure” mixed paradigm on this the continuum, toward the qualitative pole. I would describe my paradigm in this study as qualitative-dominant mixed methods. In relying on my pragmatic worldview, I believe that the inclusion of both qualitative and quantitative data best allows the research problem to be addressed.

Context

The geographical context of this study is in Canada, it will take place and focus on documenting and developing the PER field in this country. The research context of this study is higher education research (HER), which is concerned with improving university teaching and
learning, professional development, and issues facing those involved in higher education (Daniel & Harland, 2017). This study’s focus is on physics education researchers and the PER field, which is rooted in higher education institutions. These are spaces where physics education occurs, therefore I make the assumption in this research that the culture bias of physics penetrates this context. Therefore, my feminist and critical stance orient my view of this context as problematic and one that requires change.

**Research Design**

This study is qualitative-dominant mixed methods design. Based on Creswell’s (2014) descriptions of standard mixed methods study designs, this study does not fit the standard models, which give more detail about the order and nature of data use, such as exploratory sequential mixed methods design (not all phases in the proposed study involve mixed methods). However, with the help of Creswell’s (2014) language to describe the proposed study, I suggest *qualitative-dominant multiphase mixed methods design*. This description indicates there is more than one phase of the study, mixing of methods will occur, and qualitative methods are the primary methods employed. Figure 3 provides an overview of the qualitative dominant multiphase mixed methods design. In phase one, objectives are met using qualitative methods, the findings of which inform objectives of later phases. In phase two, objectives are met using quantitative methods and then qualitative methods, the findings of which inform objectives in phase three. In phase three, mixed methods (the Delphi technique) are used, findings from which inform the final objective of the research, which is framework development.
Study Design

**Figure 3**

**Note.** Overview of the qualitative-dominant multiphase mixed methods design, which depicts how phases follow temporally after one another and also inform subsequent research objectives. Objectives that are boxed together indicate they will be met through a single method.

**Summary of Methodology**

The system of methods, data collection, and data analysis used in this study are summarized in Table 1 according to each of the three phases that comprise the overall study. Each phase of the study is presented as an individual chapter in the following three chapters. As such, the methodological approach specific to each phase of the study is detailed within each phase’s chapter. The summary table included below is intended to provide a picture of the overall study’s methodology.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Research Question(s)</th>
<th>Research Paradigm</th>
<th>Data Collection Method(s)</th>
<th>Data Source</th>
<th>Sampling</th>
<th>Data Analysis Method(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What can be learned from PER experts about supporting gender equity in physics education?</td>
<td>Qualitative</td>
<td>Systematic search and scan of website biographies for PER engagement</td>
<td>Website biographies of Canadian and international Physics and Education faculty members who engage in PER</td>
<td>Purposive. Faculty from Canadian universities with a physics department and education department, then those with either or, starting with physics.</td>
<td>Descriptive content analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qualitative</td>
<td>Semi-structured interviews</td>
<td>Prominent international PER experts</td>
<td>Purposive and snowball. Existing knowledge and asking PER journal editors to identify prominent researchers.</td>
<td>Inductive thematic analysis</td>
</tr>
<tr>
<td>2</td>
<td>What is the landscape of PER in Canada; who are our PER experts and what are their areas of research focus?</td>
<td>Mixed methods</td>
<td>Questionnaire</td>
<td>Canadian Physics and Education faculty members who engage in PER</td>
<td>Purposive and volunteer. Questionnaire sent to all identified individuals with PER engagement and completed on volunteer basis.</td>
<td>Descriptive statistical analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semi-structured interviews</td>
<td>Canadian PER experts</td>
<td></td>
<td>Purposive. Participants selected based on “expert” inclusion criteria from questionnaire findings.</td>
<td>Inductive thematic analysis</td>
</tr>
<tr>
<td>3</td>
<td>What do Canada’s PER experts consider to be the most pressing needs and priorities to address the gender equity issue?</td>
<td>Mixed methods</td>
<td>Delphi technique (iterative questionnaire rounds)</td>
<td>Canadian PER experts</td>
<td>Purposive and volunteer. Identified experts from phase 2 will be invited to voluntarily participate in the Delphi.</td>
<td>Inductive thematic analysis and descriptive statistical analysis</td>
</tr>
<tr>
<td></td>
<td>What is a framework that could guide and support Canada’s ongoing PER to achieve gender equity in physics education?</td>
<td></td>
<td>n/a</td>
<td>Literature, phase 1 and 2 findings, and consensus results.</td>
<td>n/a</td>
<td>Integration of literature, phase 1 and 2 findings, with Delphi consensus results to develop model, guidelines, and/or recommendations.</td>
</tr>
</tbody>
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Chapter 2

Phase One: Learning from Five International Researchers About Supporting Gender Equity in Physics Education

Introduction

Many of the longstanding issues related to gender inequities in physics education are being increasingly interrogated in physics education research (PER). For example, stereotype threat (Steele, 1997; Marchand & Taasoobshirazi, 2013; Maries et al., 2018), sexism (Barthelemy et al., 2016), interpersonal and institutional microaggressions (Ong, 2018), and sexual harassment (National Academies of Sciences, Engineering, and Medicine, 2018) are key issues of inequity being targeted in physics education.

While attention to inequities in physics education is necessary for addressing them, many popular approaches to PER on inequities are being described as problematic in current literature. For example, deficit framing infers that minoritized students are unsuccessful in school due to inherent deficiencies (Exarhos, 2020). Other approaches that put emphasis on underrepresentation, and thus increasing numbers of women, fail to challenge physics culture itself (Gosling & Gonsalves, 2020). Similarly, the demographics of PER subjects are reported to be a narrow and unrepresentative subset of physics students in general, and therefore PER findings may be less generalizable to all student groups (Kanim & Cid, 2020).

More encouraging discussions with potential to influence gender inequities are also present in the literature. Researchers are questioning how physics department climate, and perceptions of the climate, influence the various people in them (White & Ivie, 2021). Additionally, scientist- and teacher-aimed discussions about the differences between sex and
gender are being undertaken to help those involved in physics education to respect and support the sex and gender identities of all students (Traxler & Blue, 2020).

With the assumption that EDI are priorities for physics departments, schools, and physics educators, the continued interrogation of inequities in physics education holds much potential. Careful framing is necessary for addressing these complex issues and is called for by the continued minoritization of women and other non-majority groups in physics while other science fields have made major progress (Sax et al., 2016).

In light of the continued need for equity and new approaches to such long-standing issues, this research sought insights and perspectives from an untapped source of knowledge: physics education researchers. Considerably more can be learned from physics education researchers than from their publications alone; namely, their perspectives on the field of PER in relation to gender inequity, lessons learned from conducting PER on gender inequity, what they observe to be successful in fostering equity, and their beliefs about where PER efforts should be directed.

This research aims to fill this knowledge gap and asks, what can be learned from PER experts about supporting gender equity in physics education? This paper presents a current snapshot of the international PER field from the perspective of expert physics education researchers who focus their research on gender inequity. The intended audience is the PER community, who may learn the researchers’ perspectives on gender equity-focused PER; specifically, what PER experts believe to be current issues, obstacles, patterns, best courses of action, and more. The PER community may benefit from this knowledge if taken as guidance for approaching, conducting, and using gender inequity PER.

Methods

This study employed qualitative methods to address the research question: What can be learned from PER experts about supporting gender equity in physics education? The methods
used to identify, recruit, and interview experts, as well as analyze the data collected, are
described.

Identifying and Recruiting the Experts

The physics education experts were identified using multiple sources: 1) the author’s
knowledge of prominent physics education researchers from reading PER literature and attending
conferences, 2) suggestions from editors of major PER-publishing journals, and 3) the content of
website biographies of researchers identified by sources 1) and 2) that was analyzed for relevance
to gender-related PER. Specifically, 46 researchers’ biographies were examined for presence of
the following variables of interest: researcher interest or focus on PER, interest or focus on
gender and/or equity, and related publications. Based on results of the content analysis that
revealed researcher profiles with the highest number of variables of interest, and the editors’
suggestions, nine researchers were identified as expert physics education researchers in the area
of gender equity. The author relied on their knowledge of the experts’ previous and current
publications to make a final decision on which of the nine experts were most appropriate to
participate in the study. In total, seven experts were invited to be interviewed; one did not
respond, one declined, and five agreed.

The Experts

This paper presents results in conglomerate form made up of individual experts’
contributions to conceal their identities. Therefore, a brief profile of the participant group, rather
than each individual, is provided. Four of the five expert physics education researchers are based
in North America, and one in Europe. All five experts work in a post-secondary education
institution as research and/or teaching faculty. Two of the experts work in or are associated with a
PER group, and three work as solo physics education researchers in their respective departments,
which are either Education or Physics for all experts. Their years of experience in PER range
from nine to 28. The average years of PER experience among experts is 19.6, and collectively, the experts have 98 years of PER experience.

**Interviewing the Experts**

The five experts were interviewed individually via online call and the interviews ranged from 45 minutes to 85 minutes in duration. The interviews were semi-structured with 16 predetermined questions but adaptive questioning allowed for conversation. Four groups of questions were asked about the following: 1) the experts themselves as researchers, including their conceptions about the topic of gender equity in physics education; 2) PER and its role, examples of high-impact PER, guiding principles, and current needs and priorities; 3) what works for supporting gender equity in physics education; and 4) their own PER.

**Analyzing the Interviews**

Audio recordings of the interviews were transcribed verbatim and sent to the experts to check that their meanings and ideas were accurately represented in the interview. If they were asked any follow-up questions and provided responses, their responses were added to their transcript. A general inductive approach (Thomas, 2006) to thematic analysis was used to derive themes from the data that address the research question: *What can be learned from PER experts about supporting gender equity in physics education?* This approach was chosen to allow the meaning of the data to emerge without a predetermined framework guiding the analysis. The analysis was conducted by carrying out open (assigning labels or “codes” to text segments), axial (grouping codes into categories), and selective (reducing categories into major themes) coding steps described by Strauss and Corbin (1990) using NVivo digital coding software.

The open coding step was completed on all five transcripts and yielded an average number of 87 codes per transcript. The axial coding step initially grouped codes into approximately 30 categories, and then further reduced the categories to 12. Finally, the selective
coding step reduced the categories into three overarching themes, which broadly represent what can be learned from the experts about supporting gender equity in physics education.

**Results**

The three major themes resulted from analysis of the PER experts’ interviews: 1) What is known and unknown about gender equity in physics education, 2) moving toward gender-equitable physics education, and 3) conducting and using PER as a tool. These broadly represent what currently can be learned from international leaders in gender-related PER. The categories and sub-categories comprising each theme further illuminate their perspectives and are described in detail in the following paragraphs. A summary of the themes, categories, and sample quotations can be seen in Table 2.

**Table 2**

Summary of Resulting Themes from Thematic Analysis of Experts’ Interviews

<table>
<thead>
<tr>
<th>Theme</th>
<th>Category</th>
<th>Sample Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is known and unknown about gender</td>
<td>Gender equity is a social justice, socio-historic, and cultural issue</td>
<td>A social justice issue...allowing more people to enter this discipline both in terms of them getting access to high-status knowledge and high-status professions.</td>
</tr>
<tr>
<td>equity in physics education</td>
<td>Current PER-based knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of knowledge on how to support gender equity well</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender equity-supportive practices in physics education</td>
<td></td>
</tr>
<tr>
<td>Toward gender-equitable physics education</td>
<td>Address problematic physics education</td>
<td>The fact that harassment is pervasive, persistent, and pernicious.</td>
</tr>
<tr>
<td></td>
<td>Enable change</td>
<td>Traditionally speaking, the culture is set by the people at the top, but I think the disruption will come from the bottom.</td>
</tr>
<tr>
<td></td>
<td>Education-related reform and PER group initiatives</td>
<td></td>
</tr>
<tr>
<td>Conducting and using PER as a tool</td>
<td>Situating PER and PER people</td>
<td>Physics education is in a weird place where we [physics education researchers] are fighting to be seen as competent professionals by physicists.</td>
</tr>
<tr>
<td></td>
<td>Role of PER experts, PER community and PER researchers</td>
<td></td>
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<tr>
<td></td>
<td>PER approaches and approach issues</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Expert guiding principles and goals for gender equity PER</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current needs and priorities for PER</td>
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</tbody>
</table>
Theme One: What is Known and Unknown About Gender Equity in Physics Education

The first major theme that emerged from the experts’ interviews relates to the current knowledge and lack of knowledge that exists about gender equity in physics education. The experts discussed topics across four categories comprising this theme.

Gender Equity is a Social Justice, Socio-Historic, and Cultural Issue

When asked how they conceptualize the gender equity issue in physics education, the experts explained that gender equity is not about achieving more than 40% women, or reducing a gap in numbers—what they say most people think gender equity is about. Rather, gender equity is giving everyone equal access. According to the experts, physics “seriously has an image problem” because it is considered very difficult and only accessible to people with certain talent. Due to physics’ high-status image, gender equity in physics education is “a social justice issue…allowing more people to enter this discipline both in terms of them getting access to high-status knowledge and high-status professions.”

The experts discussed gender equity as a socio-historic problem with the social institution that is the field of physics; physics is fundamentally inequitable and non-inclusive because it was defined by a very narrow group of people. “Women were never part of defining the field, what it means to do physics, or be a physicist.” Consequently, “the content of [physics education], the way in which it is taught, i.e., the practices, what is considered knowledge, ontology, what it means to be a physicist…all of those things are fundamentally inequitable and non-inclusive.” The experts explain that what resulted from the early development of Western physics was a “neutral, objective, rationalist kind of area, which are not the same traits people have been [socially and historically] associating with women.” Dissociating women from that which is considered to be scientific is a socialization pattern seen throughout Western history and is a
pattern that the experts say—combined with other societal steering mechanism and constraints—continues to negatively influence women’s participation in physics education.

According to the experts, physics’ socio-historic development influences the field’s present attitudes, norms, beliefs, and practices—or its culture. For this reason, experts view gender equity in physics education as a cultural issue: “It’s everybody. It’s our culture…so at every educational level it’s a problem, and we have to solve it at every educational level.” The problematic nature of physics’ cultural influence was exemplified when an expert commented that “physics itself sometimes feels like an unfriendly place.” The experts fault the culture for perpetuating the problematic high-status image and stereotypes associated with physics. For example, when discussing the popular cultural belief that physics people are brilliant, one expert explained that this is “a hurtful stereotype” because students see professors as very different from themselves, which has consequences for students’ ideas of who can be a physics person.

Overall, the experts conceptualize gender equity in physics education as a broad issue and one they say is related to social justice in terms of access, physics’ inequitable socio-historic development, and its culture.

**Current Physics Education Research-Based Knowledge**

The second category in this theme describes the current PER-based knowledge surrounding gender equity in physics education. The experts shared the opinion that there has been much quantitative PER looking at male-female gaps, referred to by the experts as “gap-gazing” research, which has been useful for pointing out the issues. However, experts say the knowledge of gender gaps on physics tests, for example, is now well-known by researchers and physics teachers:

We already know what the problems are…these are pretty well defined in the literature…there’s no debate that it’s an issue, the only debate that really exists is what we should do about it. And we need more evidence for what we can do and change.

The known problems referred to by the expert have the symptomatic effect of incredibly poor representation of women in physics—from the student level to hiring.
While all experts acknowledged the value and knowledge gained from PER to date, they explained that the existing body of work on supporting gender equity in physics education largely reveals what does not work: “That’s a difficult one. We know a lot about what doesn’t work.” They said that merely knowing the information alone and providing role models isn’t enough. Similarly, making physics relevant for a particular group often ends up stereotyping.

The experts also explained that gender equity issues begin earlier than post-secondary physics education on which most of PER focuses. The challenging and unfortunate reality is that women’s representation in physics education is not changing, despite gender equity-focused PER efforts; an observation that the experts shared unanimously. Still, vast efforts for improvement being made by gender-equality focused PER experts and the broader PER community should not be minimized. The experts highlighted promising research looking at supportiveness of undergraduate programs and sense of belonging, changing the culture of physics around workplace options, and studying different ways of teaching, disseminating the research, and giving workshops. These topics are discussed further in later themes.

Overall, the experts reported that current PER-based knowledge includes awareness of gender gaps, what does not work to support gender equity, and the fact that gender inequities begin very early in students’ lives. This knowledge has revealed promising new directions for PER.

Lack of Knowledge on How to Support Gender Equity Well

The third category is about experts not knowing how to support gender equity in physics education based on a lack of examples. When asked where gender equity in physics education is being supported well, almost all experts were unable to provide an example of a school, university, province or state. They reported they wished they had examples of gender-equitable physics education on which to ground research-based solutions; however, they explained that gender equity support does not happen very well in the Western world, meaning that challenges
of women’s representation remain widespread, and no evidence of change is able to be built upon. Further, the barriers to solving gender equity issues are not only a matter of being afforded more time or money, one expert explained, but rather the lack of knowledge and evidence showing what works.

**Gender Equity-Supportive Practices in Physics Education**

While no evidence depicts a clear solution, there are known PER-based gender equity-supportive practices promoted by the gender equity PER experts. Experts shared their views on what practices seem to support gender equity in physics education, but emphasized that there is no one solution and therefore a holistic approach should be taken. Some experts also mentioned the collection of “what works” papers by Barbara Whitten and colleagues (e.g., 2003, 2007) as containing strong examples of PER-based gender equity-supportive practices. Experts recognized the following as supportive of gender equity in physics education.

1. Caring for students by building community among them, helping them feel a sense of belonging, and listening to students in classes: I.e., about their ideas, how they solve problems, how they find the class is working, whether their peers and teachers/professors are listening to them and if they know or care what they think.

2. Making students aware of broad opportunities in physics beyond becoming an academic.

3. Specific to higher education: employing holistic admission practices that consider indicators of success, and providing multi-tiered, non-hierarchal mentoring that allows for diverse mentorship relationships.

4. Having diverse representation of people on staff at schools and in departments, and training all individuals to be supportive of women.

5. Conversations on gender equity with PER experts among department members and in physics classrooms to promote flow of ideas.
6. Training educators to do the following: Increase self-awareness to counter unconscious and implicit bias. Utilize gender-equitable teaching strategies (e.g., increasing kindness, non-gendered praising, and asking carefully-posed questions to reduce riskiness of students raising a hand and being either right or wrong). Facilitate explicit classroom discussion around gender equity issues as both teachers and students uphold traditional ideas of physics in the classroom. Focus on countering often-gendered societal messaging in the classroom. Finally, broaden what ‘counts’ as physics and being good at physics in classrooms. In other words, elicit the ‘physics-ness’ of students’ prior experiences and knowledge, which also broadens student identities available in the classroom.

These practices were promoted by the PER experts as supportive for gender equity in physics education.

In summary, theme one represents experts’ perspectives on what is known and unknown about gender equity in physics education. Four overall messages from the experts can be summarized. 1) Gender equity is a broad issue of social justice, socio-historic development, and culture. 2) Current PER-based knowledge is limited in its effect on gender equity but has inspired promising new PER. 3) There is a lack of examples of gender equity being well-supported in physics education on which PER can build evidence-based solutions. 4) While no single solution exists to gender inequity in physics education, there are gender-equitable practices promoted by the PER experts. Building on theme one, theme two is about moving toward gender-equitable physics education.

**Theme Two: Toward Gender-Equitable Physics Education**

The second major theme that emerged from the experts’ interviews is concerned with moving towards gender-equitable physics education. The experts discussed topics across three categories related to this theme.

*Address Problematic Physics Education*
This category is about the many issues within physics education that the experts identified as particularly problematic for women. The first step to moving toward gender-equitable physics education is being aware of and addressing issues such as these. Many of the issues are large-scale because they are rooted in larger cultural and socialization problems.

The first issue raised by the experts is the subtle transmission of cultural biases that collectively disadvantages certain groups of people—women, in this case—who have multiple, intersecting identities that are disadvantaged within the culture of physics. The experts refer to these as the “double or triple or quadruple bind,” depending on how multiple one’s disadvantaged identities are.

Similarly, experts described “societal constraints” for women related to the lack of accommodation of diverse pathways in physics education. For example, women are socialized to be nicer, kinder, and less war-like people than men. Therefore, when considering physics as a military tool, physics seems a less logical field “for nice, kind, smart people to spend their time and energy.” The experts noted that engineering is doing a better job than physics at marketing or explaining how engineering is a profession that helps people, and therefore seems like a “very logical place” for people socialized to be kind and helpful (typically women in the Western world).

The experts discussed a second issue very candidly: their observations of the lack of care, motivation, and limited, superficial solutions for gender inequity in physics education. When comparing other science fields’ rapidly improving representation of women, one expert said, “the physical sciences just will not budge.” They said one reason for stagnation is that “a lot of people actually don’t care, and they only care enough to make it seem like they care because, politically, you can’t not care now.” Another candid observation was of “perspectives of physicists…they’re looking for very superficial solutions.” Examples given included female guest speakers, discussing famous female physicists, or using stereotypically female examples in problems.
These efforts, however, do not have strong evidence of affecting young women in classrooms.

One expert described a time they interviewed physicists to ask them, ‘what can you do?’:

Many of them were men and they said ‘I can’t do anything, that’s on women. Women need to do that. We need more women in the profession, and when we have more women, then it’ll be better for the girls.’ So, it’s like they were passing off the responsibility to somebody else.

The third issue was about professors and teachers and was a large part of the interview discussions. As is the case in many fields, one expert pointed out that “there is still a problem with physicists teaching the way we were taught.” They explained that most professors pretend it is not a known fact that lecture-style teaching helps only a minority of students, and one reason for ignoring that fact is that those professors themselves “made it through the broken system, so it worked for [them].” Further, “There are some students that you cannot break with bad teaching, I guess, and they tend to become graduate students in physics and then maybe professors.” The experts suggested the following reminder to fellow teachers and professors:

We are not in fact presented with a whole bunch of people who want to be us when they grow up. They could be physics professors, but they are busy becoming the people that they want to be.

The fourth issue was certain power structures that exist within physics education between physicists, professors and teachers, and students. The experts explained that a hierarchical structure exists between physicists, teachers, and students. Physicists are at the top of the hierarchy practicing physics, and they define the culture and content of the field. Professors and teachers are lower on the hierarchy and deliver the physics curriculum that is decided at the top of the hierarchy. Due to this structure, the experts suggest that physicists must engage in making changes in order to create trickle-down change in physics education. Students, the main subjects of the cause for gender-equitable physics education, are at the bottom of the power structure hierarchy. The experts explained, “students don’t feel like they have the power…they just follow the norms set by the professor because the professor holds the power. And similarly, at the K-12
level, the teacher holds the power.” The experts say these power structures are aspects of physics education that can be problematic for working to increase gender equity.

The fifth issue focused on issues pertaining to students. The experts identified problematic images of physics, including the previously mentioned belief that physics is only for people with certain talent as it is particularly difficult. More specific to the post-graduate level of physics education, experts say the image of physics is worsened by the impressions many departments give students about the difficulty of having a life or family outside of being a physicist, which is perceived as particularly exclusionary to women. Experts also identify certain pedagogies that are particularly problematic for women, such as the traditional lecture where the professor doesn’t know your name, and when physics content is presented only via examples of stereotypically male relevance.

The sixth and final issue with physics education raised by the experts was about women’s experiences in physics education. One aspect of their experiences epitomizes gender inequity and injustice: “The fact that harassment is pervasive, persistent, and pernicious.” Experts say there is evidence to show that women’s negative experiences in physics education are still largely the same as in the past. Another example was that women and other minoritized people experience a lack of community with people like themselves all the way up the physics education ladder.

Overall, the consequences of problematic physics education, or that which is gender-inequitable, include lack of improvement to representation of women in physics education and the field, women choosing not to participate in physics education “for the wrong reasons”—as one expert put it, and talented people not being welcomed into physics. One of the gender equity PER experts summarized the wider consequences by saying, “That’s bad for physics, that’s bad for our countries, bad for economies—and so if we want to be the best physics field that we can be we need to not discourage anybody.”
Enable Change

Various avenues that may enable the needed changes in physics education to be possible or likely were identified by the experts. They discussed five major topics related to enabling change.

The first avenue is time; as more women of all kinds, “women who don’t look like the classic normative physicist,” participate, this will push the field toward more inclusive and equitable definitions. “But that’s a very slow process,” one expert said. Another suggested the idea that in time, the physics community will age out of the problem of teaching the way they were taught as more people are taught with reformed methods.

The second avenue is a more active view of enabling change, it is about student positions. The experts discussed the important role of students in changing the culture of physics education and physics broadly. They assert that students must be mobilized in order to be drivers of cultural change; because students are the least enculturated, they see issues the faculty and even researchers cannot see. They refer to mobilizing students as providing communal, accessible, non-traditional physics learning. One expert said, “traditionally speaking, the culture is set by the people at the top, but I think the disruption will come from the bottom.” While they said the students “have to be supported by PER researchers and faculty who understand the need for cultural change,” experts believe that “it’s going to be driven from the bottom because [students] outnumber the top—thousands to one.”

Related to this powerful idea is the third avenue: physics departments and decision-makers as enablers of change. The experts viewed change being enabled “from the individual charges of different departments.” The people identified as key decision-makers in departments of physics include chairs of undergraduate and graduate programs and hiring and curriculum committees. Helping these decision-makers enable change (e.g., by mobilizing students) by sitting down with them and talking “about the challenges they face and thinking about solutions...
directly with them,” is a strategy one expert suggested. The experts also identified decision-makers as the most effective people for sharing PER.

The fourth avenue of enabling change is via PER impact and sharing PER. The experts discussed that a necessary activity of PER is to be asking critical questions about change, which some experts said comes down to the image, content, and purpose of physics. They identified features of PER that has had high-impact and features of PER that may have impact on gender equity. High-impact PER has generally been intervention studies and large-scale quantitative studies. These studies are easily recognizable to physicists and easy to communicate to external stakeholders and policymakers who are also typically familiar with quantitative methods. The features of PER that may have impact on gender equity were identified as research that shines light on the biggest issues affecting women (e.g., awareness and implicit bias PER) or PER that challenges masculine contexts in physics education. Finally, experts noted that all high-impact PER is that which has been shared and published formally and informally.

The final avenue is one that the experts discussed at length: the importance of sharing research via collaboration between faculties (e.g., education, mathematics, chemistry), other research universities, and professional associations (e.g., American Association of Physics Teachers). Conferences, publications, giving formal talks, and informal conversation are all important. Conferences allow communication with other researchers and reach out to the broader science faculty, teacher educators, secondary and elementary teachers, and there are workshops for these people to adopt reformed ways of teaching physics that PER has learned in the last generation. Publications are the main method most experts share their research in order to reach other PER people, science education research (SER) people, teacher educators, and teachers. The experts noted that giving talks is high-impact for sharing best practices and improvement ideas because the research reaches outside PER and the expert comes away with new ideas. In a similar nature, experts said that talking person-to-person about gender equity in physics education is
often the best way to “change minds and hearts and sort of push people in the right direction.” Interestingly, of all of these sharing methods, experts stated that to reach physicists specifically, talks, conversation, translation, and evidence are necessary. One expert said about giving talks, “[I] say ‘we’ a lot, [when] I’m saying physics departments have not been great to people…and now ‘we’ can do better. Kind of come at it all with the growth mindset.” Another expert uses the PER they conduct as a conversation starter with physicists to talk about gender equity. When writing publications, the experts described doing a form of translation of their PER for physicists: “Pulling in words like ‘well you just have to go from one state to another state’ and use some physics terms…‘that’s all we need is a phase change of people’ or something.” Another expert (also a physicist) found that translating for physicists requires “some of the same skills that let me teach astronomy to people who are just taking a physical science class so that they can graduate.”

The following summarizes the experts’ views on factors that may enable change in physics education: 1) Time for more and diverse women to participate in physics, and time for progressive teaching to emerge; 2) mobilizing students to take positions of drivers of change; 3) decision-makers and physics departments; 4) increasing PER impact; and 5) sharing PER via collaboration, conferences, publications, giving formal talks, and informal one-on-one conversations. These are factors that may facilitate the move toward gender equitable physics education.

**Education-Related Reform and Physics Education Research Group Initiatives**

This category exemplifies the move toward gender equitable physics education. It is based on expert-identified educational reform and PER group initiatives that are pushing evidence-based reform of physics education.

The first topic of reform was directed at the physics community to challenge ideas, assumptions, and biases. The experts asserted that the whole community—researchers, professors, teachers, teachers-in-training, and students—must all acknowledge the roots of gender
inequities in physics by reflecting on and discussing historic and persistent biases existing in all people, instead of pretending they do not exist. They also suggested that the assumption that physics is merely kinematics should be challenged because physics applies broadly across contexts and systems. Similarly, the misconception that physics is a discipline only for elite people is one that should be corrected widely.

Another example of reforming physics education raised by the experts is rethinking the purpose of physics education. The experts encouraged thinking about various imagined futures for physics students, as there are numerous pathways from physics and just as many ways to utilize physics knowledge. They also encouraged educating students in a way that teaches the value of physics and its use in the workplace. And unsurprisingly, the gender equity PER experts all try to engage more young women in thinking about physics via physics education.

Professors and teachers are recognized by the PER experts as playing an important role in reforming physics education. Experts discussed how examining one’s teaching philosophy is a method to reform and improve teaching. For example, a physics teacher ought to question whether their students are just like them; should the teacher be teaching to themselves—or, should the teacher be teaching to the students they actually see in the classroom? Further, a professor ought to question how the high-quality person-to-person teaching that occurs in office hours might occur instead in large introductory physics courses. The experts also pointed out that broader notions are needed of what is relevant to students of all kinds and minoritized backgrounds (academic and otherwise); therefore, physics educators ought to examine how those diverse backgrounds may be built upon. Finally, improved physics teaching may occur when teachers and professors examine their own humanness and share that with their students. For example, the experts recalled getting B grades in their first year of physics and now they share with their students times when they “screwed up physics.” They explain to students that they sometimes do not know the answer, and they “make it clear that we’re not always brilliant and
perfect.” These ways of examining teaching philosophies are examples of what the experts believe may be methods for reforming and improving physics teaching.

The final point raised by the experts about education-related reform is about supporting women students explicitly and in policy, equitable testing, admission to higher education, and later in hiring. One expert explained that success is about getting needed support, so at their institution they provide their graduate students many support people in the form of multi-tiered mentoring. Also at the higher education level, experts say it would help support women by organizing large introductory physics courses in a way that someone (a teacher or other student) knows them, talks to them, and listens to their ideas and opinions. One expert provided examples of institutions where high-stakes testing has been reduced because it differentiates women and people of colour, where admission consideration of the Graduate Record Examinations (GRE) has halted in order to support gender-equitable admission, and where supportive policies are in place, e.g., graduate students have multiple faculty mentors so no one student has just one faculty from whom to get support. Specific hiring and admissions considerations were discussed by the experts in relation to the need for supporting women explicitly: “Confidential admittance to university completely obscures the fact that people don’t come from the same starting place,” this is an example of ignorance to gender equity. Similarly, in hiring, comparing women to men is inequitable: “She hasn’t been in the field as long…hasn’t had the same opportunities…think of all the barriers that she has faced compared to this other person.” Experts raise the issue that supporting women is part of physics education reform and must include implicit bias training for admissions and hiring committees.

In terms of PER group initiatives for gender equity, the experts shared eight PER-based physics education reform initiatives. The first six examples relate to PER group initiatives within physics departments at post-secondary institutions (where most PER groups live).
1. Including and empowering university women in PER groups by teaching the students about the culture of physics and the socio-historic issues, professors providing students feminist physics readings and discussing students’ questions together, and empowering the students to become gender-equality advocates in their own circles (e.g., one young woman became the go-to student to raise questions to a professor in class when other students were too afraid to ask).

2. Supporting university physics students socially in the physics department by having social events alongside faculty, such as informal snack sessions before seminars, picnics two times per year, and potlucks at holidays, which serve to make the department a welcoming place for students.

3. Promoting active learning opposed to traditional-style physics learning in physics departments, including group work, taking equity seriously, and noticing who is in the classroom and the dynamics present. An example of active learning is at one university where a modeling physics course size has tripled and has more women than men—the course has zero lectures and it is all group work and discussion-based.

4. Playing a role in educating and pushing physics departments on active learning until professors begin seeing more women students, and educating them on reformed teaching methods.

5. Promoting and supporting communal physics learning environments for students that move away from competitive, individualistic environments important for students banding together and helping one another, and that engages more people who are marginalized. This initiative learns communal ways of doing physics from Latino Critical Theory and Indigenous theories.

6. Learning assistant (LA) program disrupts traditional structures of physics education and mobilizes students. LAs are prior students who help students during discussion or group
work in classes. They bridge cultural and linguistic gaps since they are culturally similar to current students. The program has been so successful, upper-year students ask why there are no LAs in those courses; this is an example of mobilizing students to push real change for inclusive practices.

7. Building a network of physics teachers and educators globally for intervention studies and communicating via blast email lessons, materials, and professional development opportunities.

8. Lastly, developing and distributing lesson-based interventions to train teachers and help students. Lesson topics include unconscious bias and careers in physics and are framed as ‘this will help your students.’ Lesson interventions make issues explicit to increase awareness, then provide tools for the classroom. In a subversive way, this initiative pushes teachers’ thinking to become reflective of their own bias and practice.

These eight examples of PER group initiatives are those identified by the gender equity PER experts as supporting educational reform for promoting gender equity.

Overall, theme two represented what was learned from the gender equity PER experts about moving toward gender-equitable physics education. This theme reported three categories of topics the experts raised: address problematic physics education, enable change, and education-related reform and PER group initiatives for gender equity. Up to this point, the reported results of the expert interviews include what is known and unknown about gender equity in physics education (theme one), and moving toward gender-equitable physics education (theme two). The final section of the results reports on the third and last resulting theme that is about conducting and using PER as a tool.
Theme Three: Conducting and Using Physics Education Research as a Tool

This is the final major theme that emerged from the experts’ interviews and is about the utility of PER as a tool for improving gender equity in physics education. The five categories of topics comprising this theme represent what was learned from experts about PER as a tool.

Situating PER and PER People

The first category of topics is about situating the PER field and the researchers who comprise the field. This is not a brief category; extensive discussion arose in the expert interviews related to the field’s position and those working in the field.

An expert’s words introduce these results best: “Physics education is in a weird place where we [physics education researchers] are fighting to be seen as competent professionals by physicists.” Further, “the difference between physicists and educators is still a thing I think.” These quotations exemplify existing resistance to PER and those who conduct it. Even the PER field itself can be resistant to certain types of education research. As one expert said, “I had leaders in the field say that my work was contradictory to large physics education research,” and “the [PER] community was not ready for me and the stuff that I was trying to do.” Another expert described that PER has (less so currently) resisted and rejected research at the K-12 level and on identity or the affective space, due to the perception of researchers in the PER field that the research was not PER if it was not about the post-secondary level, cognitive outcomes, conceptual understanding, or performance. One expert urged that more PER researchers are needed from education to reach down to the K-12 level because when PER lives in physics very little research reaches there.

Issues of PER researcher position were discussed by the experts in terms of labels and limitations. The experts have experienced being “othered” when, for example, they “wanted to deconstruct gender and equity issues in physics.” Yet, progress was noted when they said, “but now I have a department that fully supports me.” The experts have worked to avoid limiting
themselves with labels and others’ definitions or bounds. One expert who has done so said, “Otherwise I would have given up doing the work I do 10 years ago when they said it’s not PER.” Another expert brought up Judith Butler’s performance theory while discussing how labels are meaningless and said, “we aren’t anything, we just do things.”

The PER experts discussed their identities as researchers, which proved to be multiple and diverse. Their identities included teacher, researcher, physics education researcher, science education researcher, discipline-based education researcher, physicist, and physics professor. How others identified the experts was also discussed, and said to be dependent on context for many experts (e.g., a PER person in the physics department, and a SER person outside of that context). Despite not ascribing to one identity, the identities of researchers have implications in a label-focused world. As one expert emphasized, “people always want to divide. Physicists think that PER is not physics, and then in PER, PER people are deciding who is and isn’t PER.” In this divisiveness is the reality that researcher identities as judged by others affects prospects of securing institutional positions like tenure, which experts identified as a privilege status or “the golden ticket.” Yet, admirably, many of the experts described that to make students’ lives better it is worth the labeling and identity challenges with gender-related PER.

Department factors influencing PER, funding, and publishing as gatekeepers were discussed by experts. For experts working in physics departments, some noted department support of their research has been dependent on winning grants and authoring publications. Some reported that their colleagues talk to them, knowing their passion and ability to help with gender equity issues. Most experts reported that people in their department are PER-friendly or PER-users. One reported external support at the university (chemistry and mathematics education research people) was required for being hired and still supports the operation of their PER group. In terms of funding and publications for the PER experts, these factors were discussed as gatekeepers to conducting their work. Funding limitations exist due to the nature of the institution
at which the experts work (limiting publication), the interdisciplinary nature of PER makes securing funding difficult, and program evaluations (much needed in many universities) are expensive and hard to secure funding for if the programs are very small. Experts also identified resistance to gender-related PER from publication venues and male privilege as a factor helpful for negotiating PER publications. Overall, the position and incentives of the PER field—often funding and publication—pose gatekeeping-like challenges for conducting PER and making changes for gender equity in physics education.

**Role of PER Experts, PER Community and PER Researchers**

Despite the unique situation of PER as a field and the positions of researchers within it, the PER community plays important roles. PER bridges the gap between educators and physicists, which the experts thought to be really important. One expert said, “sometimes we laugh that part of our job is to translate work from science and feminist studies of science for physicists.” One expert reported they feel proud to be the person who understands both physicists and educators and can explain them to one another. Another said, interestingly, “I am a sociologist of physicists.” Many of the experts reported the need to engage physicists in PER, for the reason that physicists define cultural norms in the field and therefore are important players in changing physics education. The community of PER is a leader in the education fields studying diversity issues, and the field itself is comprised of more women than in the physics field. One expert said, “[women] are the helpful physicists I guess, [women] are the people who obsess about the teaching, which is a helpful thing to do.”

The experts reported that there is a growing body of individual PER researchers who have equity and inclusivity knowledge. As individual PER researchers, including the expert interviewees, different communities are bridged as they try to understand broader, interconnected cultural issues related to gender equity. Some experts work as solo PER researchers but maintain community with colleagues in PER, and others work in PER groups and/or institutional groups.
focused on reforming and mobilizing the transformation of physics teaching and learning. Overall, the PER community is growing, broad-based across physics, education, and other disciplines, and increasingly includes gender equity PER researchers.

**PER Approaches and Approach Issues**

With a high variety of researchers from diverse backgrounds who conduct PER, the experts identified a number of topics categorizing approaches to PER and issues associated with approaches to conducting PER.

As PER is a relatively young field, some experts reported that this characteristic increases the field’s openness to topics, opposed to a field with a longer history and established norms. The experts reported that when PER researchers have freedom to study broad topics of physics education, the opportunities to make novel considerations and contributions increase.

The experts reported stances on gender gap PER—that which compares educational outcomes based on binary genders. The experts credited this type of research as increasing awareness of gender inequity in physics education and as the first step that ignited the need for change. However, most experts have an anti-gender gap PER stance and they are starting to reframe gap-gazing research. One expert said, “Let’s be sure that when we say that women don’t do as well as men in this class, what we’re not saying is there’s something wrong with women, but what we’re saying is there’s something wrong with the class…if I’m still going to publish something that says the women didn’t do as well as the men, [I’ll] say there’s something broken and it’s probably not the women.”

Theoretical approaches to gender equity PER identified by the experts include: Judith Butler’s performative notion of gender, Bernstein and Foucault theories of power (helping to think about what is implicitly communicated in classrooms, for example), MOGII (Marginalized Orientation, Gender Identity, and Intersex), identity, and figured worlds. The experts viewed implicit bias and stereotype threat less as theoretical approaches to PER and more as well-
researched underlying structures in place that directly affect the gender inequity in physics education.

Building on the above theoretical approaches, the experts identified approaches to PER that could make a difference to gender equity in physics education. A methodology that could make a difference is deeper ethnographic longitudinal classroom studies. Similarly, talking to women to learn about their experiences in order to then modify the experiences of others. Two common themes raised by experts are addressing problems by shining light on them and that it is important to conduct PER that is easily communicable to physicists (e.g., using theoretical models that can be scaled to large quantitative studies). Overall, the experts said that necessary approaches to PER seeking to improve gender inequity in physics education include: dramatically changing the way we talk about physics in PER and teach physics and questioning how we can change the culture of physics to not have inherent problems continually repeated in Western contexts.

In approaches to understanding and considering women in PER, experts assert that all women—not only those who gravitate toward physics anyway—should be considered in light of how physics education may not be connecting to their personhood; their values, goals, and needs. Support for all women (and other underserved groups) should be reinforced with policies directly intended to support them.

A final approach that some PER experts have been advocating for 20 years is to shift the focus of PER to earlier levels of physics education where the problems with gender equity begin. The rationale is that “you can’t fix a problem at the undergraduate or graduate level when the problem is already full swing.” They would like to study levels of education as early as elementary and pre-Kindergarten, but since most PER is conducted by physicists who are primarily concerned with their own environments in higher education, “getting physicists to buy into that is impossible.” However, the experts reported that some buy-in has happened as more
people begin to realize that gender equity issues are not possible to Band-Aid later on. One expert’s stance on approaching issues of climate and supportive undergraduate spaces is clear: “Those issues are mute to me unless you go back earlier and start to get more women into the field.”

The challenges some PER experts have had in advocating for certain approaches are related to larger PER approach issues. Importantly, the experts pointed out the difficult reality that no PER has changed anything significantly for gender equity in physics education. Taking a careful look at the way PER is approached reveals issues that the experts say may preclude PER from addressing gender equity.

1. PER in the Western world is largely carried out within universities. The focus is on higher education and traditionally confined to conceptual understanding, a narrow perspective on physics.

2. It is known that women on average perform better than men on assignments and in overall grades, but not on high-stakes testing: “Maybe there is some problem in the framing of those inventories, the framing of that testing that leads to this biased thinking about women not being as smart, or as good or as capable of understanding physics, or not having enough preparation in physics.”

3. With respect to gender equity, “rather than putting the onus on the field, they [the field] constantly are putting the onus on the women”—by asking ‘how to change women,’ rather than ‘what's wrong with physics?’ These subtle framing differences have consequences for the type of PER conducted and how it is approached.

4. As mentioned earlier, quantitative PER is recognizable, comfortable, and doable for physicists who are the primary conductors and users of PER. The resulting body of knowledge largely represents the research traditions in physics; however, an insufficient
complement of qualitative work exists as many PER researchers are not trained in qualitative methods.

5. Approaches that compare people and are particularly damaging to gender equity: the binary gender deficit model, which categorizes and compares people by assuming gender is a binary; using gender gaps to explain differences in performance (e.g., by comparing men and women’s prior preparation differences instead of examining problems with the culture of what it means to be prepared); and the implicit assumption that men are the standard. One expert explained that representation will not improve “if we’re still comparing women, people of colour, LGBT people to the white, straight man’s game. It’s not a fair comparison and it continually puts people at a disadvantage.” There is a lack of careful thought about measuring performance without accounting for barriers women face that are unique to them.

6. Finally, issues with approaches to PER are related to people’s stances on gender equity and/or PER. An expert said, “There aren’t people that are willing to make the big sacrifices and the big changes that are necessary to actually support women.” A core of PER people view “equity and social justice work as being foreign and not of the field, which is an issue.” Some traditionalists in PER believe the death of PER is affective research because physicists will not be convinced it is really PER. The experts describe this issue as one with people being “stuck in an old paradigm.” Lastly, some people in physics education do not recognize problems, such as a 30% rate of physics students getting Ds, Fs, or withdrawing from introductory calculus-based physics courses. Some think “that makes sense that 20 or 30% of all people in the class are either stupid or lazy.”

Overall, this category of topics represents what the expert PER interviewees identified as approaches to conducting PER, and issues associated with approaches to conducting PER, particularly through the lens of PER as a tool for increasing gender equity in physics education.
**Expert Guiding Principles and Goals for Gender Equity PER**

The experts recommended guiding principles for conducting PER on the topic of gender equity and shared their personal goals as PER researchers conducting gender equity PER. A major principle raised by the experts was to implement changes based on evidence: “To focus on evidence and not to focus on anecdote.” Propagating an intervention for physics education, for example, must be based on evidence from testing on students to learn the effects it has on students. Interventions should be very context- and situation-sensitive. For conducting socially-relevant PER, a guiding principle suggested by the experts is to focus on why improved physics education is important and considering this in light of what we have lost by discouraging women from entering physics. Also noted was the importance of mixed methodologies and thinking across the methodological divide when conducting PER, which is traditionally rooted in quantitative methods. The experts recommended against the socio-historic tradition of argumentative discourse in science research; rather, in PER, consider others’ research intentions and find solutions communally. Another suggested principle is to look at other science disciplines in a nuanced way to then understand the uniqueness of the gender equity and socio-historic problems in physics. Around the framing of PER, experts say the research should be framed around improving physics, not women. Lastly, the experts say a key for PER is to have a theoretical perspective on gender and identity (versus common notions of gender as differences). Whether the research draws on structural gender theory, social psychology, or sociological perspectives, these must be clearly communicated in PER. The experts recommend that all PER embeds understanding of broader gender literature for development of interventions, thorough testing, and dissemination.

The experts advocate these principles and ultimately work for students' improved experiences in physics education the field; they have goals for their overall research and hopes for physics education. They aim for their research to afford different perspectives to think about what
matters in the physics classroom. They hope their work provides tools for thinking about participation in physics, not only of individual students, but in thinking about the “structures and patterns and how women and men are treated within this discipline.” One expert explained, “for women and people from minoritized backgrounds to be able to see that their story isn’t just their individual story. This fits into a pattern.” Another expert said, “I want to see physics and the general culture change enough so that any woman who wants to go into physics feels welcome there and can do it and can succeed.” Experts are motivated by overarching hopes: “My whole goal is to make change and support people.” They are also motivated by social justice perspectives, such as the notion that people should be able to make informed decisions about their own lives with physics knowledge. Reflecting on the roles of PER researchers and their hope for gender equity in physics education, one expert said, “I’d love for us to be obsolete.”

The reported hopes and goals are bolstered by the guiding principles identified by the experts for PER focused on increasing gender equity in physics education.

**Current Needs and Priorities for PER**

The experts identified the current most pressing needs and priorities both for conducting PER and thinking about its use. One sentiment expressed was discouragement about not knowing what is needed, which emphasizes how challenging the problem of gender inequity is to address and solve. Below are topics the experts feel are current needs and priorities for PER.

1. Wider topics and approaches are needed in gender equity PER, such as policy, programmatic, and action research. A broader base than recruitment and retention is needed to increase gender equity. Half-jokingly, one expert suggested a different approach: “I could just imagine this grant application; I just need to go take every single physics professor out to a long good dinner and just say ‘dude…’”

2. PER needs to take up gender equity by studying and understanding the socio-historic, cultural implications on the participation of women and how this differs across the globe.
3. Think beyond gender gap and gender comparison research unless it is theoretically and explicitly justified. Experts stated gender should be examined, but in ways not only concerned with how women compare to men; they report the need for PER focused on higher education, specifically, to broaden perspectives and shift discussions away from gender as limited to the comparison of women to men.

4. To look beyond what physicists think is needed and what one needs to fit into physics, bring in outside perspectives such as: theories of power, gender theory, and sociology of education. Experts reported new frameworks are needed to address gender equity issues, and importantly, solutions should be considered with broader gender literature and women’s unique standpoints.

5. Knowledge and action from evidence, not anecdote, is needed. As one expert said, “We’re not moving the needle very much even though there’s been now decades of work on this…focus on the evidence of what helps these young women and not just on anecdotal thinking of what might help these women.” In terms of the knowledge needed, this includes: evidence for what works, what should be done and changed, and evidence for what programs attract, recruit, and retain women.

6. Of high priority is improving K-12 messaging, positive student experiences, and teacher training. Experts say the biggest need is to get the message out “for 13 [school] years, that women belong in science, we need women in physics.” The rationale is that if K-12 experiences are positive, interactive, and uplifting, this may translate to more women in physics education at the post-secondary level. In order for this to happen, experts said teachers need easy-to-implement strategies that have direct or visible effects. Therefore, a priority focus of PER should be teacher training and interventions at the K-12 level.

7. Expand to lower levels of physics education. Shifting the focus is integral since the problems with gender equity are everywhere, as is the culture. Issues of climate should be
worked on simultaneously. The lower levels of physics education have largely been ignored, as such, one PER group within which an expert works has a primary priority to expand to the lower levels.

8. Lastly, a priority for PER is to re-conceptualize the purpose of physics education at different levels and who can find a place in it. Steps to doing so include reducing the high-status nature of physics and increasing pathways from physics, thinking about recreating the physics mould to fit many people, and emphasizing that diverse women need to be included (not only those who culturally resemble or have the same masculinities as the men in the field).

To summarize the third resulting theme of the expert interviews, the following five categories about conducting and using PER as a tool were discussed by the experts: Situating PER and PER people, role of PER researchers and community, PER approaches and approach issues, expert guiding principles and goals for gender equity PER, and current needs and priorities for PER. Collectively, these represent what was learned from the gender equity PER experts about conducting and using PER as a tool to increase gender equity in physics education.

**Discussion**

This study set out with the aim of learning perspectives, beliefs, observations, and lessons from PER experts about supporting gender equity in physics education. Through the thematic analysis of one-on-one interviews with five international PER experts, three main themes emerged: 1) What is known and unknown about gender equity in physics education, 2) moving toward gender-equitable physics education, and 3) conducting and using PER as a tool. This section highlights the most noteworthy findings within each of these themes, and notes possible implications of these for the PER field globally.

Perhaps the most interesting finding within the first theme, what is known and unknown about gender equity in physics education, is that our biggest source of knowledge about gender
equity in physics education exemplifies what does not work. As gender-equitable physics education does not happen very well in the Western world and there is a lack of knowledge and evidence showing what works to support equity, there is little foundation upon which to build change. While our knowledge of what does not work explains in part the lack of progress for equity in physics education despite over 50 years of PER, it underscores key ideas for PER moving forward.

First is the complexity of gender inequity described by the experts. This is a social justice issue in terms of access to physics education and a socio-historic issue rooted in physics’ development and its culture. The experts’ calls for equity in the name of social justice are reinforced by literature that recommends increasing access (and in turn the representation of women) by moving beyond “gender gap” research and focusing on adapting classroom culture and reimagining institutional structures to fit the students (Gosling & Gonsalves, 2020). Likewise, the experts’ acknowledgement of the culture of physics as a root of the issue is a topic also examined in a recent interesting study, in which the effect of culture on women was compared in Muslim majority countries—where women have high representation in physics education—and the West—where they do not (Moshfeghyeganeh & Hazari, 2021). This research is an example of how learning about physics education cultures in which gender equity is the norm may help improve gender equity in Western physics cultures where persistent inequities and underrepresentation exists.

Another key idea for PER moving forward is that no single solution exists for gender inequities in physics education, evidenced by decades of research that has not solved the issue, and so nor should PER continue to build knowledge about gender equity with hopes for a quick fix. The experts on gender equity in this study clearly communicated that a comprehensive and holistic approach to gender inequity is showing evidence of success. Therefore, it is recommended that the vast range of knowledge about gender equity-supportive practices be
pursued and embraced if there is hope of major changes in physics education. To highlight some of the most noteworthy gender equity-supportive practices indicated by the experts, a few are restated here: 1) holistic admission practices and multi-tiered, non-hierarchal mentoring in higher education, 2) training educators to counter unconscious bias, be self-aware, and be supportive of women, 3) broaden what “counts” as physics to include more student identities and experiences, and 4) facilitate classroom discussions on gender equity. The final practice listed was written about recently by high school student and teacher co-authors, who found that using a simple survey about gender inequity in their own class, discussing data, and collectively creating next steps to address inequities, were powerful ways to improve their physics classroom culture (Eickerman & Rifkin, 2020).

With respect to this study’s aim, which is to learn from gender equity PER experts about how to support gender equity in physics education, the second theme that emerged from the expert interviews shone a spotlight on the pressing issues in physics education relating to gender equity. These included 1) societal constraints and cultural biases that disadvantage women with multiple intersecting identities; 2) the stubbornness of physics culture to improve, including the lack of care many of its members have about gender equity; 3) negative image of physics and of physics education by extension; and 4) “the fact that harassment is pervasive, persistent, and pernicious.” Harassment has been written about in the literature and is recognized as a cause for the continued marginalization of women in physics (Barthelemy et al., 2016; Aycock, et al., 2019). The importance of understanding experiences of students with intersectional identities is echoed in literature (Ong, 2005; Dickens et al., 2020) and can help educators and researchers reform physics education to make the experience more congruent with marginalized students’ identities. Overall, the issues raised in theme two represent current top-of-mind issues in physics education for international gender equity experts. These may be useful for guiding ongoing PER tackling gender inequity in physics education.
In addition to highlighting current issues, the second theme also represents the experts’ perspectives on how progress toward gender equity could be made. Specifically, by 1) physics educators and the physics community taking responsibility for their role in gender equity, 2) disrupting the power structures that exist in physics education (e.g., enabling and mobilizing students to assist upward change), and 3) with PER group initiatives facilitating departmental and school-level physics educational reform. These suggested moves toward gender-equitable physics education do not focus on “fixing” students to fit and work within problematic physics education; rather, they focus on improving physics education with the assumption that inequities in physics education are symptoms of the larger socio-cultural issues in physics. This is an orientation discussed in recent literature as one that is necessary to produce equity-oriented research and that will promote student-centered physics education (Exarhos, 2020). Problematic approaches were a particularly prevalent topic in the third theme.

As mentioned in the introduction, there is much to be learned from expert researchers on gender equity in physics education—beyond what may be gleaned from their research writings alone. In this study’s pursuit to learn from their expertise, perhaps the most valuable learning that can be taken from the experts comes from their perspectives on conducting and using PER as a tool for achieving gender equity in physics education. While the experts identified challenges in doing so, they also provided guiding principles for PER and its current needs and priorities for achieving gender equity.

The experts’ observations and insights about the PER field are consistent with previous reviews of its challenges, such as its divisive nature in terms of its position and the position of its researchers within and outside of physics (Beichner, 2009; Cummings, 2011; Heron & Meltzer, 2005). Similarly, various gatekeepers to conducting PER were reported by the experts and have been documented in PER literature, such as department support, funding limitations, and publishing ability and capacity (e.g., in Canada; Antimirova & Goldman, 2008). Increasingly
present in the PER literature is a challenge emphasized strongly by the experts, which is that many problematic approaches exist in PER that are not supportive of or oriented toward gender equity. Examples include PER’s narrow focus on higher physics education (Kanim & Cid, 2020), scarcity of qualitative research (Otero & Harlow, 2009), and binary gender deficit framing of gender-related PER (Traxler et al., 2016; Exarhos, 2020).

However, the experts also provided perspectives on PER’s current needs and priorities, as well as guiding principles for conducting and using PER as a tool for improving gender equity. The experts contrast the reality of divisiveness in the field with an alternative view, which is that PER importantly bridges the gap between physics and education for increased collaboration. They noted that as more of the PER community is gaining knowledge about gender equity, its bridges with other disciplines are increasing. The experts’ guiding principles for conducting and using PER as a tool for improving gender equity include: embedding a broader understanding of PER literature, working toward solutions between and within disciplines communally rather than via argumentative research traditions, and learning from other science disciplines about what has worked for them in creating equitable education. Similarly, the experts recommended focusing on evidence, not anecdote, building an understanding of why improving gender equity is important, using diverse and mixed methodologies, and including theoretical perspectives on gender and identity in this type of work.

These guiding principles are aimed to address PER’s current needs and priorities for improving gender equity identified by the experts, which are reiterated here: 1) wider topics and approaches, 2) understand physics’ socio-historic and cultural implications, 3) shift research beyond gender gap work and work limited to comparisons of women and men, 4) utilize new frameworks and perspectives from broader gender literature, 5) produce knowledge and action from evidence, 6) improve K-12 messaging by providing teachers with easy-to-implement
actions, 7) expand PER to lower levels of physics education, and 8) reconceptualize the purpose of physics education at its various levels and who belongs.

**Conclusion**

This study sought to learn from international PER experts about supporting gender equity in physics education. It was conceived in light of the lack of progress on the part of physics education to increase gender equity in its practice and overall culture, evidenced by the continued marginalization and underrepresentation of women at all levels. With the generosity of the experts who shared their perspectives and insights on this topic in the field, this study offers the PER field an expert opinion on addressing the complex and long-standing gender inequities in physics education. Specifically, the study elucidates what is known and unknown about gender equity in physics education, describes necessities for moving toward gender-equitable physics education, and suggests guiding principles for conducting and using PER as a tool for addressing gender equity in physics education. Overall, it supports the idea that PER should include the interrogation of gender inequities in its research.

This paper is aimed at those who engage in PER and particularly those who engage in PER focused on gender equity. The knowledge gained from the experts provides new, clear, and specific directions for future research. The major limitation of this study is that its five participants do not represent the whole of international PER perspectives on issues of gender equity. As gender equity issues are highly intertwined with culture and socio-historic norms, various parts of the world have unique issues. In spite of its limitations, this study adds both broad perspectives and specific recommendations to our understanding of how PER may better address gender inequities in physics education.
Chapter 3

Phase Two: Characterizing Canadian Physics Education Research and Understanding its Approach to Gender Equity

Introduction

Physics education research (PER) as a field of study is said to have begun in the 1970s in the United States when PER publications began appearing, focused on student understanding of concepts taught in physics (Beichner, 2009; Cummings, 2011). Since then, PER has developed into a field that: is comprised of researchers in physics, education, and other domains (Kelly, 2016; Meltzer, 2003); in which increasingly diverse methodologies are being used (Ding, 2019; Heron, 2018; Otero & Harlow, 2009); and in which longstanding inequities are being probed (Traxler & Blue, 2020; White & Ivie, 2021).

The history of PER in Canada, specifically, remains undocumented. The current extent and demographic landscape of PER in Canada is also unknown. While it is clear that the Canadian PER field is younger and less well-developed than in the U.S., evidenced by fewer publications, PER degree-granting programs, and funds for PER, there is a growing interest in PER among Canadian researchers. Doctoral programs are being offered at a handful of universities across the country, membership in the Canadian Association of Physicists’ (CAP) Division of Physics Education (DPE) has increased by more than 50% in less than ten years even though general CAP membership remains constant (Antimirova et al., 2014), and CAP’s DPE session numbers are increasing over the years (Antimirova et al., 2014).

Canadian PER has observed particularly accelerated growth in the areas of EDI research. The Canadian Association of Physicists conducted the first ever national survey on EDI in physics in Canada, for which they have released preliminary results (Smolina et al., 2021) Expanded results will be published in a special issue of their publication, Physics in Canada, that
will feature EDI-related contributions from authors across the country. With the most recent international swell of social justice and human rights movements, attention to issues of EDI within Canadian physics education is being demanded.

This study is part of a larger research project that seeks to determine if and how Canada’s physics education researchers are working to address gender inequities in physics education, and to develop an expert knowledge-based framework to guide Canada’s ongoing PER to increase gender equity in physics education. Therefore, in response to the lack of knowledge about the PER field in Canada and its increasing attention to EDI issues, this study asks, what is the landscape of PER in Canada? Who are our experts and what are their areas of research focus?

Presented in this paper are the first demographic data describing the landscape of PER in Canada, including researcher demographics, areas of research focus, and levels of expertise, as well as Canadian PER engagers’ perspectives on PER in Canada and in relation to EDI issues. The paper is intended to inform and support the Canadian PER community in its endeavours by sharing knowledge about Canadian PER’s current activities, position, attributes, and challenges.

**Methods**

**Content Analysis**

This study sought to determine the landscape of PER in Canada and identify Canada’s expert physics education researchers and their areas of research focus. To develop an understanding of the landscape of PER in Canada, physics education researchers were considered representative of the field’s current landscape. In order to identify the maximum potential number of PER people in Canada, a broad definition of *physics education researcher* was adopted: any member of a Canadian university physics or education department engaging with issues relating to the teaching and learning of physics. The methods used to identify such individuals included requesting names of Canadian physics education researchers from editors at the Canadian Journal of Physics and committee leaders of the Division of Physics Education and the Division for
Gender Equity in Physics at the Canadian Association of Physicists, and conducting an online search for Canadian physics education researchers. Specifically, content analysis was conducted for online faculty profiles at all 96 Canadian universities’ physics and education departments. This process involved the following steps: 1) reading each biography for clues of possible relation to PER engagement, 2) recording in a spreadsheet the relevant biographies and contact information associated with each person, and 3) following Schreiber and Ferrara’s (2017) content analysis procedure to systematically examine each biography by coding the text for variables of interest (Table 3). Development of the variables of interest was informed by prior content analysis of website biographies of international PER experts. Additional variables were added as coding progressed to maintain a broad catchment for identifying the largest potential number of PER-engaged people in Canada. Coding was conducted with the help of NVivo software and, once complete, biographies with no coded variables of interest were excluded. The above methods enabled the identification of 150 people in Canada who have possible engagement with issues related to the teaching and learning of physics.

Table 3

Variables of Interest

<table>
<thead>
<tr>
<th>Variables of Interest in Biographies</th>
<th>Conceptual definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest or focus on physics education research</td>
<td>The words “physics education research,” or otherwise combined. Or words describing it such as teaching, learning, understanding, development, or synonyms.</td>
</tr>
<tr>
<td>Interest or focus on gender equity</td>
<td>The words “gender” and “equity.” Or “women,” “equality,” “inclusion,” “diversity,” or synonyms. Or broadly related terms such as “culture” or “climate,” or synonyms.</td>
</tr>
<tr>
<td>Publications in physics education research venues</td>
<td>Papers, presentations, lectures, or otherwise indicating contribution(s) to physics education research knowledge and/or involvement in physics education research.</td>
</tr>
</tbody>
</table>
Role related to physics education  
Teaching, instructing, coordinating courses or labs.

Interest or focus on science education  
General science education, teaching, researching, pedagogical development.

Interest or focus on science education research  
Research interests listing science education, cognition, student learning, science teaching for a particular purpose, etc. Not specific to physics.

*Note:* Conceptual definitions for the variables of interest being coded for in the content analysis of faculty’s website biographies.

**Survey**

To gain more information about the people whose biographies suggested possible PER engagement, a survey was distributed to all people identified as having possible PER engagement. The survey’s purposes were to 1) confirm researchers’ PER engagement and 2) learn the areas of research on which they focus. The survey included questions about demographics and areas of research focus, both in general and specific to PER (Appendix B). The questionnaire responses were useful for developing an understanding of the landscape of PER in Canada, and also for determining who the Canadian PER experts are.

To describe the landscape of PER in Canada, the survey responses were collated and summarized according to variable (e.g., area of research focus) using counts and percentages. The summarized survey data are presented in the results section. If survey respondents indicated no engagement in PER by selecting “No” in response to the question *have you conducted or been involved in PER*, their survey data were excluded from the analysis. If survey respondents indicated definite or possible PER engagement by selecting “Yes” or “Not sure” in response to the above question, their survey data were included in the analysis.

To identify the expert physics education researchers from the general population of Canadian PER people, expertise criteria were developed and applied to participants’ survey data in order to assign each participant an expertise score. Specifically, criteria for PER expertise was
developed based on characteristics and activities of leading international PER experts who were interviewed in a prior study that is part of this research. For example, the experts had been working in the field for a high number of years and were actively conducting PER. The criteria of expertise applied to the Canadian PER people’s survey responses included the following variables: number of years engaged with PER, number of PER publications, and self-reported level of expertise.

Questionnaire responses were collected as numerical values for publications and years in PER, and a choice of 0-3 for self-reported level of expertise in PER (0=no expertise, 1=limited expertise, 2=moderate expertise, and 3=high expertise). The responses were expressed as a percentage of the highest score for each variable. Each variable was assigned equal weighting by applying a factor of 1/3 to the scores. Equal weighting was chosen to not value self-reported level of expertise over number of years in PER, for example. The sum of the three variable scores produced individuals’ expertise scores, which were sorted from highest to lowest, revealing the most and least expert Canadian physics education researchers.

Importantly, the expertise criteria were developed for the purpose of identifying relative expertise and are not suggested as a comprehensive representation of expertise in physics education research. Additionally, in a parallel analysis of expertise, engagement with gender-related PER was included as a variable in the expert criteria, as this study was conceptualized within a larger research project investigating how the Canadian PER field may be guided and supported to improve gender equity in physics education. The changes in relative expertise when engagement with gender-related PER is included as a variable in expertise criteria are reported in the results section.

Interviews

To understand more deeply the areas of research focus, activities, and perspectives of Canadian physics education researchers, 14 questionnaire respondents were selected for a 30
minute, one-on-one, semi-structured interview in which they were asked eight questions in total. The questions related to the respondents’ self-reported expertise, whether they work in a PER group, their connections to other physics education researchers in Canada, their areas of research focus and interest, their conceptualization of gender equity issues in physics education, and the role of physics education and PER.

The interviewee selection process was limited by questionnaire respondents’ consent to be contacted about participating in further study activities (i.e., an interview). To learn from researchers with the highest expertise in PER, researchers with the highest expertise score who consented to be contacted again were selected for the interview. The interviewees’ expertise relative to the general population of Canadian PER people is reported in the results section.

Results

Identifying Canadian Physics Education Research People

The content analysis of online biographies yielded 150 people in Canada who possibly engage with issues related to the teaching and learning of physics. Figure 4 shows the distribution of number of variables of interest found in the biographies analyzed. Of all biographies, 97 had a single variable of interest, the least often being PER publications. Almost a third of biographies (n = 43), had two variables of interest, the most often being interest or focus on PER. Few biographies had more than two variables of interest; seven biographies had three variables of interest, and three biographies had four variables of interest. No biographies had five or all six variables of interest.
Confirmation of PER engagement was obtained from the results of the *PER in Canada* survey, which was distributed to all 150 people in Canada identified as having possible engagement with issues related to the teaching and learning of physics. Of 150 people who received the survey, 36.6% ($n = 55$) completed the survey, and 42 of those confirmed they engage with PER (Table 4).
Table 4

Response Rate for “PER in Canada” Survey

<table>
<thead>
<tr>
<th>Number of survey recipients</th>
<th>Number of completed surveys</th>
<th>Response rate</th>
<th>Number of people who engage with PER</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>55</td>
<td>36.6%</td>
<td>42</td>
</tr>
</tbody>
</table>

Results of the survey are summarized in Table 5. The survey results revealed that Canadian researchers engaging with PER are most commonly in their 40s (34%), less commonly in their 50s (29%) or 60s (22%), and only 12% of Canadian PER engagers are in their 30s. Women comprise 36% \((n = 15)\) of PER engagers, while men represent 59% \((n = 25)\), and 5% \((n = 2)\) preferred not to answer about their gender identity. In terms of geographical location, most PER engagers are in British Columbia (29%) and Ontario (29%), with fewer in Alberta (15%), Quebec (10%) and Nova Scotia (10%). Only 2% of PER engagers are in Manitoba, Prince Edward Island, and Newfoundland and Labrador, respectively. Canadian PER engagers are most commonly affiliated with or work in a Department of Physics (52%) or Education (40%), and others work in a Faculty of Science (5%) or work in both Education and Astronomy (2%). Of Canadian PER engagers, 39% have been engaged with PER for 1-5 years, and 29% have been engaged with PER for 6-10 years. Only 15% have been engaged with PER for 11-15 years, and lower percentages have been engaged with PER for 16-20 (5%), 21-25 (10%), 26-30 (0%), and 31-35 (2%) years. Zero Canadian PER engagers self-reported having no PER expertise, while 39% reported having limited expertise, 49% reported having moderate expertise, and 12% reported having high expertise. The three most prominent areas of PER focus among Canadian PER engagers are curriculum and instruction (21%), effective use of technology in teaching (17%), and student conceptions (11%).

The survey also asked about general areas of research focus, and areas of research focus within the topic of gender equity, as this research is part of a series of studies interested in this topic. General areas of research focus included: science education research (SER; 20%),
assessment (6%), science teacher education (2%), and physics and astronomy research areas (13%). PER gender equity topics were: EDI in physics and STEM, science education research on gender equity, higher education, gender, identity, discourse, affective outcomes’ contribution to achievement differences, gender dynamics in group work, and gender differences in self-efficacy and test anxiety. Of Canadian PER engagers’ publication types, conference presentations are the most common (72%), followed by publications in academic journals (19%), practitioner journals (6%), and other, such as books (3%).

Table 5

Summary Data for “PER in Canada” Survey Results

<table>
<thead>
<tr>
<th></th>
<th>Count</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (n = 41)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-29</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>30 - 39</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>40 - 49</td>
<td>14</td>
<td>34%</td>
</tr>
<tr>
<td>50 - 59</td>
<td>12</td>
<td>29%</td>
</tr>
<tr>
<td>60 - 69</td>
<td>9</td>
<td>22%</td>
</tr>
<tr>
<td>70 or older</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Gender (n = 42)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woman</td>
<td>15</td>
<td>36%</td>
</tr>
<tr>
<td>Man</td>
<td>25</td>
<td>59%</td>
</tr>
<tr>
<td>Non-binary</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other gender identity</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I prefer not to answer</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Province (n = 41)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia</td>
<td>12</td>
<td>29%</td>
</tr>
<tr>
<td>Alberta</td>
<td>6</td>
<td>15%</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manitoba</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td>Ontario</td>
<td>12</td>
<td>29%</td>
</tr>
<tr>
<td>Quebec</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td>Newfoundland and Labrador</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Department (n = 42)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics</td>
<td>22</td>
<td>52%</td>
</tr>
<tr>
<td>Education</td>
<td>17</td>
<td>40%</td>
</tr>
<tr>
<td>Other (Faculty of Science)</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>Education, Astronomy</td>
<td>1</td>
<td>2%</td>
</tr>
</tbody>
</table>
Years engaged in PER (n = 41)

<table>
<thead>
<tr>
<th>Years</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>16</td>
<td>39%</td>
</tr>
<tr>
<td>6-10</td>
<td>12</td>
<td>29%</td>
</tr>
<tr>
<td>11-15</td>
<td>6</td>
<td>15%</td>
</tr>
<tr>
<td>16-20</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>21-25</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td>26-30</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>31-35</td>
<td>1</td>
<td>2%</td>
</tr>
</tbody>
</table>

Self-reported expertise (n = 41)

<table>
<thead>
<tr>
<th>Level</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No expertise</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Limited expertise</td>
<td>16</td>
<td>39%</td>
</tr>
<tr>
<td>Moderate expertise</td>
<td>20</td>
<td>49%</td>
</tr>
<tr>
<td>High expertise</td>
<td>5</td>
<td>12%</td>
</tr>
</tbody>
</table>

Area of PER focus (n = 41)

<table>
<thead>
<tr>
<th>Area</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive mechanism</td>
<td>10</td>
<td>7%</td>
</tr>
<tr>
<td>Research methods</td>
<td>4</td>
<td>3%</td>
</tr>
<tr>
<td>Curriculum and instruction</td>
<td>29</td>
<td>21%</td>
</tr>
<tr>
<td>Socio-cultural mechanisms</td>
<td>6</td>
<td>4%</td>
</tr>
<tr>
<td>Epistemology and attitudes</td>
<td>10</td>
<td>7%</td>
</tr>
<tr>
<td>Student conceptions</td>
<td>15</td>
<td>11%</td>
</tr>
<tr>
<td>Gender equity</td>
<td>6</td>
<td>4%</td>
</tr>
<tr>
<td>Teacher education and TA training</td>
<td>13</td>
<td>9%</td>
</tr>
<tr>
<td>Identity</td>
<td>4</td>
<td>3%</td>
</tr>
<tr>
<td>Effective use of technology in teaching</td>
<td>23</td>
<td>17%</td>
</tr>
<tr>
<td>Institutional change</td>
<td>3</td>
<td>2%</td>
</tr>
<tr>
<td>Problem solving and reasoning</td>
<td>10</td>
<td>7%</td>
</tr>
<tr>
<td>Other: Assessment</td>
<td>4</td>
<td>3%</td>
</tr>
<tr>
<td>Other: Learning environment</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Other: Mentoring</td>
<td>1</td>
<td>1%</td>
</tr>
</tbody>
</table>

PER publications (n = 40)

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic journal papers</td>
<td>143</td>
<td>19%</td>
</tr>
<tr>
<td>Practitioner journal papers</td>
<td>48</td>
<td>6%</td>
</tr>
<tr>
<td>Conference presentations</td>
<td>557</td>
<td>72%</td>
</tr>
<tr>
<td>Other</td>
<td>22</td>
<td>3%</td>
</tr>
</tbody>
</table>

Comparison of Canadian PER engagers’ areas of research focus and their self-reported expertise was made in Figure 5. This figure shows a breakdown of the areas of PER focus according to the levels of self-reported expertise of the Canadian PER engagers. As can be seen in the figure, the highest number of PER engagers who reported high expertise focus their PER on effective use of technology in teaching. The highest number of PER engagers who reported moderate expertise and limited expertise focus their PER on curriculum and instruction. Conversely, the lowest number of PER engagers who reported high expertise focus their PER on assessment, identity, and mentoring. The lowest number of PER engagers who reported moderate
expertise focus their PER on gender equity and learning environment. The lowest number of PER engagers who reported limited expertise focus their PER on problem solving and reasoning, assessment, and institutional change.

Figure 5

Canadian PER Engagers’ Areas of Research by Self-Reported Level of Expertise

Note. Canadian PER engagers’ areas of research focus are shown in terms of their self-reported levels of expertise in PER.

Data from the figure above may be compared to data in Figure 6 below, which shows the breakdown of PER area of focus by the department in which Canadian PER engagers work. Relatively even numbers of physics- and education-based PER engagers focus their research on curriculum and instruction, the topic on which the highest number of PER engagers focus. For the second highest area of research focus, effective use of technology in teaching, education-based PER engagers comprise about half the number of physics-based PER engagers who focus research on this area. A similar case can be seen for problem solving and reasoning, assessment, and institutional change areas of research focus. The third highest area of research focus, student
conceptions, has almost double education-based PER engagers focusing research on this topic compared to physics-based PER engagers focusing research on this topic. A similar case can be seen for teacher education and TA training, socio-cultural mechanisms, and research methods. The area of research focus gender equity and identity are areas of research focus for few PER engagers, whom tend to be education-based slightly more often than physics-based when focused on gender equity, and strictly education-based when focused on identity.

Figure 6

Canadian PER Engagers’ Areas of Research Focus by Department

Figure 7 characterizes the Canadian PER engagers by their age and number of years engaged in PER. The figure illustrates that the majority of PER engagers (n = 27) have less than or equal to 10 years engagement with PER. It may be expected that the lower the age of the PER engager, the lower the number of years they would engage in PER; however, this is not clearly
observed in the figure below. Of the PER engagers who have less than or equal to 10 years of PER engagement, seven are in their 60s, six are in their 50s, 10 are in their 40s, and four are in their 30s. The opposite may have also been expected, that the higher number of years engaged in PER would mean a higher age; however, it can be seen that fewer PER engagers have a high number of years engagement \((n = 13)\), and of these individuals, one is in their 30s, four are in their 40s, five are in their 50s, and two are in their 60s. A number of factors related to PER in Canada may be relevant to this depiction of PER engagers’ age and years of engagement, which will be explored further in the discussion.

**Figure 7**

*Canadian PER Engagers’ Age by Number of Years Engaged with PER*

*Note.* The number of Canadian PER engagers shown as bars are broken down to depict age group composition by colour.

**Identifying Canadian Physics Education Research Experts**

The relative expertise of survey participants was calculated by applying the developed expertise criteria to their survey data. Figure 8 shows all 42 Canadian PER engagers’ expertise scores sorted from lowest to highest, revealing the relative expertise of Canadian physics
education researchers. As the expertise criteria were designed to determine relative expertise of Canadian PER engagers, there is no threshold which designates expert and non-expert. Rather, a researcher may be considered more or less expert in PER compared to another researcher, based on their relative expertise scores.

The relative expertise aided in determining who of the 42 Canadian PER engagers would be invited for an interview. Because not all survey respondents consented to be contacted in the future for further study activities (i.e., an interview), interviewee selection was limited to consenting participants with the highest relative expertise. These researchers, identified with an asterisk in Figure 8, were invited for an interview to learn more about their activities, perspectives, and areas of research focus.

When gender equity focus in PER was included as a criterion for expertise, some PER engagers’ expertise scores increased. Changes in relative expertise of the Canadian PER engagers can be observed in Figure 8.
Figure 8

*Expertise Scores of Canadian PER Engagers*

*Note.* PER engagers who were selected for interviews are indicated with * in the figure, which shows the relative expertise scores of Canadian PER engagers.

**Understanding Canadian Physics Education Research Activity and Researcher Perspectives**

The thematic analysis of conversations from the one-on-one interviews with 14 Canadian PER engagers yielded five overarching themes about PER in Canada, the people who engage with this research, and the topic of gender inequity in physics education. The resulting five themes are:

1. Canadian PER is dilute, underfunded, and needs championing.
2. Canadian PER is uniquely characterized by its position, role, dissemination, and problems.
3. Canadian PER engagers are heterogeneous.
4. Identity, non-belonging, and deep skepticism are barriers to being a physics education researcher.

5. Gender (in)equity has complex definitions, causes and explanations, solutions, and responsibility.

**Canadian PER is Dilute, Underfunded, and Needs Championing**

Canadian PER engagers reported a dilute PER community in Canada that does not have a critical mass. While Canada does have people with significant expertise in PER, such individuals usually have other jobs within their departments (e.g., teaching- or physics research-focused positions) and PER is done peripherally. PER groups range from informal and loosely-knit, which are the most common, to less common structured meetings with funding for research.

Funding is a factor that limits PER, PER groups, and PER students in Canada. PER engagers reported limited knowledge of SSHRC or NSERC funding for PER due to Tri-Council resistance to fund PER, and named PER a victim of this funding model in Canada. While PER engagers said a PER group can still exist without funding, they also said:

Everything changes when you can get money…it’s easier to convince your colleagues it’s a reasonable project, it’s easier to get publications and other accomplishments important for tenure and promotion…access to funding graduate students…you can do projects you can’t do without [funding].

Funding to support PER graduate work and PhD students is said to not exist in physics departments, and for the few known PER graduate students, their program was said to be funded by special arrangements with local grants and research assistants. Faculty-level funding for graduate students wanting to do PER was suggested as a solution to the issue of no funding for them.

When asked about other Canadian physics education researchers, most interviewees could name one to three others, and very few could name four or five others. Nearly all interviewees disclosed that they struggled to think of other Canadian PER engagers, and two could not name a single other member of the Canadian PER community. It was common for interviewees to mention Canadian expatriates or American and international PER people, noting the strong influence the larger PER field has on Canadian PER.
The Canadian PER engagers called for championing of PER in Canada, stating that it needs advocates, expansion, and to be appreciated as a field of study with a lot of people working really hard on PER. A specific need discussed was a Canadian PER conference to develop an annual congress of PER engagers in Canada, separate from U.S. PER, to foster Canadian-specific funding structures, professional development, and network creation.

**Canadian PER is Uniquely Characterized by its Position, Role, Dissemination, and Problems**

Canadian PER engagers reported a “turf war” in PER between physics and education fields. Researchers from both fields (and other fields, too) conduct PER by drawing on and applying their respective expertise to issues relating to the teaching and learning of physics. However, according to some Canadian PER engagers, education researchers do not fit the “conception of a physics education researcher,” who is someone in a physics department.

The slowness of PER to learn from education was reported by the PER engagers, some of whom stated it is “very hard to convince [physics professors] to look at education literature.” Many physicists are said to not see PER particularly favourably unless it is quantitative. One Canadian PER engager shared that, as a classical physicist themselves, they have never formally taken a course on education. Someone else reported that when they finally engaged with their education colleague they got up to speed with what they now see should have been “blindingly obvious…what’s your hypothesis here? What do you think you’re trying to accomplish? And how are you going to determine that?”

The culture of physics topic arose in the interviews as an influential factor in PER’s position. Physics was described as a tribal community that has its own culture, which reflects the attitudes of the people in the tribe. Physics’ culture was described as potentially destructive because it has a lot of “historical baggage,” is elitist and self-selecting, and in it exists the idea that physics is a calling, which calls into question people’s sense of belonging. The PER engagers
explained that people learn the ways of being and knowing in a culture (their examples included attacking or dismissive conversation), and some struggle to accept other ways of knowing.

In terms of the role that PER plays or may play in general and for addressing gender inequity, the Canadian PER engagers identified the following PER roles.

General PER roles:

- disseminating research
- increasing awareness of problems
- produce peer-reviewed research, not only teaching literature about ideas
- filling knowledge gaps (much research in science education, less physics specific)
- conducting longitudinal, applied research in collaboration with teachers
- conduct research on lower levels of education for teaching science conceptual understanding
- conduct research on broad populations, not focusing too narrowly on particular groups

PER roles pertaining to addressing gender inequity:

- understand numbers of populations represented as a start
- conduct classroom studies on equity
- understand perception of high school physics and hidden bias in classrooms
- determine inclusive instructional strategies and test their effects
- employ feminist perspectives in PER to break stereotypes
- employ sociocultural perspectives in PER to understand how gender is produced and reproduced in physics education
- stop reproducing gender inequities with gender binary focused PER
- change the relationship between male/masculine and physics
- question the best outcomes of PER–useful, just, non-exclusionary physics community?
conduct case studies, experience impact studies, studies on epistemology and attitude shifts, holistic and longitudinal studies, across various ages and backgrounds

- promote active learning and Teaching Assistant interactions shown to close gender gaps
- take large scale actions that are research-informed

The Canadian PER engagers described the dissemination methods for PER and some are said to be more effective than others. Big journals were reported to be less effective at generating interaction with other researchers, and these publications prevent teachers’ access. Sharing PER with teachers is a knowledge mobilization strategy reported to be impactful and should be done more. However, PER engagers place high value on rigorous, peer-reviewed research in journals and books. Many Canadian PER engagers said that talking to people is the best way to share their work, which happens at conferences, workshops, and teaching and learning sharing events.

Overall, conferences and presentations were reported as being by far the best way to share PER; these venues foster community building, networking, exchange of ideas, reactions and feedback, and thinking about the applicability of research to one’s own context. Other less traditional methods included a university-based science education open house where education research is shared, sharing results of PER with study participants who may find the research most relevant, and posting PER-based resources on webpages to increase uptake.

Finally, Canadian PER engagers reported the problems they perceive with Canadian PER, many of which concerned how PER addresses (or inadequately addresses) gender inequity. Some PER engagers said PER in general represents a closed community of thought and should be more open to diverse interpretations of data, criticisms, using tools of science, inquiry, and debate. Others said that PER needs more rigorous and scientific, hypothesis-based approaches to developing teaching strategies, as a lot of PER results from physicists trying cool things without questioning the impact on students. An issue specific to non-PER-based assessments is that they
may cater to certain people or life experiences due to implicit biases. Also, PER is deficient in lower grades due to the lack of explicit physics teaching that occurs there.

Canadian PER problems specific to gender equity PER were also reported by the interviewees. The biggest issue reported is the binary gender deficit approach, which splits students up into two groups and does not respect or capture the full student experience. The challenges to gender equity PER include: the fact that most demographic datasets are based on forced binary gender choices, being thoughtful about the non-binary nature of gender, avoiding implicitly asking how women can be more like men, and asking how gender research can be conceptualized in new ways. Overall, it was reported that PER on gender equity has been too focused on inbound trajectories of underrepresented groups and on sealing the pipeline that supplies physics, and PER has done little to solve the gender inequities present in physics education. The PER engagers recommend researching everyone's experiences in physics education to understand how a culture has been constructed that puts certain people on the inside and certain people on the outside.

*Canadian PER Engagers are Heterogeneous*

The Canadian PER engagers reported various: interests that sparked their PER engagement, levels of education that they focus their PER on, areas or topics of PER focus, and self-reported levels of expertise.

The researchers reported becoming engaged in PER out of curiosity, an interest and/or observations in their own teaching, motivation to be a better teacher, or having problems with teaching physics. Other factors that influenced PER engagement among the researchers included exposure to new ideas or programs in physics education, prior education, teacher training, or experience in physics education, direct exposure to PER, and finally, personal experiences as an underrepresented person and student led some researchers to engage with gender equity-related PER.
The levels of education that the PER engagers focus on ranged from middle school to university graduate level physics education. Middle school and high school were reported to be levels of focus as physics-like topics and concepts begin to arise, and physics is separated out as an individual topic of study. Post-secondary level physics education was reported as a level of PER focus because of the access to physics students as well as the motivation from university administration to conduct PER also exists. The most commonly reported level of physics education focus was introductory level university physics education, which was described as getting “the most bang for your buck,” as this level affords: a wide variety of students, flexibility to experiment with teaching across a variety of topics, robust statistics on assessments, and accessibility to these courses for the people who teach them and whose teaching can be helped by researching them. Graduate level physics education was reported as a level of PER focus when researching its specific culture and its impacts, female student attrition, and barriers existing at this level of physics education. Finally, pre-service teacher education was reported as a level of physics education on which some PER engagers focus, particularly on primary teachers with no science background.

Diverse areas of PER focus were reported by the Canadian PER engagers. Assessment was described as “the final frontier in pedagogy research in PER,” and named an area of PER focus for a number of the Canadian PER engagers. Gender equity and culture are topics that were mentioned often but were described as “niche” areas. Example topics include how culture and the ideal physicist image impact individuals’ experiences, counterspaces in higher education in physics, and learning what strategies people use to persist in physics education and how these can be supported by schools. Group interactions was reported as a specific area of PER focus, specifically relating to student personality types and autonomy in group selection. Physics pedagogy in general was a reported area of PER focus as PER engagers are aware of and relate their research to their own teaching if applicable. Other reported areas of PER focus include:
problem solving, institutional change, curriculum development, improving student experience, attitude shifts and epistemologies, and teacher training.

The self-reported levels of expertise reported by the Canadian PER engagers were spread fairly evenly across limited, moderate, and high expertise. The most common self-reported expertise level was moderate expertise, and no researchers indicated no expertise. Limited expertise was reported for reasons including: having a broader focus than physics education, identifying as a science education researcher rather than a physics education researcher, feeling like “a fish out of water” having no physics pedagogy focus or little content knowledge, and having done limited PER. Moderate expertise was reported for reasons including: being fairly well-read in PER, feeling neither like a novice nor advanced researcher, recognizing there is more to learn and they are developing expertise, being early in their career, building comfort and direction in their PER, working in an education department (versus physics department) and/or do not teach physics, engaging more so in science education research, having no PER publications, and having engaged in some conferences and PER projects. High expertise was reported for reasons including: identifying as a physics education researcher, feeling part of the PER community, attending conferences and producing PER publications, having a PER-focused curriculum vitae, feeling comparable to other PER experts, long term experience in PER, and supervising students conducting PER projects.

Identity, Non-Belonging, and Deep Skepticism are Barriers to Being a Physics Education Researcher

This theme was developed from a number of Canadian PER engagers’ reports of their position in relation to the PER field and other PER people. Some PER engagers do not consider themselves “physics education researchers” because of existing barriers to being this type of researcher. Specifically, identity (as a multi-faceted characterization of a person) was described as a requisite to being a physics education researcher; that is, researchers needed to feel that they identify as a physics education researcher to really be one—even if others identify them as a
physics education researcher, identify their work as PER, or have invited them to PER conferences to speak. A sense of non-belonging or feeling “very much [like] an interloper” in PER was reported by Canadian PER engagers. This was most commonly the case if the individual reported no physics background. Non-belonging is exacerbated by and continues to keep some Canadian PER engagers on the outside of the PER field when PER engagers are confronted with “deep skepticism of qualitative methodology” at PER-related conferences. PER engagers said that presenting work alongside colleagues in their specific PER area of focus, on a panel, for example, would increase the likelihood of these PER engagers attending such conferences.

Many PER engagers reported that they identify and situate themselves more so within the science education research (SER) field opposed to PER, in part due to the described barriers to being a physics education researcher.

*Gender (In)Equity has Complex Definitions, Causes and Explanations, Solutions, and Responsibility*

Canadian PER engagers reported complex definitions of gender equity. To some, gender equity is about early empowerment of girls, making sure that all people have access to opportunities that interest them, all students feeling comfortable in class, more participation from diverse groups in the physics community, and supporting women in physics departments. Others are careful not to define gender equity as counting bodies and balancing gender numbers because balance does not necessarily relate to equity. However, PER engagers do see 50:50 representation of the broad gender categories of women and men as a good target. They report the ideal to work toward—unlike historically, when individuals commonly worked in isolation on physics problems—is to have people with diverse talents, backgrounds, perspectives, and communication means working in together in teams on today’s difficult physics problems.

Complex definitions of the gender inequity problem in physics education were also reported by Canadian PER engagers. The problem was said to be that people’s experiences do not align with those of the archetypal physicist, and therefore they “experience things like imposter
syndrome, microaggressions, implicit bias” at the micro and miso levels, which deeply impact their experiences.

In terms of conceptualizing the issue, it was said that the “right way” to think about gender inequity is about bias and questioning imbalance. Some PER engagers are working to conceptualize gender inequity as an issue with the environment in classes rather than issues the students are bringing in. PER engagers said gender inequity physics education is different than in other fields due to the complexity and perceptions of physics. Further, they said it is particularly hard to tackle as it comes from multiple sources and is part of a larger problem. However, Canadian PER engagers have observed that definitions and understandings of gender inequity in physics education are evolving with PER as it increasingly focuses on the affective domain (e.g., self-efficacy, test anxiety, sense of belonging), and seeks to gain nuanced understanding of the student experience.

Still, the PER engagers say inequities among students themselves, their attitudes toward one another, and to women faculty continue to need attention. One PER engager said, “The first thing I have to do when I walk into a classroom is to convince students that I know physics. And a male professor doesn't need to do that.” PER engagers also urged that the gender inequity issues begin much earlier than university level physics education and therefore should be addressed earlier than the university level.

Causes and explanations for gender inequity (and the gender gap) reported by the PER engagers were diverse. Some PER engagers said that the inception of the problem is unclear, or that they have no explanation for why some fields of physics (e.g., astronomy) seem to have better representation of women. Other perspectives about gender inequities in physics education included: women’s rejection of physics happens before they are taught physics in university; the way we teach physics tends to exclude women because of the untrue association of rigour, objectivity, and neutrality of physics with masculinity; and competitiveness, masculine feel, lack
of support, and isolation are barriers to women in physics education that are particularly prevalent after high school physics and beginning of university physics, where PER engagers identify a disconnect in physics education.

Some PER engagers reject the idea that the underrepresentation of women in physics education can be explained by biases in physics education. These PER engagers do not deny that there are gender inequities in physics education, but do not necessarily believe gender inequities are the explanation for girls and women’s choices to reject physics. Rather, the accumulation of women’s life experiences contributes to their choice to reject physics. A final idea reported was that the physics community is a refuge for "high intelligence neuroatypical" people (e.g., people with high functioning Autism or Asperger’s), who happen to be men more often than women in the general population.

Solutions to gender inequities in physics education were reported by the PER engagers and ranged widely. The solutions are summarized below, but it is important to note that PER engagers stated there is no single solution or general Band-Aid as there are specific subcultures in physics education and multiple sources of difficulty.

1. Greatest impact will be had by engaging and arming non-PER colleagues who teach physics with tools and resources about gender equitable practices.

2. Help women become interested and persist in physics with ethnic and minority teachers, role models, supportive voices, kinder and gentler teaching approaches, and increasing diversity at all levels of physics departments.

3. Learn transferrable lessons from other fields doing parallel research on gender equity issues (e.g., engineering outreach efforts and research).

4. Strengthen lines of communication between PER and teachers.

5. Recognize gender fluidity and that perceptions of students’ genders are just perceptions.
Complex views about responsibility and gender equity were reported by Canadian PER engagers. Overall, the perspectives were roughly divided into perspectives that view gender equity as the discipline’s responsibility, and perspectives that do not assume responsibility for gender equity in physics education.

The first type of perspective is exemplified by PER engagers reporting that once one becomes more aware of social justice issues they tend to internalize and accept the issues. One said, “As a physics educator and a person who is a physics education researcher, I absolutely think it's my responsibility to think about these issues in my research and in my teaching.” They reported their hope for others to feel the same. Another PER engager said it is everyone’s responsibility to address issues of inequity in every classroom, and name microaggressions and negative messages that still occur everywhere if one listens and watches. Others want to know what they can do in their classroom to support gender equity.

The second type of perspective that does not readily assume responsibility for gender equity in physics education is based on a number of factors. One factor raised by the PER engagers is naiveté: “To think that we might be able to create massive change by changing how we teach a first-year course might be extremely naïve.” They note that concern for students’ entire experience in physics education is important. This type of perspective is based on the difficulty of conceptualizing systemic change for something that is as much related to people’s lifetime of experiences they bring to physics education as it is their experiences within physics education.

Another factor that the PER engagers reported is skepticism—specifically rejecting the answer that physics education is doing something to turn women away. They reported that there are still people who need convincing that gender inequities in physics education is an ongoing issue, and some think complaints about women’s underrepresentation are unwarranted because some progress has been made. The PER engagers also reported that not all people involved in
physics education reach a point when they begin to question how improvements can be made to their teaching, and nor are all physics educators convinced they play a role in gender inequities (whether causing or mitigating).

**Discussion**

This study sought to map the landscape of PER in Canada and discover expert physics education researchers and their areas of research focus. This was achieved via 1) content analysis of online biographies of researchers at all 96 of Canada’s universities’ physics and education departments, 2) a survey of Canadian PER engagers and identification of those with the highest relative expertise, and 3) interviews with 14 Canadian PER engagers about PER in Canada, their work, and perspectives on gender inequity in physics education. These methods resulted in a large amount of both quantitative and qualitative data about PER in Canada.

The resulting “map” of Canadian PER revealed 42 individuals who engage in PER in this country. These individuals: are most commonly in their 40s; are more often men than women or undisclosed gender; are located primarily in British Columbia or Ontario; are working in physics departments and somewhat less often in education departments; most often have less than five years PER engagement; most often self-report moderate expertise in PER; predominantly focus their PER on *curriculum and instruction, effective use of technology in teaching, and student conceptions*; most often identify their general area of research as SER; identify gender equity-specific PER areas of research they engage in; and indicate that conference presentations are by far the most common publication type for sharing PER (Table 5).

Interestingly, Canadian PER engagers with high expertise are focusing their PER fairly evenly across the PER topics, whereas those with moderate expertise or limited expertise are focusing their PER more disproportionately on topics such as *curriculum and instruction, the effective use of technology in education, or student conceptions* (Figure 5). One possible explanation for this is that individuals with high expertise may occupy a kind of niche in their
respective area of PER focus, and individuals with moderate or limited expertise may be focusing on “big” PER topics that are more common and visible in literature or departments.

It is also interesting to compare the areas of PER focus among PER engagers who are based in physics or education departments, the two most common places for physics education researchers to work. Education-based PER engagers, more than those in physics, were found to focus their research on socio-cultural mechanisms, gender equity, and identity, areas relating to students’ affective experience in physics education (Figure 6). Education-based PER engagers also focus more than physics-based PER engagers on student conceptions, epistemology and attitudes, and teacher education and TA training. These areas of foci among education-based PER engagers suggest their greater concentration on student-centered issues in general. Conversely, areas of PER focus among physics-based PER engagers, such as curriculum and instruction, effective use of technology in teaching, problem solving and reasoning, and assessment, suggest their greater concentration on physics teaching and learning issues. Both student-centered issues and teaching and learning issues are equally imperative for improvements to physics education via PER. These results highlight the value of both education- and physics-based PER engagers as contributors of important learning about physics education to the field, an idea supported in the literature (Beichner, 2009).

There are interesting insights about the Canadian PER field that may be gleaned by looking at the age of PER engagers and how long they have been engaged in PER. The majority of PER engagers ($n = 27$) have less than or equal to 10 years of PER engagement, and of those, 55% ($n = 15$) have less than or equal to five years PER engagement. These data may reflect the youth of PER in Canada as a field with many recent engagers, or could also point to challenges for researchers persisting long-term in PER (more on this later in the discussion). Somewhat surprisingly, the data indicate that low years of PER engagement do not equate to low age, as almost half of PER engagers with less than or equal to 10 years PER engagement ($n = 13$) are
over 50 years of age. These data may suggest the increasing popularity of PER over the last decade or so that has attracted both early and later career researchers. However, it is important to note that the above interpretations of the data are made with caution in light of the study’s small sample size.

The interviews with 14 Canadian PER engagers resulted in five themes that, for the first time, richly characterize various aspects of the PER field in Canada. To reiterate, the five themes are: 1) Canadian PER is dilute, underfunded, and needs championing; 2) Canadian PER is uniquely characterized by its position, role, dissemination, and problems; 3) Canadian PER engagers are heterogeneous; 4) identity, non-belonging, and deep skepticism are barriers to being a physics education researcher; 5) gender (in)equity has complex definitions, causes and explanations, solutions, and responsibility. Particularly noteworthy findings are discussed here along with connections to the quantitative results and existing literature and implications for the Canadian PER field.

PER in Canada is diluted by few researchers who are spread thinly over multiple responsibilities, rarely have a formal PER group, lack structured funding support, and are not well-known or well-connected to one another nationally. Almost all Canadian PER engagers interviewed in this study struggled to or could not name another Canadian physics education researcher. Fragmentation of PER researchers, while not previously described in Canada before this study, has been noted in literature in terms of low degree of collaboration and disjointed goals and priorities (Yeung et al., 2005; Cummings, 2011). An annual congress of PER engagers in Canada was called for to foster Canadian-specific PER network creation, promotion, and funding structure development. Importantly, this conference would support increased collaborations and connections among Canadian PER engagers, who, in this study, reported that conference presentations were the best way to share PER and make up 72% of Canadian PER
engagers’ PER publications (Table 5). A number of other findings supported this call and are discussed.

While the Canadian Association of Physicists Congress includes a Division of Physics Education with their number of sessions increasing over time (Antimirova et al., 2014), there is the possibility that without a conference space specifically dedicated to PER, the field may remain a sub-field of physics and continue to pose barriers for non-physics PER engagers in terms of skepticism of their work (i.e., qualitative methodology), their identities, and non-belonging reported by some Canadian PER engagers. An open conference, one that requires no special membership or area of expertise, is suggested as a possible combatant against exclusion from the Canadian PER field.

The Canadian PER engagers cited conferences as important for community building, networking, exchange of ideas, gaining reactions and feedback to research, and applying research to different contexts. These functions could serve to help the Canadian PER field address identified issues such as closed-minded thinking and non-evidence-based approaches as knowledge sharing and collaboration increases. This could be particularly helpful for Canadian PER in addressing persistent gender inequities in Canadian physics education, which are increasingly being corroborated in recent research (Smolina et al., 2021). The Canadian PER engagers reported problematic definitions, conceptualizations, and approaches to gender inequities, such as the binary gender deficit approach (Exarhos, 2020) and research geared at pipeline sealing rather than solving present inequities. If the conversation on approaching gender inequities in physics education included non-physics-based PER engagers, there is a greater possibility of broadening thinking and research orientations that may help solve the issues. The findings of this study suggest that a Canadian PER conference is a promising avenue to advance PER on gender equity.
The fact that the Canadian PER engagers cited such varied interests that sparked their PER engagement and diverse areas and topics on which they focus their PER suggests that PER is of relevance to a lot of Canadian researchers and educators for many reasons. A PER-dedicated conference in Canada would provide the academic and collegial space for PER engagers with diverse interests to share and grow these.

Canadian PER engagers who reported high expertise in PER cited that feeling part of a PER community and attending conferences and producing PER publications are reasons for their high level of PER expertise. This also supports the rationale for developing a Canadian PER conference as it could be particularly helpful to Canadian PER engagers who self-reported limited and moderate expertise due to feeling “like a fish out of water,” identifying primarily as a science education researcher, recognizing there is more to learn, building comfort and direction in their PER, being early in their career, and having no PER publications.

**Conclusion**

This study is the first that describes the landscape of PER in Canada. Specifically, this study highlights the diversity of Canadian PER in terms of engagers’ age and time engaged in PER, levels of self-reported expertise, department of work, and areas of PER focus. It also illuminates characteristics of Canadian PER from the perspective of researchers engaged in this field, which ultimately represents one that has tremendous potential for growth. Canadian PER may benefit from building inclusivity and collaboration into its community, championing the field and funding structures to reinforce it, and working collectively to establish goals and priorities on issues like gender inequity in physics education.

Overall, challenges facing Canadian PER are augmented by a lack of connection and collaboration among PER engagers. Many of the findings in this study, including the diluted nature of Canadian PER, funding limitations, and high percentage of conference publications favoured by researchers pointed to and supported the participants’ suggestion of an annual
Canadian PER conference. The field, which is showing growth in numbers and interest (Antimirova et al., 2014), may have reached the point in time and its development that is both logical and instrumental to actively create connections between its stakeholders.

The major implication of this study is in line with participants’ call for the development of a Canadian PER conference; this active, academic community-building endeavour could improve many aspects of the current field, support those engaging in Canadian PER, and ultimately advance the Canadian PER field in ways that it requires to make improvements to Canadian physics education.
Chapter 4

Phase Three: Defining Current Issues and Priorities for Canadian Physics Education Research to Address Gender Inequity: A Delphi Study

Introduction

Despite over 50 years of research on gender inequity in physics (Clancy, 1962; Scherr, 2016), women continue to be underrepresented in physics and at various levels of physics education in Canada (Smolina et al., 2021). Issues ranging from climate (White & Ivie, 2021) to systemic and implicit bias (Blue, Traxler, & Cid, 2020) to harassment (Knaub et al., 2020) are pressing concerns for Canadian physics education.

Physicists and education researchers are among the Canadian academics tackling issues of gender equity in physics education, mainly within the field of physics education research (PER). However, as Cummings noted, “[PER in America] seems to have become more and more fragmented, quite divergent. This may be a natural consequence of increasing number of researchers, but there seems to be a lack of consensus on priorities and goals of the field.” (Cummings, 2011, p. 10). For Canadian PER, the challenge of establishing priorities and goals is augmented by the fact that there are fewer physics education researchers and thus fewer PER publications produced, funding limitations exist for PER (Antimirova & Goldman, 2008), and only a handful of institutions are offering PER degrees that train physics education researchers.

No consensus on priorities and goals for PER in Canada has been established; yet, this is an important prerequisite for effectively addressing gender inequities in physics education. This study seeks to fill this knowledge gap by asking, what do Canada’s physics education researchers consider to be the most pressing needs and priorities to address gender inequities in physics education? The answers to this question were sought via direct consultation with expert physics
education researchers in Canada with two main objectives: (1) to increase applicability and usefulness of the findings, and (2) to engage Canadian PER leaders in a process of consensus-building to learn about their shared goals and priorities for addressing gender inequity in physics education.

This paper presents a Delphi study that comprised three rounds of questionnaires sent to Canadian physics education researchers, the results of which reveal the current issues, needs, priorities, and reasoning related to addressing gender inequity in physics education. The intent of these results is to help inform and guide researchers, individually and collectively, in their efforts to address the gender inequities present in physics education in Canada.

**Methods**

This study employed mixed-methods to address the research question: What do Canada’s physics education researchers consider to be the most pressing needs and priorities to address the gender equity issue?

**The Delphi Method**

The Delphi technique was the ideal method to address this research question because it allowed for structured, systematic consensus-building with a panel of participants. While the Delphi technique has had many definitions throughout its development (Brown, 1968; Linstone & Turoff, 1975; Rowe & Wright, 1999), the Delphi was understood in this study as “a communication structure aimed at producing a detailed critical examination and discussion” (Green, 2014, p. 1). Similarly, the purpose of Delphi studies may range from building consensus (Brewer, 2011) to forecasting (Guest et al., 2017), and exploring and describing current issues and problems (Green, 2014). For this study, the purpose of the Delphi was to build consensus and to achieve group development of common goals; specifically, to build consensus on the most pressing needs and priorities in Canadian PER to address the gender equity issue in physics education.
Based on Linstone and Turoff’s (1975) list of research properties leading to the need for employing Delphi, the following were reasons in support of using this method to address the research question: 1) The problem does not lend itself to precise analytical techniques but can benefit from subjective collective judgments; 2) the individuals needed to contribute to examining the complex problem have no history of adequate communication and may represent diverse backgrounds with respect to expertise or experience; 3) time and cost make frequent group meetings infeasible; and 4) the heterogeneity of the participants’ opinions must be preserved to assure validity of the results (p. 4).

A further reason to employ Delphi was that this study could meet the optimal conditions for a Delphi study to have a strong impact in higher education, as described by Green (2014): “A solution to a recognized problem is actively being sought; the persons who will be affected and whose cooperation is needed are involved with the Delphi study; and the persons who conduct the Delphi are able to act upon the results” (p. 2).

**Procedure**

The Delphi method procedure involved distributing questionnaires to a panel of participants to collect qualitative and quantitative data, which were analyzed separately, followed by the comparison, interpretation, and integration of results. Results informed a subsequent questionnaire sent to participants, and this procedure was repeated with a total of three questionnaires or three “cycles.” Three cycles were completed because three or more rounds are optimal when the goal is reaching consensus, and more than three may compromise participants’ enthusiasm and response rates (Stone Fish & Busby, 2005). For the same reason, the method of participation was via online questionnaires using Qualtrics online survey software.

**Delphi Questionnaire One.** The first questionnaire was sent to participants with three open-ended prompts for idea and issue generation. The three prompts formed the three sections of future questionnaires. Participants were encouraged to answer as comprehensively as possible,
not omitting any ideas that came to mind, and were asked to respond in point-form. Each prompt included examples to help elicit ideas. The examples were drawn from research interviews with international PER experts about gender inequity in physics education from the study in the first phase of this research project. The participants were informed that their answers need not be related to the examples provided.

The responses provided by participants were analyzed using inductive thematic analysis (Thomas, 2006) by coding the responses (Strauss and Corbin, 1990) to derive the theme or main idea. The researcher ensured all ideas were phrased as statements. All of the statements generated in qualitative form in questionnaire one were collated and transformed into quantitative questionnaire items for questionnaire two.

**Delphi Questionnaire Two.** The second questionnaire aimed to determine the level of agreement among panelists on the ideas generated in questionnaire one. Participants were provided with the group’s ideas each paired with a Likert (1932) type scale with six options [strongly disagree; disagree; somewhat disagree; somewhat agree; agree; strongly agree], of which they could select one to indicate their level of agreement with each item. Participants were also encouraged to provide a comment or reason for their agreement level selection.

The quantitative scores were analyzed in Microsoft Excel to obtain summary statistics. The median (M; the middle value of agreement level selections) was calculated as the measure of central tendency, and the interquartile range (IQR; the middle 50% of selections) was calculated as the measure of spread. The M and IQR are the preferred analysis measures of consensus in the Delphi method (Puig & Adams, 2019). The percentage distribution of participants who selected each agreement level was also calculated to summarize responses for each item. The qualitative responses for each item were summarized and integrated into the summary of data for each questionnaire two item.
**Delphi Questionnaire Three.** The third questionnaire aimed to establish consensus among the panelists by providing them an opportunity to consider their responses in relation to the group’s responses, and to adjust their level of agreement if they wished. *Questionnaire three* was sent to participants with the following information for each item, summarizing the panel’s previous responses: percentage distribution of participants’ agreement level selections, M, IQR, their own previous agreement level selection, and a summary of comments. Participants were asked once again to indicate their level of agreement with each item in light of the group’s responses and provide a comment or reason for their selection.

The quantitative scores for each item were analyzed using the same methods described above for analyzing scores for *questionnaire two* to determine percentage distribution of participants’ agreement level selections, M, and IQR. The qualitative responses for each item were summarized. Quantitative and qualitative results of *questionnaire three* represent the reasons for and levels of consensus corresponding to each item in the Delphi. These will be presented in the *Results* section. While consensus levels of agreement are inconsistent across literature (Hsu & Sandford, 2007), in this study consensus was reached when there was 70% or greater agreement among panelists.

Following all three questionnaire rounds, further analysis was carried out on both quantitative and qualitative data. Consensus levels were calculated for each statement based on participants’ level of agreement selections for both *questionnaire two* and *questionnaire three*. Specifically, the percentages of *somewhat agree, agree* and *strongly agree* were summed, as were the percentages of *strongly disagree, disagree*, and *somewhat disagree* selections. The percentage of participants who agree (right), and disagree (left) are shown in the *Results* section. Where a percentage is bolded, consensus was reached (≥ 70% agreement).

The comments or reasons provided by participants in *questionnaire two* and *questionnaire three* were analyzed using inductive thematic analysis (Thomas, 2006; Strauss and
Corbin, 1990). The purpose of this analysis was to enable key themes to emerge from the commentary, which are useful for understanding this massive amount of data in a meaningful way. This analysis considered all comments that participants offered in both questionnaire two and questionnaire three. However, comments were excluded from the analysis if they 1) contained ideas that reiterated the item’s meaning and did not add new meaning, or 2) reiterated the participants’ quantitative agreement level selection without adding new meaning. The themes are reported in the results section.

Participants

In a prior study that is part of this research project, a survey was distributed to Canadian researchers who engage with PER to characterize their self-reported expertise, area of research focus, years engaged with PER, and number of PER publications—variables which were considered representative of expertise in PER. Of the researchers who consented to continue to participate in future research activities, 14 researchers with the highest relative expertise were purposively selected for an interview aimed at gaining a deeper understanding of their research activities, area of focus, and perspectives on PER and gender inequity in physics education. These 14 individuals were recruited via email invitation to participate in the current study.

Participants were informed of the following: 1) Participation would involve completing three successive questionnaires; 2) that they have valuable perspectives on physics education and gender equity and therefore were selected to represent one of 14 individuals on a diverse panel of participants across Canada; 3) the topic of questionnaires would focus on the needs and priorities in Canadian PER to address gender equity issues in physics education; 4) participation in the study would be an opportunity to inform recommendations for ongoing PER in Canada on gender equity in physics education; and 5) their participation would be confidential as their identity would be known only to the researcher.
The participants are described in aggregate form to protect the participants’ identities.

There were 7 women and 7 men in the participant group. Six participants (42%) among the group were in the 40–49 age group, followed by 21% in the 30–39 age group, and 14% in both the 50–59 and 60–69 age groups. In terms of geography, 3 participants were based in British Columbia, 1 in Alberta, 4 in Ontario, 3 in Quebec, 1 in Nova Scotia, and 1 in Newfoundland and Labrador.

Participants were all associated with a Canadian university and worked in a faculty of education \((n = 6)\) or physics \((n = 8)\).

Participants’ areas of research focus spanned 13 topics, of which the 5 highest percentages were the following areas of focus: effective use of technology in teaching (15%), curriculum and instruction (13%), teacher education and TA training (10%), student conceptions (10%), and equally, three areas of gender equity, socio-cultural mechanisms, and problem solving and reasoning (each 8%) (Figure 9).

**Figure 9**

*Percentage of Participants’ Areas of Research Focus*

![Pie chart showing areas of research focus](image)

*Note.* Areas of research focus by percentage of participants who engage in these topics.

More than half of participants (57%) self-reported having moderate expertise in PER, and fewer participants self-reported limited expertise (21%) and high expertise (21%). No participants
self-reported no expertise in PER. The participants’ publications in PER (including academic and practitioner journal papers, conference presentations, and other types) ranged in number from 6 to 115, with the mean and median publication number being 24 and 13, respectively. In terms of number of years engaged with PER, the participants’ reported between 2 and 25 years in PER, with the mean and median number of years engaged in PER being 9 and 8, respectively.

**Validity Efforts**

The following efforts for increasing validity of the Delphi, as described by Gordon and Helmer (1966), were prioritized. Participation remained stable (response rates reported in Results section). Time lapses between questionnaires were minimized; each questionnaire was distributed three weeks apart with two weeks allowance for completion by participants. Items on the questionnaires were written unambiguously as possible. Responses with reasons for agreement level selections were requested and encouraged. Consensus was not measured with mean or average scores to prevent skew toward outliers. A varied panel of participants were selected (researchers from different schools and provinces) to include diverse perspectives and expertise of many types. Keeping the identities of participants confidential avoided domination of status or strength of opinions (Linstone & Turoff, 1975). The first questionnaire allowed idea input from the participants to increase its reliability (Iqbal & Pipon-Young, 2009). Questionnaire items contained an even number of response options, forcing participants to choose on one side or the other of the imaginary neutral response; this scale design was important because middle-range responses can lead to false consensus (Green, 2014). The author followed-up with non-responders to maintain high response rates and therefore increase credibility of the study (Beretta, 1996).

**Results**

Response rates for the three Delphi questionnaires were 71% \((n = 10)\) for questionnaire one, 100% \((n = 10)\) for questionnaire two, and 100% \((n = 10)\) for questionnaire three (Table 6).
People who did not complete the first questionnaire were not invited to participate in later questionnaires.

**Table 6**

*Response Rates for Each Delphi Questionnaire*

<table>
<thead>
<tr>
<th>Questionnaire</th>
<th>Number of questionnaires sent</th>
<th>Number of respondents</th>
<th>Response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questionnaire 1</td>
<td>14</td>
<td>10</td>
<td>71%</td>
</tr>
<tr>
<td>Questionnaire 2</td>
<td>10</td>
<td>10</td>
<td>100%</td>
</tr>
<tr>
<td>Questionnaire 3</td>
<td>10</td>
<td>10</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Questionnaire One**

The idea- and issue-generating prompts in *questionnaire one* were as follows: 1) I consider the following to be current issues in physics education related to gender inequity, 2) I consider the following to be current research needs, priorities, and/or guiding principles for PER aiming to address gender inequity in physics education, and 3) I think the following guidance, supports, and/or developments could help the PER field in Canada address gender inequity in physics education.

Following inductive thematic analysis of all ideas generated, a total of 47 statements resulted from *questionnaire one* (Table 7). Prompt one yielded 16 statements, prompt two yielded 18 statements, and prompt three yielded 13 statements.

**Table 7**

*Statements Generated in Response to Three Prompts on Round 1 Questionnaire*

1. I consider the following to be current issues in physics education related to gender inequity:
   1.1. Whether anyone really knows the extent of the gender inequity problem is a current issue.
   1.2. Sexist department culture is a current issue. As one example, women faculty experience sexism from students as much as, or more than, from their colleagues.
   1.3. Overall department culture is a current issue. It relates to hiring, experiences and retention of undergraduate and graduate students and employees, acceptable pedagogical approaches, family-related values, and whether overworking is allowed, encouraged, and rewarded.
   1.4. Cultures in physics that are insufficiently mindful of gendered and sexual harassment are a current issue and contribute to hostile climates for minoritized students in physics.
1.5. The need for regular training in micro-aggressions and bystander responsibilities for students and staff is a current issue.

1.6. How physics is thought of in relationship to femininity and masculinity is a current issue. This thinking constructs departmental cultures that define who is “in” and who is “out,” and how people’s identity performances are understood as “inside” or “outside” as a result.

1.7. It is a current issue that intersectional identities or diverse pathways are not accommodated in physics education.

1.8. It is a current issue that men are the vast majority of physics student and faculty populations.

1.9. Lack of supports for women is a current issue, including: role models (e.g., teachers and professors who are women, women in related careers like engineering); seeing examples of gender diversity in physics; and support programs for both women students and physicists.

1.10. More programs are needed that target younger students (e.g., elementary level students) and encourage physics education continuation.

1.11. Support groups for students and staff need safe spaces to meet within university departments.

1.12. Long term funding is needed for stable and sustainable leadership of Equity Groups within physics departments (volunteers come and go).

1.13. Curricular materials that are dominated by white male presence and traditionally male domains (e.g., military, sports, and cars in examples, figures, and some standardized assessments), and canonical texts being written by “old white guys” are current issues.

1.14. Problematic pedagogy is a current issue, including: presenting physics as a difficult subject, lack of hands-on learning in lower levels of physics education, lack of connection to authentic situations and affecting change for good (e.g., electric cars, solar and wind power), and disadvantaging marginalized students in group work or in assessments.

1.15. The stereotype that boys are better at application and girls are better at memorizing content knowledge is a current issue. This stereotype must be broken and may have to do with the idea that physics is the application of math.

1.16. A technocratic view of physics education is a current issue. Many different visions of physics education should cohabit; democratic, humanist, and utilitarian visions should take a bigger place in physics education.

2. I consider the following to be current research needs, priorities, and/or guiding principles for PER aiming to address gender inequity in physics education:

2.1. Research is needed to determine if, indeed, there is a problem with gender inequity in physics education. The simple observation of a gender imbalance at a particular level is not strong evidence that there is gender inequity at that level.

2.2. Research is needed to determine if our approaches to physics education are introducing or perpetuating gender bias, and if we can be more inclusive in physics education, how?

2.3. The first step is to evaluate how big the problem is and how much it is perceived by women students (e.g., look at gender disparities in first year university physics across Canada, and where gaps shrink, look at those programs or courses for clues as to what might be working).

2.4. We need to talk to students to find out what needs and problems women students perceive in the current system and what they would find useful.

2.5. We need to frame the goal of PER on gender inequity in detail. Existing research highlights the present that we find unacceptable, seldom with concrete examples of possible outcomes or futures we would find acceptable.

2.6. PER needs to be data- and evidence-driven. Example areas needed include: instructional techniques, existing best practice knowledge, efficacy of micro-aggression and bystander training, effective support groups for students and staff, and support needed for students developing physics identity.
2.7. Evidence-based research is not that important. A diversity in methodology or theoretical frameworks is more interesting and helpful.

2.8. The most promising work is supported by theoretical frameworks that move away from gender as a binary construct and rather investigates how masculinities and femininities are produced in physics cultures in ways that position some "inside" and some "outside."

2.9. Research is needed that highlights identity rather than differences between genders because it is more inclusive and accurate. We need to move away from gap-gazing research; decades of this has not resulted in any meaningful change. Time to move on.

2.10. PER on gender equity should be fueled by other fields such as feminist science studies or feminist epistemology.

2.11. To address departmental physics cultures, we need to look at possibilities of counterspaces to 1) provide opportunities for people from minoritized groups or identities to come together and find support and 2) find ways to integrate structural changes into departmental practices.

2.12. PER is needed on gender in relation to physics identity, self-efficacy, beliefs and attitudes about physics, and test anxiety.

2.13. PER is needed on gender dynamics in relation to group composition in group activities.

2.14. PER is needed on the impact that contextual information in a problem has on gender-based outcomes (e.g., military context versus same problem in a different context).

2.15. PER is needed on the impact the gender of the instructor or teacher has on outcomes.

2.16. We need to be designing, implementing, and doing longitudinal studies of curriculum.

2.17. We really need action research or classroom-based research directly targeting classroom issues (e.g., what activities increase K-9 students' interest, at what age should students be introduced to physics instead of general science, and do students of all genders receive the same amount of teacher interaction and feedback?).

2.18. It is important to focus on different levels of physics education and different groups of people (i.e., students, teachers) as each have different issues and require different approaches.

3. I think the following guidance, supports, and/or developments could help the PER field in Canada address gender inequity in physics education:

3.1. Recognition of the value of PER could help.

3.2. A strong community dedicated to PER and to gender issues could help.

3.3. A survey in Canada could help: ask about researchers' interest in attending a PER conference, and who reads and publishes PER. It would be useful to know the extent of the Canadian PER community.

3.4. Canada needs a PER conference or noticeable PER sessions at other conferences. Bring researchers together through a specialized conference devoted to the topic. People need a place to come together around scholarship and make professional friends.

3.5. Special issues in research journals on the topic of gender inequity in physics education would be helpful for PER in Canada to address the topic.

3.6. Canada needs stable funding structures in order for PER to be productive in Canada. Funding could support partnerships between schools and researchers, knowledge synthesis, increase of PER degree-granting institutions, longitudinal and large-scale studies, and gender equity research programs.

3.7. Expansion of PER to STER (Science and Technology Education Research) would help; physics shares many features of its educational model with other sciences and engineering with similar concerns.

3.8. Openness to new theoretical framings (e.g., post-structural approaches to gender, non-binary approaches to research) and qualitative approaches will be helpful, as well as making these more
visible in PER conferences.

3.9. The huge amount of research currently being done in equity, diversity, and inclusion should be put to work in PER.

3.10. Researchers should be trained in feminist science studies and feminist epistemologies.

3.11. Researchers should be trained in physics and in education. Understanding the fields of interest makes the researcher more credible, even when their ideas may seem radical.

3.12. Utilizing unbiased evidence would be helpful because it is the best tool for convincing skeptics.

3.13. Physicists do not see PER as physics because physics’ scientific method to interrogate evidence cannot be used in PER, especially for gender equity research. Perhaps PER on gender equity should be more overtly open to falsifiability.

Questionnaires Two and Three

Quantitative results of questionnaire two and questionnaire three are presented together to show the changes to participants’ agreement levels between the questionnaires, and on which items the panel achieved consensus (≥ 70% agreement). Each questionnaire had three sections corresponding to the three prompts, as such, results are presented in three sections.

1. I Consider the Following to be Current Issues in Physics Education Related to Gender Inequity

By the end of questionnaire three, participants reached consensus on 87% of items (n = 14). All items that reached consensus were oriented toward agree. Participants reached 100% consensus on 12.5% of items (n = 2), 90% consensus on 18.7% of items (n = 3), 80% consensus on 43.7% of items (n = 7), 78% consensus on 6% of items (n = 1), and 70% consensus on 6% of items (n = 1). No consensus was reached on 12.5% of items (n = 2), although one of these items (number 1.15.) previously had consensus in questionnaire two. In total, 37.5% of items (n = 6) weakened strength of support between questionnaire two and questionnaire three, 25% of items (n = 4) increased strength of support between questionnaire two and questionnaire three, and 37.5% of items (n = 6) maintained the same strength of support between questionnaire two and questionnaire three. Individual items’ agreement levels, consensus levels, M scores, and IQR scores in both questionnaire two and questionnaire three are shown in (Table 8).
Table 8

Consensus Levels for Prompt 1 Items in Questionnaire 2 and Questionnaire 3

<table>
<thead>
<tr>
<th>Prompt</th>
<th>Description</th>
<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
<th>IQR</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.</td>
<td>Whether anyone really knows the extent of the gender inequity problem is a current issue.</td>
<td>20%</td>
<td>0%</td>
<td>80%</td>
<td>5</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>1.2.</td>
<td>Sexist department culture is a current issue. As one example, women faculty experience sexism from students as much as, or more than, from their colleagues.</td>
<td>20%</td>
<td>20%</td>
<td>80%</td>
<td>5</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>1.3.</td>
<td>Overall department culture is a current issue. It relates to hiring, experiences and retention of undergraduate and graduate students and employees, acceptable pedagogical approaches, family-related values, and whether overworking is allowed, encouraged, and rewarded.</td>
<td>20%</td>
<td>20%</td>
<td>80%</td>
<td>5</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>1.4.</td>
<td>Cultures in physics that are insufficiently mindful of gendered and sexual harassment are a current issue and contribute to hostile climates for minoritized students in physics.</td>
<td>10%</td>
<td>10%</td>
<td>90%</td>
<td>5.5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1.5.</td>
<td>The need for regular training in micro-aggressions and bystander responsibilities for students and staff is a current issue.</td>
<td>20%</td>
<td>20%</td>
<td>80%</td>
<td>5</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>1.6.</td>
<td>How physics is thought of in relationship to femininity and masculinity is a current issue. This thinking constructs departmental cultures that define who is “in” and who is “out,” and how people’s identity performances are understood as “inside” or “outside” as a result.</td>
<td>20%</td>
<td>10%</td>
<td>80%</td>
<td>5.5</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>1.7.</td>
<td>It is a current issue that intersectional identities or diverse pathways are not accommodated in physics education.</td>
<td>10%</td>
<td>20%</td>
<td>90%</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1.8.</td>
<td>It is a current issue that men are the vast majority of physics student and faculty populations.</td>
<td>10%</td>
<td>20%</td>
<td>90%</td>
<td>5</td>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>1.9.</td>
<td>Lack of supports for women is a current issue, including: role models (e.g., teachers and professors who are women, women in related careers like engineering); seeing examples of</td>
<td>10%</td>
<td>20%</td>
<td>90%</td>
<td>5</td>
<td>2.25</td>
<td></td>
</tr>
</tbody>
</table>
gender diversity in physics; and support programs for both women students and physicists.

1.10. More programs are needed that target younger students (e.g., elementary level students) and encourage physics education continuation.

1.11. Support groups for students and staff need safe spaces to meet within university departments.

1.12. Long term funding is needed for stable and sustainable leadership of Equity Groups within physics departments (volunteers come and go).

1.13. Curricular materials that are dominated by white male presence and traditionally male domains (e.g., military, sports, and cars in examples, figures, and some standardized assessments), and canonical texts being written by “old white guys” are current issues.

1.14. Problematic pedagogy is a current issue, including: presenting physics as a difficult subject, lack of hands-on learning in lower levels of physics education, lack of connection to authentic situations and affecting change for good (e.g., electric cars, solar and wind power), and disadvantaging marginalized students in group work or in assessments.

1.15. The stereotype that boys are better at application and girls are better at memorizing content knowledge is a current issue. This stereotype must be broken and may have to do with the idea that physics is the application of math.

1.16. A technocratic view of physics education is a current issue. Many different visions of physics education should cohabit; democratic, humanist, and utilitarian visions should take a bigger place in physics education.
2. I Consider the Following to be Current Research Needs, Priorities, and/or Guiding Principles for PER Aiming to Address Gender Inequity in Physics Education

By the end of questionnaire three, participants reached consensus on 94% of items \((n = 17)\). Of items that reached consensus, 94% \((n = 16)\) were oriented toward agree, and 5.8% \((n = 1)\) were oriented toward disagree. Of these, participants reached 100% consensus on 41% of items \((n = 7)\), 90% consensus on 23.5% of items \((n = 4)\), 80% consensus on 29.4% of items \((n = 5)\), and 78% consensus on 5.8% of items \((n = 1)\). No consensus was reached on 5.5% of items \((n = 1)\), which had 50% of participants agree and 50% disagree in both questionnaire two and questionnaire three. In total, 5.5% of items \((n = 1)\) weakened strength of support between questionnaire two and questionnaire three, 16.6% of items \((n = 3)\) increased strength of support between questionnaire two and questionnaire three, and 77.7% of items \((n = 14)\) maintained the same strength of support between questionnaire two and questionnaire three. Individual items’ agreement levels, consensus levels, M scores, and IQR scores in both questionnaire two and questionnaire three are shown in Table 9.

Table 9

Consensus Levels for Prompt 2 Items in Questionnaire 2 and Questionnaire 3

| 2. I consider the following to be current research needs, priorities, and/or guiding principles for PER aiming to address gender inequity in physics education: | | |
| --- | --- | --- | --- |
| 2.1. Research is needed to determine if, indeed, there is a problem with gender inequity in physics education. The simple observation of a gender imbalance at a particular level is not strong evidence that there is gender inequity at that level. | | |
| Round 2 \((n=10)\) | 50% | | 50% | 3.5 | 3.25 |
| Round 3 \((n=10)\) | 50% | | 50% | 3 | 3 |
| 2.2. Research is needed to determine if our approaches to physics education are introducing or perpetuating gender bias, and if we can be more inclusive in physics education, how? | | |
| Round 2 \((n=10)\) | 0% | | 100% | 5 | 1 |
| Round 3 \((n=10)\) | 0% | | 100% | 5 | 1.75 |
| 2.3. The first step is to evaluate how big the problem is and how much it is perceived by women students (e.g., look at gender disparities in first year university physics across Canada, and where gaps shrink, look at those programs or courses for clues as to what might be working). | | |

115
2.4. We need to talk to students to find out what needs and problems women students perceive in the current system and what they would find useful.

| Round 2 (n=10) | 20% | 80% | M | IQR |
| Round 3 (n=10) | 20% | 80% | 4 | 1.25 |

2.5. We need to frame the goal of PER on gender inequity in detail. Existing research highlights the present that we find unacceptable, seldom with concrete examples of possible outcomes or futures we would find acceptable.

| Round 2 (n=10) | 10% | 90% | M | IQR |
| Round 3 (n=10) | 10% | 90% | 5 | 1 |

2.6. PER needs to be data- and evidence-driven. Example areas needed include: instructional techniques, existing best practice knowledge, efficacy of micro-aggression and bystander training, effective support groups for students and staff, and support needed for students developing physics identity.

| Round 2 (n=10) | 0% | 100% | M | IQR |
| Round 3 (n=10) | 0% | 100% | 5 | 0.25 |

2.7. Evidence-based research is not that important. A diversity in methodology or theoretical frameworks is more interesting and helpful.

| Round 2 (n=9) | 56% | 44% | M | IQR |
| Round 3 (n=10) | 80% | 20% | 3 | 3.5 |

2.8. The most promising work is supported by theoretical frameworks that move away from gender as a binary construct and rather investigates how masculinities and femininities are produced in physics cultures in ways that position some "inside" and some "outside."

| Round 2 (n=9) | 22% | 78% | M | IQR |
| Round 3 (n=10) | 20% | 80% | 5 | 1.5 |

2.9. Research is needed that highlights identity rather than differences between genders because it is more inclusive and accurate. We need to move away from gap-gazing research; decades of this has not resulted in any meaningful change. Time to move on.

| Round 2 (n=10) | 10% | 90% | M | IQR |
| Round 3 (n=10) | 10% | 90% | 5 | 1 |

2.10. PER on gender equity should be fueled by other fields such as feminist science studies or feminist epistemology.

| Round 2 (n=8) | 25% | 75% | M | IQR |
| Round 3 (n=9) | 22% | 78% | 5.5 | 3.5 |

2.11. To address departmental physics cultures, we need to look at possibilities of counterspaces to 1) provide opportunities for people from minoritized groups or identities to come together and find support and 2) find ways to integrate structural changes into departmental practices.

| Round 2 (n=10) | 20% | 80% | M | IQR |
| Round 3 (n=10) | 20% | 80% | 5 | 1.25 |

2.12. PER is needed on gender in relation to physics identity, self-efficacy, beliefs and attitudes about physics, and test anxiety.

| Round 2 (n=10) | | | M | IQR |
| Round 3 (n=10) | | | 5 | 1.25 |
2.13. PER is needed on gender dynamics in relation to group composition in group activities.

<table>
<thead>
<tr>
<th></th>
<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
<th>IQR</th>
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<tr>
<td></td>
<td>0%</td>
<td>0%</td>
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2.14. PER is needed on the impact that contextual information in a problem has on gender-based outcomes (e.g., military context versus same problem in a different context).

<table>
<thead>
<tr>
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<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
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<tr>
<td></td>
<td>0%</td>
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</table>

2.15. PER is needed on the impact the gender of the instructor or teacher has on outcomes.

<table>
<thead>
<tr>
<th></th>
<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
<th>IQR</th>
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<tbody>
<tr>
<td></td>
<td>30%</td>
<td>20%</td>
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</table>

2.16. We need to be designing, implementing, and doing longitudinal studies of curriculum.

<table>
<thead>
<tr>
<th></th>
<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>0%</td>
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<td></td>
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</tbody>
</table>

2.17. We really need action research or classroom-based research directly targeting classroom issues (e.g., what activities increase K-9 students' interest, at what age should students be introduced to physics instead of general science, and do students of all genders receive the same amount of teacher interaction and feedback?).

<table>
<thead>
<tr>
<th></th>
<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>10%</td>
<td></td>
<td></td>
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</tbody>
</table>

2.18. It is important to focus on different levels of physics education and different groups of people (i.e., students, teachers) as each have different issues and require different approaches.

<table>
<thead>
<tr>
<th></th>
<th>Round 2 (n=10)</th>
<th>Round 3 (n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
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</tbody>
</table>

3. I Think the Following Guidance, Supports, and/or Developments Could Help the PER Field in Canada Address Gender Inequity in Physics Education

By the end of questionnaire three, participants reached consensus on 92% of items (n = 12). Of items that reached consensus, 100% (n = 12) were oriented toward *agree*. Participants reached 100% consensus on 46% of items (n = 6), 90% consensus on 15% of items (n = 2), 80%
consensus on 15% of items ($n=2$), and 70% consensus on 15% of items ($n=2$). No consensus was reached on 7.6% of items ($n=1$), which was the only item to switch agreement orientation, i.e., from 67% agree in questionnaire two to 60% disagree in questionnaire three. In total, 92% of items ($n=12$) maintained the same strength of support between questionnaire two and questionnaire three. Individual items’ agreement levels, consensus levels, M scores, and IQR scores in both questionnaire two and questionnaire three are shown in Table 10.

Table 10

Consensus Levels for Prompt 3 Items in Questionnaire 2 and Questionnaire 3

<table>
<thead>
<tr>
<th>Prompt</th>
<th>Consensus Levels</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1. Recognition of the value of PER could help.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 2 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>5</td>
</tr>
<tr>
<td>Round 3 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>5</td>
</tr>
<tr>
<td>3.2. A strong community dedicated to PER and to gender issues could help.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 2 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>5</td>
</tr>
<tr>
<td>Round 3 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>5.5</td>
</tr>
<tr>
<td>3.3. A survey in Canada could help: ask about researchers’ interest in attending a PER conference, and who reads and publishes PER. It would be useful to know the extent of the Canadian PER community.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 2 ($n=10$)</td>
<td>10%</td>
<td>90%</td>
<td>5</td>
</tr>
<tr>
<td>Round 3 ($n=10$)</td>
<td>10%</td>
<td>90%</td>
<td>5.5</td>
</tr>
<tr>
<td>3.4. Canada needs a PER conference or noticeable PER sessions at other conferences. Bring researchers together through a specialized conference devoted to the topic. People need a place to come together around scholarship and make professional friends.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 2 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>6</td>
</tr>
<tr>
<td>Round 3 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>6</td>
</tr>
<tr>
<td>3.5. Special issues in research journals on the topic of gender inequity in physics education would be helpful for PER in Canada to address the topic.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 2 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>5</td>
</tr>
<tr>
<td>Round 3 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>5.5</td>
</tr>
<tr>
<td>3.6. Canada needs stable funding structures in order for PER to be productive in Canada. Funding could support partnerships between schools and researchers, knowledge synthesis, increase of PER degree-granting institutions, longitudinal and large-scale studies, and gender equity research programs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 2 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>6</td>
</tr>
<tr>
<td>Round 3 ($n=10$)</td>
<td>0%</td>
<td>100%</td>
<td>6</td>
</tr>
</tbody>
</table>
3.7. Expansion of PER to STER (Science and Technology Education Research) would help; physics shares many features of its educational model with other sciences and engineering with similar concerns.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>10%</td>
<td>90%</td>
<td>6</td>
</tr>
<tr>
<td>Round 3</td>
<td>10%</td>
<td>90%</td>
<td>5.5</td>
</tr>
</tbody>
</table>

3.8. Openness to new theoretical framings (e.g., post-structural approaches to gender, non-binary approaches to research) and qualitative approaches will be helpful, as well as making these more visible in PER conferences.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>20%</td>
<td>80%</td>
<td>6</td>
</tr>
<tr>
<td>Round 3</td>
<td>20%</td>
<td>80%</td>
<td>6</td>
</tr>
</tbody>
</table>

3.9. The huge amount of research currently being done in equity, diversity, and inclusion should be put to work in PER.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=8)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>0%</td>
<td>100%</td>
<td>6</td>
</tr>
<tr>
<td>Round 3</td>
<td>0%</td>
<td>100%</td>
<td>6</td>
</tr>
</tbody>
</table>

3.10. Researchers should be trained in feminist science studies and feminist epistemologies.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>30%</td>
<td>70%</td>
<td>4.5</td>
</tr>
<tr>
<td>Round 3</td>
<td>30%</td>
<td>70%</td>
<td>4.5</td>
</tr>
</tbody>
</table>

3.11. Researchers should be trained in physics and in education. Understanding the fields of interest makes the researcher more credible, even when their ideas may seem radical.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>20%</td>
<td>80%</td>
<td>5</td>
</tr>
<tr>
<td>Round 3</td>
<td>20%</td>
<td>80%</td>
<td>4.5</td>
</tr>
</tbody>
</table>

3.12. Utilizing unbiased evidence would be helpful because it is the best tool for convincing skeptics.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=10)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>30%</td>
<td>70%</td>
<td>5.5</td>
</tr>
<tr>
<td>Round 3</td>
<td>30%</td>
<td>70%</td>
<td>3</td>
</tr>
</tbody>
</table>

3.13. Physicists do not see PER as physics because physics' scientific method to interrogate evidence cannot be used in PER, especially for gender equity research. Perhaps PER on gender equity should be more overtly open to falsifiability.

<table>
<thead>
<tr>
<th>Round</th>
<th>(n=9)</th>
<th>M</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 2</td>
<td>33%</td>
<td>67%</td>
<td>4</td>
</tr>
<tr>
<td>Round 3</td>
<td>60%</td>
<td>40%</td>
<td>5</td>
</tr>
</tbody>
</table>

Overall, 43 (91.4%) of the total 47 items on the questionnaire reached consensus. Four items (8.5%) did not reach consensus. Consensus levels which varied ≤10% between
questionnaire two and questionnaire three are considered stable (Duffield, 1993). Overall, 95% of items that reached consensus had a stable consensus level (Table 11).

**Table 11**

*Stability of Consensus Among Questionnaire Items That Reached Consensus*

<table>
<thead>
<tr>
<th>Questionnaire section</th>
<th>Total number of items</th>
<th>Number of items reached consensus</th>
<th>Items with stable consensus (≤10% variation between questionnaires)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt 1</td>
<td>16</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Prompt 2</td>
<td>18</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Prompt 3</td>
<td>13</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>43</td>
<td>41</td>
</tr>
</tbody>
</table>

**Thematic Analysis of Comments**

Participants provided comments and reasons for their agreement level selections in questionnaire two and questionnaire three ($n = 316$). After excluding comments that 1) reiterated the item’s meaning and did not add new meaning, or 2) reiterated the participants’ quantitative agreement level selection and did not add new meaning, a total of 151 comments remained and were coded. The inductive thematic analysis of these comments and reasons resulted in six overarching themes:

1. Fragmented researchers, visions, and approaches
2. Lack of widespread knowledge, or willful ignorance?
3. Physics fragility
4. Research drivers
5. Urgency to act now
6. What PER is and who can do this research are disputed topics

The themes represent key ideas in the commentary between the participants as they made agreement level choices in both questionnaire two and questionnaire three. Depicting the linkage of themes to each questionnaire item was limited by the high number of items ($n = 47$) and total
coded comments \((n = 151)\). However, the composition of themes (categories) and representation of themes (percentages of comments) across the questionnaire prompts reveals in more detail the ideas present in the participants’ commentary. Table 12 shows the categories (named groups of raw coded comments) that form the themes. Table 12 also shows the total percentage of comments constituting each theme. Themes ordered from highest to lowest percent of total comments are: lack of widespread knowledge, or willful ignorance? (27.1%), research drivers (20.5%), physics fragility (17.8%), fragmented researchers, visions and approaches (15.8%), what PER is and who can do this research are disputed topics (13.9%), and urgency to act now (4.6%). Additionally, Table 12 shows the prominence of themes across the three prompts of the questionnaires by the percentage of comments. As an example, the theme urgency to act now is the most prominent theme for prompt 2 (relating to current research needs and priorities) as 85.7% of this theme’s comments were in response to items in prompt 2.
<table>
<thead>
<tr>
<th>Theme</th>
<th>Categories comprising theme</th>
<th>Sample comment</th>
<th>Percent of total comments</th>
<th>Prominence of theme across prompts (% of comments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of widespread knowledge, or willful ignorance?</td>
<td>Call for more research on reality of inequity</td>
<td>Inequity problem is unknown but gender balance problem is known. This research exists, not knowing is just willful ignorance.</td>
<td>27.1%</td>
<td>70.7% 29.2% 0%</td>
</tr>
<tr>
<td></td>
<td>Call for increased awareness of problem to make change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evidence of issues exists</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender imbalance is a symptom of issue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Image and culture have consequences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research drivers</td>
<td>Canadian data needed</td>
<td>Impact of role modeling lacks evidence; yet, “counterspaces” suggest support for minoritized students.</td>
<td>20.5%</td>
<td>83.8% 16.1% 0%</td>
</tr>
<tr>
<td></td>
<td>Conflicting or absent evidence points to need for more research</td>
<td>Money equals power and we should be cautious of who we give power to.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intersectional identities concern small group of students</td>
<td>Need evidence that women are in inequitable positions in my department to effect change.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Issue will be forgotten without ongoing research</td>
<td>Programs must acknowledge and address student sexism.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Learn from women and non-minority groups who rejected physics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Money, space, and time equal respect and power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Need department-specific research</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PER can help solve the issue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physicians respond poorly to Education or equity language</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Programs can take responsibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics fragility</td>
<td>Gender blindness</td>
<td>We continue to subsume other fields and approaches into PER and we run the risk of devaluing a physicist’s framework here.</td>
<td>17.8%</td>
<td>33.3% 25.9% 40.7%</td>
</tr>
<tr>
<td></td>
<td>Gender equity problem fatigue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inequity denial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fragmented researchers, visions, and approaches</td>
<td>Diverging ideas for solving the issue</td>
<td>A “vision” may not be possible with research signaling different visions among researchers.</td>
<td>15.8%</td>
<td>29.1% 41.6% 29.1%</td>
</tr>
<tr>
<td></td>
<td>Error bars haven’t helped</td>
<td>Comments demonstrate the gulf between research epistemologies and probably a reason why this problem persists in PER and physics generally.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hanging onto “gap” research traditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of openness and readiness for EDI-supportive approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Need help from and collaboration with other disciplines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PER community does not know who each other are</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unsure of direction to go with PER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What PER is and who can do this research are disputed topics</td>
<td>Academic freedom for researchers</td>
<td>Physics ed. issue, not PER. Not a PER topic? Surely, how we teach and behave in front of students is the core of change.</td>
<td>13.9%</td>
<td>28.5% 19.0% 47.6%</td>
</tr>
<tr>
<td></td>
<td>Certain topics deemed not PER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marginalization within PER community</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urgency to act now</td>
<td>Accept problems and find solutions</td>
<td>More research might help those needing convincing, but we must move, these are the climate change deniers.</td>
<td>4.6%</td>
<td>14.2% 85.7% 0%</td>
</tr>
</tbody>
</table>

Note. *Prompts have been given an abridged label to simplify table headings. Prompt 1: I consider the following to be current issues in physics education related to gender inequity. Prompt 2: I consider the following to be current research needs, priorities, and/or guiding principles for PER aiming to address.
gender inequity in physics education. Prompt 3: I think the following guidance, supports, and/or developments could help the PER field in Canada address gender inequity in physics education.
An overall depiction of the participants’ commentary is shown by the percentage of total comments according to theme and prompt in Table 13. The highest percentage of comments were related to the themes *lack of widespread knowledge, or willful ignorance?* (19.2%) and *research drivers* (17.1%) in response to items in prompt 1 (related to current issues). The lowest percentage of comments were seen related to the three themes: *urgency to act now, lack of widespread knowledge, or willful ignorance?* and *research drivers*. Only 0.6% of comments were related the theme *urgency to act now* in response to items in prompt 1 (related to current issues), and 0% in response to items in prompt 3 (related to support and development of PER). Similarly, 0% of comments were related to both themes, *lack of widespread knowledge, or willful ignorance?* and *research drivers*, in response to items in prompt 3 (related to support and development of PER).

**Table 13**

*Overall Distribution of Participant Comments Across Themes and Questionnaire Prompts*

<table>
<thead>
<tr>
<th>Theme</th>
<th>Percent of total comments</th>
<th>P1*</th>
<th>P2*</th>
<th>P3*</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of widespread knowledge, or willful ignorance?</td>
<td>19.2%</td>
<td>7.9%</td>
<td>0%</td>
<td></td>
<td>0-1%</td>
</tr>
<tr>
<td>Research drivers</td>
<td>17.1%</td>
<td>3.3%</td>
<td>0%</td>
<td></td>
<td>2-5%</td>
</tr>
<tr>
<td>Physics fragility</td>
<td>5.9%</td>
<td>4.6%</td>
<td>7.2%</td>
<td></td>
<td>6-10%</td>
</tr>
<tr>
<td>Fragmented researchers, visions, and approaches</td>
<td>4.5%</td>
<td>6.5%</td>
<td>4.5%</td>
<td></td>
<td>11-15%</td>
</tr>
<tr>
<td>What PER is and who can do this research are disputed topics</td>
<td>4.6%</td>
<td>2.6%</td>
<td>6.6%</td>
<td></td>
<td>16-20%</td>
</tr>
<tr>
<td>Urgency to act now</td>
<td>0.6%</td>
<td>3.9%</td>
<td>0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: *Prompts have been given an abridged label to simplify table headings. Prompt 1: I consider the following to be current issues in physics education related to gender inequity.*

Prompt 2: I consider the following to be current research needs, priorities, and/or guiding principles for PER aiming to address gender inequity in physics education. Prompt 3: I think the following guidance, supports, and/or developments could help the PER field in Canada address gender inequity in physics education.
Discussion

Very little was found in the literature on the question of Canada’s approach to addressing gender inequities in physics education. No studies have investigated Canada’s PER field with respect to its views about and approach to addressing gender inequities in physics education. As such, this study was designed to address the following research question: What do Canada’s physics education researchers consider to be the most pressing needs and priorities to address the gender equity issue? Both the quantitative and qualitative data collected during the Delphi study produced noteworthy results that are discussed here in particular and in broader terms of implications for Canadian PER, global PER, and higher education research in general.

First, a high-level overview of the findings is provided. The research question was answered with a sizeable total of 47 statements produced by 10 participants during the Delphi, covering three topics relating to gender inequities in physics education: 1) current issues, 2) current research needs, priorities, and/or guiding principles for PER, and 3) guidance, supports, and/or developments that could help PER. Maintaining a 100% response rate in the second and third questionnaires was an encouraging occurrence that implied eagerness on the part of the participants in contributing to this first-time study on PER in Canada, and supports the credibility of this study. The Delphi facilitated a consensus-building process among participants, who reached consensus on 91.4% (n = 43) of the total 47 items, and 95.3% (n = 41) of consensus items had a stable consensus level. Throughout the process, participants helpfully explained their agreement level selections with a total of 316 comments in the second and third questionnaires. After processing these, 151 were analyzed thematically and yielded six themes that represent the participants’ commentary and reasoning during consensus-building: 1) fragmented researchers, visions, and approaches (15.8% of total comments); 2) lack of widespread knowledge, or willful ignorance? (27.1%); 3) physics fragility (17.8%); 4) research drivers (20.5%); 5) urgency to act now (4.6%); and 6) what PER is and who can do this research are disputed topics (13.9%).
The term *physics fragility* was derived from the term *white fragility*, coined by Dr. Robin DiAngelo in her 2018 book that explores White people’s discomfort, defensiveness, and denial when confronted about racism. This *fragility* was represented in the Delphi participants’ commentary when some responded to items related to gender inequity with denial of evidence, discomfort with the idea that non-physics perspectives be used in PER, or defending physics education’s influence on women’s experiences.

Prompt 1 asked participants what they consider to be current issues in physics education related to gender equity. Of the 16 issues generated, 87% reached consensus oriented toward *agree*. Based on the current literature surrounding issues of gender equity in physics education, the Canadian PER experts who participated in this could be considered a reasonably representative sample of PER experts in general, or as having expert-like knowledge, given how closely their suggestions of current issues are reflected in the literature.

In a prior study within this research project that asked international PER experts about gender equity in physics education, it was found that most of our knowledge on this topic exemplifies what does *not* work. All 100% of the Canadian experts in this study agreed on whether anyone really knows the extent of gender inequity is a current issue (item 1.1). In their comments, they made calls for more research on the reality of inequities and increased awareness of the issues. They also emphasized that evidence of gender inequities exists, saying “not knowing is just wilful ignorance,” and that the gender imbalance in physics education is a symptom of systemic inequities. One participant explained that the gender inequity problem is still unknown but the gender balance problem is known. Other current issues agreed on by greater than or equal to 90% of participants are issues established in literature, including: gendered and sexual harassment (1.4; Aycock et al., 2019; Knaub et al., 2020); gender performance norms defining insiders and outsiders (1.6; Ong 2005; Ong et al., 2018; Gonsalves & Chestnutt, 2020); lack of support for women students and educators (1.9; Doucette & Singh, 2020; Herrera et al.,
2020); and funding for sustainable equity groups in physics education spaces (1.12; Ong et al., 2018).

Items that reached consensus at slightly lower levels (i.e., less than 90%) included issues such as problematic pedagogy (1.14), sexist and gendered curricular materials (1.13), support groups, sexist department cultures (1.2), overall department cultures (1.3), training need for microagressions and bystander responsibilities (1.5), and accommodating intersectional identities (1.7). Possible explanations for the lower consensus levels on these items could include controversy, less familiarity with the topics, or need for more research, which would be consistent with the fact that 70.7% of comments comprising the theme lack of widespread knowledge, or willful ignorance? were made on this prompt, and 83.3% of comments comprising the theme research drivers were made on this prompt. For example, comments on sexist and gendered curricular materials described existing research as highly conflicting. One participant said that they personally wrote an introductory textbook with stereotypical masculine examples and they do not believe that this is the problem. Similarly, comments about supporting intersectional identities included uncertainty about what this means and that “PER doesn’t know what intersectionality means.”

Interestingly, some issues related to physics education, such as the need for regular training in micro-aggressions and bystander responsibilities, were deemed “not a PER topic” by some participants, and “very much a PER topic” by others who cite literature on the significant effects of microaggressions on women’s physics experiences (Barthelemy et al., 2016). This exemplifies the dispute about what PER topics can be, one of the themes of the participants’ commentary.

Overall, prompt 1 results are characterized by highly agreeable consensus levels on current issues of gender inequity in physics education reflected in PER literature, and by commentary centered around the themes lack of widespread knowledge, or willful ignorance? and
research drivers, which make up large portions of the total comments—19.2% and 17.1%, respectively.

Prompt 2 asked participants about current research needs, priorities, and/or guiding principles for PER aiming to address gender equity in physics education. This prompt generated the highest number of items out of all three prompts with a total of 18 items. Of these, 94% (n = 17) reached consensus, 94% (n = 16) of which were oriented toward agree and 5.5% (n = 1) of which was oriented toward disagree.

Items related to current PER needs, priorities, and/or guiding principles that were most agreed-upon (those with 100% consensus), included topics such as how to make physics education more inclusive (item 2.2), the need for PER to be data- and evidence-driven (2.6), and the need for more PER on: physics identity (2.12), gender dynamics and composition in group work (2.13), the impact of contextual information in problems on outcomes (2.14), longitudinal studies of curriculum (2.16), and on various levels of physics education and different groups of people (2.18). Many of these are priorities for Canadian PER are present in international PER literature and science education research literature, such as gender and identity research and frameworks specific to physics education (Gonsalves & Danielsson, 2020; Hazari et al., 2010; Hyater-Adams et al., 2018). Research on gender inequities in group work (Quinn et al., 2020; Alexopoulou & Driver, 1997; Ding & Harskamp, 2006), the effects of gendered contextual information in physics problems (McCullough, 2004; Lawlor & Niiler, 2020), and the need to diversify the demographic of PER (Kanim and Cid, 2020) are topics that are increasingly present in the literature. These are areas of shared priority for Canadian PER and the wider field, on which research exists and is emerging that Canadian PER engagers may learn from.

Items for which some disagreement was present among panelists, items with consensus levels between 70% and 90%, included topics such as: evaluating the extent and perception of gender imbalance (2.3), talking to students about women’s needs and problems (2.4), framing
PER goals in detail (2.5), using non-binary gender theoretical frameworks (2.8), highlighting identity rather than gender differences in gender-based PER (2.9), fueling PER with feminist knowledge (2.10), exploring the possibilities of counterspaces (2.11), researching the impact of instructor’s gender (2.15), and classroom-based action research (2.17).

Some of these ideas, particularly relating to gender, identity, feminist knowledge, and using theoretical frameworks, are newer in PER as the discipline increasingly focuses on students’ experiences and the affective aspect of physics education. The newness could explain disagreement among panelists who said “this stance is, in some ways, too advanced for where we [PER] are now,” or “we’re not quite there yet, we need to keep addressing the gap,” and “I’m not sure it is time to move on.” These comments resemble PER’s deep quantitative traditions, but whose underpinnings are being increasingly examined and said to be misunderstood (Ding, 2019). Physics fragility, an emergent theme of panelists’ commentary, could also explain disagreement and the apparent hesitancy to adopt non-typical PER approaches. Defensiveness is suggested in comments such as, “we privilege feminist studies as the supreme epistemology?” opposed to other comments acknowledging that Canadian PER can learn from other disciplines including medicine and biology that showed “gender gaps can close with feminist studies.” Differences in opinion may be representative of the theme lack of widespread knowledge, or wilful ignorance?

Perhaps the most interesting result for a single item was the item that did not reach consensus. Item 2.1 is about the need for research to determine if, indeed, there is a problem with gender equity in physics education under the assumption that gender imbalance is not evidence of gender inequity. This statement remained at 50% agree and 50% disagree throughout the consensus building process, and the strength of agreement increased in the final questionnaire. This division of agreement levels exemplifies the theme fragmented researchers, visions, and approaches, 41.6% of which is comprised by prompt 2 comments. The comments on item 2.1 are
particularly illustrative: “No amount of research is going to convince inequity deniers who are still out there,” “More research might help those needing convincing, but we must move, these are the climate change deniers,” “Gender imbalance and inequity are problems,” and “Need evidence that women are in inequitable positions in my department to effect change.” Important to note, the theme urgency to act now was represented almost entirely by comments in prompt 2 about current needs and priorities.

Overall, disagreement among panelists reveals division of ideas, even though they ultimately agreed on items that are important needs, priorities, and/or guiding principles. As one panelist commented, “a “vision” may not be possible with research signaling different visions among researchers.” However, their reasoning and comments are useful in guiding gender-based PER toward shared priorities and principles. Specifically relating to gender, identity, and feminist frameworks, panelists state that “gender research that does not draw on these frameworks is woefully uninformed.” Panelists indicated that Canada-specific data are indeed needed to establish the extent and details of the gender inequities. However, they caution that gender is an issue for all people, not only women, so gender-based PER must address gender broadly. They also caution against gender-based PER that reinscribes gender as a binary, such as studies of teacher-student interactions based on gender. Panelists plead for new approaches to gender PER with a reminder that there has been “little progress doing the same thing over and over again but expecting different results.” Similarly, stating “this work has already been done and is not a first step” in response to an item stating that the first step evaluating the gender issues in physics education (2.3). Prompt 2 comments overall are spread fairly evenly across all six qualitative themes, the two most represented themes being lack of widespread knowledge, or wilful ignorance and fragmented researchers, visions, and approaches, and a very high percentage (94%) of items for this prompt reached consensus.
Prompt 3 asked panelists about what guidance, supports, and developments would help PER address gender inequity in physics education. Of 13 items, 92% (n = 12) reached consensus, all oriented toward agree, and all maintained the same strength of agreement between rounds (100% stability). A high percentage (46%) of items achieved 100% consensus. Comments made by panelists on prompt 3 items represent only three themes, which together constitute 18.3% of total comments made by panelists; physics fragility (7.2%), what PER is and who can do this research are disputed topics (6.6%), and fragmented researchers, visions, and approaches (4.5%). To highlight the high percentages of prompt 3 comments that constitute themes, prompt 3 comments constitute 40.7% of physics fragility comments and 47.6% of what PER is and who can do this research are disputed topics comments. A number of the prompt 3 items consensus levels and commentary are discussed.

Six items relating to helpful guidance, supports, and developments for PER reached 100% consensus, these were about recognizing the value of PER in Canada (3.1), dedicating a strong community of PER addressing gender issues (3.2), having a specialized conference for PER people to come together (3.4), including special issues or journals for PER on gender equity (3.5), having stable funding structures for Canadian PER (3.6), and applying the huge amount of EDI work to PER (3.9). Notably, the need for stable funding structures for PER in Canada is the item with the highest strength of agreement with 80% of panelists voting strongly agree. Comments on this support include “this is the core problem for PER in Canada,” “money equals respect,” and “without funding, PER will never really thrive.” This particular need for support and the difficulty in attaining it was noted by Canadian physics education researchers over 14 years ago (Antimirova & Goldman, 2008). Other important comments about these items include the issue of who is “in” and who is “out” of PER in Canada, as one panelist expressed concern about attending a PER conference because they have been previously marginalized at PER conferences due to their focus on science education more broadly. This type of concern represents
the theme *what PER is and who can do this research are disputed topics* and could inhibit the development of a community of people in Canada who engage in PER. In terms of PER addressing gender inequities specifically by applying broader EDI work to physics education, panelists’ comments represented *physics fragility* with suggestions that physics is receiving undue special attention while ignoring well-known inequities that exist in physics education and instead referring to ratios.

It is simply a fact that more women are getting a university education than men (in Canada). Either physics is special or it isn't, we can't have it both ways unless we do mean that even if women were a majority in physics that we would continue to want to increase those ratios.

Other panelists acknowledge “this battle has been fought for decades—the women in science movement. Physics, engineering, math, and the trades are like last bastions.”

Just over half of items in prompt 3 had disagreement present in the consensus level. Helpful guidance, supports, or developments for PER that achieved 90% consensus included expanding PER to science and technology education research (3.7). Panelists said “so much more progressive research happens in science education.” Those who disagreed expressed concern over how this would work, and one suggested the need for people doing the research to be part of the disciplinary community they are studying. Another item that achieved 90% consensus was surveying physics education researchers in Canada, their activity and interests, particularly in attending a conference (3.3). Panelists said “the community needs organization and that starts with identifying who is interested.” This need was addressed in an earlier part of this research project in a study that sought to map the “landscape” of PER in Canada that was previously unknown even to PER’s own researchers. Panelists commented that focusing on Canada alone ignores the work happening elsewhere in similar contexts, and questioned how Canada is different from the U.S. However, these comments opposing the majority of agreement on these items reflect *physics fragility* and *what PER is and who can do this research are disputed topics*.
with hesitancy to allow non-physics people to do PER, which could explain others’ hesitancy to be part of the development of a Canadian-specific PER community.

Consensus items with slightly lower levels of disagreement present, those with 80% agreement, included openness and promotion of new theoretical framings such as non-binary gender approaches to research and qualitative approaches (3.8). Panelists note that “these are approaches that physicists find less convincing.” While this may be true due to physicists’ affiliation to quantitative methods (Ding, 2019), other panelists find this concern “hilarious” because “decades of the kind of work that physicists find convincing has not done much to change a seemingly intractable problem.” Others probe the reasons for physicists’ skepticism, asking “physicists find less convincing—because we do not like the results?” Some of this commentary exhibits physics fragility and fragmented researchers, visions, and approaches in light of physicists’ general unacceptance of research conducted through lenses less familiar or even aversion to challenging research findings. The other consensus item with 80% agreement is the idea that physics education researchers should be trained in physics and in education (3.11). The commentary on this item suggests that while this idea would be helpful, marginalization and a lack of acceptance in PER can and does happen to researchers who do not have physics training (no mention of this happening when they do not have education training). The solution, as some panelists commented, is that “we need both physics folks and non-physics folks to collaborate.” Similarly, “with time and many researchers focusing on EDI, physicists will listen as they [other scientists] did across sciences not long ago.” The issue of what PER is and who can do this research are disputed topics is reflected in the discussion of this item’s suggestion to help PER address gender inequity in physics education.

The consensus items with the most disagreement, those with 70% agreement, included two items. One is related to researchers being trained in feminist science studies and feminist epistemologies (3.10). Comments to this suggested support for PER include the point that
academic freedom is necessary for researchers. Comments of a defensive nature were present, such as “should feminist studies researchers be trained in physics? This idea puts feminist studies ahead of physics on a hierarchy of knowledge. I reject this.” Other comments expressed concern about the usefulness and transferability of research based on this type of training, “physics departments often respond poorly to “educationese.” Other comment warned about “creating new in and out groups.” Certainly, comments represented fragmented researchers, visions, and approaches for this item and one panelist wrote “the comments here are so disheartening.”

However, a suggestion was made by a panelist which could support both feminist epistemology training to assist PER in addressing gender inequities, as well as preserve researcher academic freedom. They suggested, “maybe this should say graduate programs should (and do) include courses on EDI and associated epistemologies.” The other item with 70% agreement is about using unbiased evidence as the best tool to convince skeptics (3.12). The comments on this item clearly represent the theme fragmented researchers, visions, and approaches. Three panelists commented, “always,” “for sure,” “is it possible that anyone would disagree with the use of unbiased evidence?” and “this will help physicists listen” clearly in favour of using unbiased evidence. Other panelists commented, “all evidence is biased, we need a lot of evidence. There will always be skeptics, we need to reduce the size of the skeptic pool,” “does ‘unbiased’ evidence exist?” “unbiased evidence is not a thing,” and “deniers be denying.” Insightfully, a panelist reflected on the fragmented views concerning evidence and skepticism: “Comments demonstrate the gulf between research epistemologies and probably a reason why this problem persists in PER and physics generally.” While panelists reached consensus that this item could guide or support PER in addressing gender inequity, the caveat is in the commentary—the lack of fusion among Canadian researchers of physics education and in particular on the issue of gender inequity—and could hinder PER’s advancement of gender equitable physics education.
The single item of prompt 3 on which panelists did not come to consensus, with 60% disagree and 40% agree, is about PER on gender equity being more overtly open to falsifiability due to the idea that physics’ scientific interrogation of evidence cannot be applied to PER and thus physicists do not see PER as physics (3.13). This item was the only item to switch orientation from 67% agree (33% disagree) in questionnaire two to 60% disagree (40% agree) in questionnaire three. As can be seen in Table 10, this item polarized the panelists; strong agreement and strong disagreement were present in both questionnaire rounds. This item’s consensus level was unstable and requires further deliberation. The comments and reasoning provided by panelists between questionnaires were integral in shifting agreement levels. Key comments on this item include “this argument is the go-to for skeptics,” “PER is not physics but is interesting to physicists because it is about the physics world. PER is one type of Science Education Research (SER), not an independent area of study,” and “PER should be evidence-based but open to all approaches.” Importantly, a couple of comments expressed confusion about this item; its lack of clarity reduces its credibility and could contribute to failure to reach consensus. Still, the responses to this item resemble the theme what PER is and who can do this research are disputed topics.

**Conclusion**

This study aimed to determine what Canada’s physics education researchers consider to be the most pressing needs and priorities to address the gender equity issue. Answers to this question were successfully acquired through the use of the Delphi technique to build consensus among a panel of 10 participants. Specifically, 47 items of priority were identified in the first questionnaire in response to prompts which asked panelists to identify 1) current issues, 2) current research needs, priorities, and/or guiding principles for PER, and 3) guidance, supports, and/or developments that could help PER in addressing gender inequity. Throughout the second and third questionnaire, panelists provided quantitative agreement levels and qualitative
comments and reasoning about the item and their agreement level selection. Overall, panelists reached consensus on 91.4% \((n = 43)\) of the items, which represent what Canada’s physics education researchers consider to be the most pressing needs and priorities to address gender inequity. While there was very high consensus achievement, the commentary among panelists throughout the questionnaires shed light on issues in the PER community and sources of disagreement within. Six themes emerged from these qualitative data, in order of most to least prominent: 1) lack of widespread knowledge, or willful ignorance? \((27.1\% \text{ of total comments})\); 2) research drivers \((20.5\%)\); 3) physics fragility \((17.8\%)\); 4) fragmented researchers, visions, and approaches \((15.8\%)\); 5) what PER is and who can do this research are disputed topics \((13.9\%)\); and 6) urgency to act now \((4.6\%)\).

General observations of the data gathered in this study are offered about the moderate alignment of ideas to current international PER literature, as well as the level of disagreement or counter perspectives and the percentage of comments present across each prompt of the Delphi consensus-building process.

Some ideas are well aligned with current international PER literature, such as the knowledge of issues like harassment in physics education \((\text{item 1.4; Barthelemy et al., 2016; Aycock et al., 2019})\). Other items saw less agreement with current thinking about gender inequities in physics education, such as using identity and gender non-binary frameworks \((\text{items 2.8 and 2.9; Traxler et al., 2016; Exarhos, 2020})\). This may be representative of a young and somewhat fragmented field in Canada, or a lack of widespread knowledge about current PER literature focused on gender equity. Regardless of the reasons, the areas where alignment with the most recent literature on gender equity in physics education is lacking could be a source of stagnation for increased gender equity in Canadian physics education.

Considering the three overall prompts or topics that panelists ranked in terms of agreement and commented on, it is interesting to note the percentage of agreement and
disagreement and the percentage of comments by prompt. A general observation is that the percentage of disagreement decreases from prompt 1 to prompt 3, and the percent of total comments also decreases from prompt 1 to prompt 3. In other words, the highest percent of disagreement and comments (93% and 51%, respectively) were present in prompt 1, regarding current issues in physics education related to gender inequity. The next highest percent of disagreement and comments (61.1% and 28.9%, respectively) were present in prompt 2, regarding current research needs, priorities, and/or guiding principles for PER aiming to address gender inequity. The least disagreement and comments (53.8% and 18.3%, respectively) were present in prompt 3, regarding guidance, supports, and/or developments that could help PER in Canada address gender inequity. These findings suggest that researchers are eager for and recognize the needed supports and developments for PER in Canada. However, these findings also suggest there is further deliberation and collaboration needed among researchers surrounding the identification and collective understanding of what the actual gender inequity issues are in Canadian physics education. Similarly, a higher degree of agreement may be necessary among PER engagers in this country on research needs, priorities, and the principles used to guide and approach this research. Without a collaborative, yet focused, approach to PER on gender equity, Canada’s progress toward gender equitable physics education may be hindered indefinitely.

The implications of this work include the need for further action based on the identified issues, research priorities, and developments for the Canadian PER field. Specifically, researchers engaging in PER may focus on the identified issues as areas of physics education requiring further investigation, they may develop and frame their PER around the identified guiding principles and priorities, and they may support the Canadian PER field in addressing gender inequity by taking initiatives individually and collectively to grow Canadian PER’s funding structures, academic community, purpose, and ultimately its impact.
Challenges and limitations that this study faced included the fact that any network of Canadian physics education researchers was imperceptible and few individual researchers were known. The number of participants was 10, their perspectives may or may not represent those of the entirety of Canada’s physics education researchers. However, this study is the first to connect (confidentially) researchers of physics education in Canada to discuss issues related to one of physics education’s most persistent and pressing concerns. Therefore, this study provides a foundation upon which the Canadian PER community and the knowledge it produces and shares may be expanded.
Chapter 5

Conclusion

To conclude the dissertation, I revisit the purpose of the research, discuss developments in the field since I began the research, summarize the key findings from the data of each study, and draw conclusions by synthesizing the findings of the study in a framework. Theoretical implications as well as implications for practice and policy are identified. Finally, the limitations of the research are noted and recommendations for future research are made.

Addressing the Purpose

The overarching purpose of this research arose from the gaps in knowledge surrounding Canadian PER and what can be done to increase gender equity in Canadian physics education, particularly in light of the long history of gender imbalance and evidence of inequities in physics education in the Western world (Blue et al., 2018). Specifically, this research sought to determine if and how Canada’s physics education researchers are working to address gender inequities in physics education, and to develop an expert knowledge-based framework to guide Canada’s ongoing PER to increase gender equity in physics education. This purpose was addressed via three individual, yet closely integrated, studies that were guided by the following research questions:

1) What can be learned from PER experts about supporting gender equity in physics education?

2) What is the landscape of PER in Canada; who are our PER experts and what are their areas of research focus?

3) What do Canada’s PER experts consider to be the most pressing needs and priorities to address the gender equity issue?
4) What is a framework that could guide and support Canada’s ongoing PER to achieve gender equity in physics education?

Together, the three studies addressed the purpose of the research by gaining knowledge about current international PER on gender equity, learning what is happening in Canada and how it compares to international PER in general and specifically on gender equity, and building consensus on what needs to be done to make progress toward gender-equitable physics education. The data suggested implications for the PER field in Canada and are presented in this conclusion as a synthesized framework for guidance and support of Canada’s ongoing PER to achieve gender equity in physics education. I preface the discussion of the key findings and the framework with some reflections on developments in the field.

**Developments in the Field**

Since beginning this research, developments in physics education research have occurred that are worth discussing, both to highlight new advancements and to situate the contributions to literature made by this research.

In Canada, particular attention is being paid to EDI in physics on a national scale; the Canadian Association of Physicists implemented the first Canada-wide survey of EDI in physics, to which over 3,000 people in the physics community responded (Smolina, 2021). In the preliminary report of findings, percentages of gender- and racially-diverse people are detailed. Across the community from undergraduate students to people working in industry, Black, Indigenous, and People of Colour (BIPOC) who are gender diverse represented the smallest percentage of physics community members. Only 1% of respondents identified as Black, and the largest group of respondents in all categories (e.g., students, faculty members) were White men (Smolina, 2021). These data represent a very important addition to the literature about the Canadian physics community, since none existed before, and even more importantly, the data provide evidence of continued EDI insufficiency in physics in Canada. The data are also crucial
for consideration in the Canadian PER community because physics education is known to be an influential factor in students’ determination of career choice, particularly for minoritized students (Hazari et al., 2010). Another PER development in Canada related to EDI is the special issue of Physics in Canada expected in 2021 but not yet available, titled *Inclusion for Excellence in the Physics Community in Canada*. This issue was born out of the exacerbation of inequalities by the COVID-19 pandemic and seeks to examine the broader state of EDI in Canadian physics in order to work toward a more inclusive community for future generations. Both of these developments reflect the need for pathways to increased equity. The findings of the current research provide such pathways via guidance of Canadian PER in addressing gender inequities in physics education.

Additional developments specific to the PER field are noted before summarizing the key findings of this study in the context of these recent developments. Important new work has emerged that expands constructions of gender and encourages research to be framed with new understandings of gender as a non-binary element of a person’s identity. A recent book by Gonsalves and Danielsson (2020) is a collection of works that focuses on extending theoretical understandings of identity to enable the exploration of gender as performative and intersectional in gender PER. This work provides strong rationales for using identity approaches to studying gender in physics education, citing benefits that include challenging dominant ideas of who can do physics and what counts as doing physics; gaining new understandings of participation in physics cultures; and learning how identities interact with inclusion/exclusion and dominance/subordination practices and structures in physics education (Gonsalves & Danielsson, 2020). My research found that experts in gender PER are in agreement that broadened theoretical frameworks ought to be a PER priority for addressing gender inequity. Along these lines, recent contributions to gender PER literature promote anti-deficit gender frameworks to limit the unhelpful comparisons of women and other gender minorities to men. Examples of such works...
include Exarhos’ (2020) paper that insists on anti-deficit reframing of sociological PER, and Traxler and Blue’s (2020) writing to physics educators that outlines the differences between sex and gender along with the consequences for students of physics teachers’ misunderstanding or disregard of gender as non-binary. These works contribute to the growing research promoting scholarship with sociocultural theoretical and conceptual frameworks to guide gender-related PER, and are in support of the findings in the current research.

While most PER has traditionally focused on the higher education level, current research indicates a focus on lower levels of physics education. One example is PER by Yonai and Blonder (2020), who suggest the insertion of nanoscale science and technology (a highly interdisciplinary field) into the middle school physics curriculum for increased connections to contemporary science and students’ authentic perspectives of the science field. Another example is a study by Lawton et al. (2021) who researched a two-week intervention program aimed at improving girls’ outcomes in high school physics education. These studies are examples of new PER that recognize the need for increased research at lower levels of physics education; challenges to learning and teaching physics are not isolated in higher education, and changes at this level may in fact depend on improved early physics education. This idea was agreed upon in the current study both by the interviewed international experts and 100% of Canadian PER engagers in the Delphi consensus-building process.

Other developments in PER since beginning the current research include continued evidence of sexual harassment in undergraduate physics education (Aycock, 2019), and efforts to improve the culture and climate of physics departments to prevent sexual harassment (Knaub et al., 2020). In the latter, recommendations are made in the form of actions that may be taken by individuals, educators, and departments, which include talking about sexual harassment and educating oneself and others with resources. The overall climate in physics is an important topic recently studied by White and Ivie (2021), who found that the perception of the climate in the
physics department among women and faculty members from minoritized groups is 11% worse than that of men and white faculty members. This type of investigation is important for determining how to support minoritized people in physics departments and to improve the overall culture that shapes and is shaped by people’s experiences in physics education. A recent study by Moshfeghyeganeh and Hazari (2021) investigated a related high-level PER topic: cultural effects on women physicists’ career choice. Their study was among the first to ask why and how cultural experiences in Muslim majority (MM) countries manifest into high representation of women in higher physics education, and how this understanding can be used to improve participation of women in physics education in the West. They found that “femininity and gender appropriate behaviors in MM countries may be shaped in ways that make them more congruent with demonstrating a physics identity compared to Western contexts” (Moshfeghyeganeh & Hazari, 2021, p. 12). This work is an example of emerging qualitative PER that offers novel approaches to improving women’s experiences in physics education via enhanced understandings of culture and gender expressions. The aforementioned studies approach gender inequity in physics education in ways contrary to that of many traditional, large-scale, quantitative, gender gap-based PER that often reduce differences in representation to women’s deficits. These are topics and methodologies that the findings of the current research urge PER to move away from in favour of broader frameworks and qualitative methods. Interestingly, a recent and important study of gender gaps, specifically gendered performance differences in introductory physics exams, found that “performance on exams and final letter grades are weakly dependent on gender” (Dew et al., p. 9). This study adds encouraging new data to the gender-gap PER literature and may benefit women physics students by helping to extinguish gender stereotypes that negatively affect many of them.
The discussion of developments in the PER field was intended to contextualize the following summary of key findings of the current research in order to highlight the extensions and contributions to PER literature made by each study.

**Key Findings**

**Phase One**

Phase one, which sought to learn perspectives from expert international physics education researchers about supporting gender equity in physics education, yielded three themes. First, what is known and unknown about gender equity in physics education: a theme representing gender equity as a social justice, socio-historic, and cultural issue, few known gender equity-supportive practices, and a major dearth of knowledge and evidence about how to support gender equity well. Second, toward gender-equitable physics education: a theme representing the need to address problematic aspects of physics education, such as harassment, the need to enable change, for example, by mobilizing students, and current movement toward gender equity in physics education via PER group initiatives and educational reform. Third and finally, conducting and using PER as a tool: a theme centered on the situation and roles of PER and PER people, considering PER approaches and approach issues, for example, binary gender deficit models, using guiding principles and goals, and addressing current needs and priorities in PER, for example, shifting focus to lower levels of physics education. Overall, phase one of this research provided sought-after lessons from international PER experts that are richly useful for guiding ongoing Canadian PER on gender equity. Specifically, this phase made clear that knowledge on gender equity in physics education showing what works does not yet exist (only some equity-supportive practices are known), and that both obstacles (e.g., problematic physics education, acceptance of PER as legitimate) and gateways (e.g., PER is an appropriate tool with which to tackle gender inequities in physics education, expanding PER approaches) must be navigated in moving toward gender-equitable physics education.
Phase Two

Phase two sought to determine the previously unknown landscape of PER in Canada, specifically to identify physics education researchers and their areas of PER focus. This first Canada-wide PER engagement survey confirmed 42 PER engagers in Canada, 52% and 42% of whom work in physics and education departments, respectively. Of the Canadian PER engagers, 63% are 40-59 years of age and 64% have less than or equal to 10 years PER engagement, suggesting the increased popularity over the last decade among both early and later career researchers. The survey also found that 72% of Canadian PER engagers’ publications are conference presentations, an important finding that is discussed in the next section. In addition to the survey, 14 Canadian PER engagers were identified via their survey responses by expertise criteria, including number of years in PER, publications in PER, and self-reported level of PER expertise. From the interviews, five themes emerged, revealing a complex field with challenges facing both its members and progress. To summarize, Canadian PER is comprised of researchers with diverse research foci and backgrounds who face barriers to being a physics education researcher, including identity, non-belonging, and skepticism of PER. Canadian PER engagers have varied conceptions of gender inequity’s definitions, causes and explanations, solutions, and responsibility, and across the country, they are fragmented in geography and unfamiliar with one another. Canadian PER is uniquely characterized by its position, role, dissemination, and problems, including its lack of critical mass, underfunding, and need for championing. Overall, phase two described for the first time the Canadian PER field with quantitative and qualitative data, which altogether reveal a field with tremendous potential for growth as well as one characterized by distinct needs (e.g., shared understanding of issues like gender inequity) and challenges (e.g., funding, barriers to researchers’ belonging).
Phase Three

Phase three asked what it is that Canada’s physics education researchers consider to be the most pressing needs and priorities to address the gender equity issue. Ten researchers from across Canada participated in a Delphi study and built consensus on a total of 47 items across the topics: 1) current issues in physics education related to gender inequity; 2) PER needs, priorities, and guiding principles to address gender inequity; and 3) supports and developments that could help PER in Canada address gender inequity in physics education. With a consistently high response rate throughout the study (100%, \(n = 10\), in questionnaire rounds 2 and 3), Canadian PER engagers demonstrated interest and commitment in discussing gender inequity with fellow Canadian PER engagers. They reached consensus on 95% (\(n = 41\)) of total items and, notably, reached consensus on 100% of items related to possible supports and developments that could help PER address gender inequity in physics education. The level of consensus on items related to current issues of gender inequity in physics education and PER needs and priorities were relatively lower (92.8% and 94.1%, respectively). The relatively lower levels of consensus in these areas indicate a higher degree of disagreement and suggest a need for a) further knowledge production and mobilization around current issues and b) increased collaboration and goal-setting among Canadian PER engagers on PER’s current needs and priorities for addressing gender inequities. In terms of qualitative data, participants’ comments made on each Delphi questionnaire resulted in six themes that both confirmed earlier findings and revealed new perspectives of PER in Canada. Confirmatory themes include lack of widespread knowledge, or willful ignorance? and physics fragility that highlight what international PER experts described in phase one about gender inequity being a social justice issue that some choose to care about and others do not. Similarly, fragmented researchers, visions, and approaches and what PER is and who can do this research are disputed topics are themes that reveal divisiveness between physics education researchers, their epistemologies, and their ability to belong, which echo the themes.
from Canadian PER engagers’ interviews in phase two. Finally, the themes *research drivers* and *urgency to act now* represented 20.5% and 4.6% of total comments made in the Delphi study, respectively. The different representation of these two themes in particular highlights the focus on determining what specific knowledge and needs should be driving PER forward and less focus on accepting issues and finding solutions. Overall, the Delphi process facilitated the building of consensus among Canadian PER engagers on issues of gender equity for the first time. These data are synthesized with knowledge gained from international PER experts on gender equity in physics education and new knowledge of the landscape of PER in Canada to recommend a guiding framework for ongoing PER in Canada.

**Conclusions**

In this section of the dissertation, the synthesized data are presented in the following framework to draw conclusions about the data collected in this research. The significance of the findings as well as theoretical, practical, and policy implications are discussed. Limitations of the research are noted, and finally, recommendations for future research are made.

**Framework**

The framework in Figure 10 is intended to guide and support Canadian researchers conducting physics education research related to gender equity by identifying directions and actions that may be more likely to lead to gender-equitable physics education in Canada. The framework suggests detailed goals of PER on gender equity with concrete examples of possible outcomes. The integration of findings from all three phases of this study enabled the development of this framework. This framework, the first of its kind, is suggested for use as a guide for PER to address gender inequity in physics education. For this reason, the framework must exist as a living document; it requires reconsideration and revision by the PER community as realities, priorities, achievements, and challenges emerge over time. Any person or group within the PER community may wish to use the framework as a starting point to develop specific purposes,
activities, intended outcomes, and effects. For example, an individual researcher could establish their own PER purpose for addressing gender inequity and associated activities. Or, a department could develop context-specific PER purposes for addressing gender inequity and account for their own resources and inputs, possible activities, outcomes, and intended effects. For all stakeholders, the use of this framework to guide Canadian PER in addressing gender inequities in physics education is not intended to be linear; additional inputs may be necessary to enact an activity, and at times, activities will need to be repeated or altered in order to achieve the desired outcomes. It is through the iterative process of this framework, and consideration of the research upon which its recommendations are based, that Canadian PER may facilitate progress toward gender-equitable physics education.
Figure 10

Framework for the Guidance and Support of Canadian PER for Addressing Gender Inequity in Physics Education

PURPOSE or MISSION: To improve gender equity in Canadian physics education via physics education research to reduce the prevalence of inequities.

INPUTS or RESOURCES
- 42 confirmed PER engagers across Canada
- Researchers with varied backgrounds, levels of expertise, and research foci
- Universities, departments, and formal and informal PER groups
- Knowledge base of problematic physics education, ineffectiveness, and equity-supportive practices
- Identified research drivers and current issues related to gender inequities in physics education
- Urgency to act now

CONTRAINTS or BARRIERS
- Limited funding
- Lack of widespread knowledge and/or acceptance of evidence of gender inequity
- Physics fragility
- Fragmented researchers, visions, and approaches

ACTIVITIES
- Organize PER conference in Canada and associated publication
- Publish special issues on gender equity in PER journals
- Establish stable funding structures for Canadian PER
- Welcome to PER community, and learn from, researchers of science education and EDI
- Obtain training and/or knowledge of gender and feminist perspectives
- Use data and evidence to convince skeptics of gender inequities
- Utilize new theoretical frameworks that move away from gender as a binary; performative notion of gender, theories of power and identity
- Research topics related to gender: identity, self-efficacy, beliefs and attitudes, test anxiety, group dynamics, contextual information in problems, gender of teacher
- Expand PER to lower levels of physics education
- Utilize methods of action research, ethnographic longitudinal studies, talking to students, programmatic research, and policy research
- Engage PER group in an initiative:
  - Include students, empower them to become gender equity advocates
  - Promote gender equity-supportive practices, policies, and programs
  - Build a network of physics teachers and educators

OUTPUTS
- Connected network of PER engagers across Canada
- PER sharing and collaboration via conference, publication, formal talks, informal conversations
- PER funds support partnerships, knowledge synthesis, PER degree-granting institutions, longitudinal and large-scale studies, gender equity research programs
- Reconceptualization of the purpose of physics education at various levels and who belongs
- Increased non-physics-based and non-university-based researchers engaging in PER
- New knowledge and evidence produced through gender equity lenses
- School or department-level implementation of PER-based practices, policies, or programs
- Increased qualitative and mixed-methods studies

EFFECTS
- Increased recognition of PER's value, nationally and internationally
- Increased strength and diversity of community dedicated to PER and gender issues
- Decreased marginalization within the PER community
- Bridging of the methodological and epistemological divide in PER
- Gender equity-improved programs of research, policies, and practices in Canadian physics education
- Increased equity, diversity, and inclusion in Canadian physics education and the field

CONTEXT or CONDITIONS: Gender inequity in physics education is a longstanding social justice, socio-historic, and cultural issue; no significant equity improvement despite decades of PER; Canadian tri-council research funding structure omits PER; care for equity is expressed genuinely by some and by others merely for political correctness; and complex definitions of gender inequity, causes and explanations, solutions, and responsibility exist.
Components

This section provides an explanation of what each component in the framework represents and describes the source of the content within each component. The components are the main boxes shown in the framework, namely, the purpose; inputs or resources; activities; outputs; effects; and context or conditions.

Purpose or Mission. The purpose of the framework was developed in light of the continued need for gender equity in Canadian physics education, despite nearly 50 years of prior work on this issue globally, and is supported by findings confirming that PER is an appropriate avenue for tackling this educational issue.

Inputs or Resources. The inputs and resources elements within the framework are based on findings from phase two’s survey of the landscape of PER in Canada, as well as the input from international gender equity PER experts in phase one.

Context or Conditions. The context or conditions described in the framework are those that fall under the purpose and issues associated with this work. These include historical, cultural, economic, and political factors that may affect the outcome of PER’s efforts to address gender inequities in physics education. These were integrated into the framework from findings of interviews with both international gender equity PER experts and Canadian PER engagers.

Constraints or Barriers. The constraints and barriers elements noted in the framework are based principally on the emergent themes from Canadian PER engagers’ comments throughout the phase three Delphi study. For example, physics fragility and fragmented researchers, visions, and approaches are themes that emerged from participants’ commentary in the Delphi process. Sub-themes associated with these themes, including gender blindness, gender equity problem fatigue, and inequity denial of physics fragility, are written about in detail in Chapter 4.
Activities. The framework’s recommended activities represent what can be done with the resources. These are based on phase one expert-identified guiding principles as well as consensus-based priorities and needs for Canadian PER developed in the Delphi study in phase three. These elements of the framework, in particular, are important to be revisited and revised as some activities require additional or varied inputs and resources to be carried out if the desired outputs and effects are to be achieved.

Outputs. The output elements listed in the framework signal the activities having been performed. For example, PER funds supporting partnerships and research programs is evidence of the activity of establishing stable funding structures for PER in Canada. The development of outputs was informed by Canadian PER engagers’ ideas of what developments and supports could help PER in Canada address gender inequity; these were discussed during the interviews in phase two and the Delphi study in phase three.

Effects. The final component of the framework is the effects, which represent the results, consequences, or impacts of having taken action. The elements listed in this section of the framework were developed from the abundant data and results from all three studies of this research; namely, literature on gender inequity in physics education, knowledge from international gender equity PER experts and Canadian PER engagers, and priorities identified through consensus-building in the Delphi study. These data informed the development of desired effects for the framework and represent the hopes of researchers for a) the Canadian PER field as a community of people and academics and b) for improved physics education in Canada.

Utility

How the framework will be used will depend on the user’s specific purpose, context, and desired effects. In this section, examples of the framework’s utility are provided in order to assist users in determining how they may use the framework. Importantly, one principle of use applies to all users, which is to proceed through the framework in the overall direction of left-to-right
with the end goal being to achieve desired effects. While the use of the framework is not expected to be linear, since the path to desired effects may not be direct, the framework is intended to guide users from inputs to effects through an overall left-to-right process. Considering the possible effects on the right side of the framework, then reading left or “backwards” toward the activities and inputs, may be helpful when initially thinking about what the framework could help users do.

Using an “if, then…” statement may help framework users to identify and connect activities to desired outputs and effects. Filling in the following statement structure is suggested:

“If we have [inputs or resources/constraints or barriers] _________, then we can [activity] _________, which will result in [output] _________ and [effects] _________.” To exemplify, two sample statements that users could create are provided in Figure 11 to demonstrate the utility of the framework in assisting the improvement of gender equity in Canadian physics education via PER.

**Figure 11**

“If, then…” Statement Structure for Framework Users to Identify and Connect Activities to Desired Outputs and Effects

| Statement Structure | Example 1. If we have 42 confirmed PER engagers across Canada, then we can organize a PER conference in Canada and an associated publication, which will result in a connected network of PER engagers across Canada and increased recognition of Canadian PER’s value, nationally and internationally. | Example 2. If we have a knowledge base of ineffective efforts, then we can utilize new theoretical frameworks that move away from gender as a binary, such as performative notion of gender and theories of power and identity, which will result in new knowledge and evidence produced through gender equity lenses and gender equity-improved programs of research, policies, and practices in Canadian physics education. |
The statements were created by filling in the above statement structure with content from the framework, specifically with items listed in the component boxes from inputs to effects, following horizontally to neighbouring items. Users may find that the individual content items within the component boxes are not lined up or linked directly to neighbouring items; the reason is that most items relate to more than one item in another box. This also allows for increased uses of the framework because the inputs or activities may be combined to achieve varied outputs and effects.

**Significance and Theoretical Implications**

Before this research was conducted, little to no literature existed that documented PER in Canada, including the people who conduct PER and what they think about gender inequities in physics education. The findings from this research make several new contributions to the current literature. First, is the contribution of perspectives of five international gender equity PER experts; knowledge gained from conversations with these experts that together offer a deeper understanding of gender inequity in physics education beyond what could have previously been surmised from their individual research publications. An example is the challenge of PER in addressing gender inequity in physics education due to skepticism of this topic being a legitimate PER issue. The second contribution to current literature is the mapping and characterization of Canadian PER with first-ever data describing the field of PER in Canada and the voices of those engaged with it. The third contribution to literature is the identification of current research needs and priorities for Canadian PER to address gender inequities in physics education. The most significant contribution to the field of PER is the framework presented above as it combines findings from all three phases of this work and addresses the purpose of the research in practical, theoretical, and conceptual ways.

The framework operationalizes the findings of the three studies in this work; it is a useable guide for the current Canadian PER field that combines current literature, expert
researcher knowledge and perspectives, and results of deliberation of the current needs and priorities for Canadian PER. The feminist and critical theoretical framing used in this study enabled the research to be carried out through a lens that problematized physics education for women, as prior and current literature has done (Keller, 1983; Knaub et al., 2020). Therefore, the data and recommendations yielded from this research address problematic situations in physics education for women and other gender minorities. The culminating framework provides guidance on what theoretical approaches to use that correct unhelpful ways of thinking about gender (i.e., as binary and deficient) and pinpoints topics of PER related to concepts of gender, culture, and physics education that require research attention to improve physics education. The major theoretical contribution of this research is that gender inequities in physics education will not be sufficiently or successfully addressed with a simple, single approach used over a short timeframe. Rather, through the iterative use of the framework designed to support and guide Canadian PER in its ongoing efforts to target inequities, culture biases in physics may weaken, cultural constructions of gender may expand, and physics education may be an increasingly supportive place for people of all genders. The framework may be utilized theoretically in considerations of how PER, as a higher education research field, can operate for positive change. This research has found PER to be a suitable and critical tool with which to disrupt the persistent and problematic constructs upholding gender inequities in Canadian physics education.

Overall, this research project expands current literature by contributing the first comprehensive investigation and confirmation of Canadian PER as an appropriate and valuable avenue for addressing gender inequities in physics education. Before this study, no research-based documentation of PER in Canada’s history, activities, or recommendations for strengthened efforts to mitigate gender inequity existed. It is expected that researchers of physics education, physics educators, and the physics education community will benefit from the results and recommendations of this work. Students, members of the physics community, and people in
society at large are the ultimate beneficiaries of more gender-equitable physics education, as access to physics learning and related work is a matter of social justice.

**Implications for Practice and Policy**

This study’s principal implication for PER practice is for researchers to employ theoretical frameworks of gender in their investigations that are not based on binary gender deficit models, which tend to compare women to men in unhelpful ways and create a deficiency. Appropriate theories understand gender as an element of one’s identity (e.g., Hyater-Adams et al., 2018; Gonsalves & Danielsson, 2020).

Although this study focuses on PER, the findings and recommended framework may well be of value in other areas of education research; the framework may be adapted and used as a living guide to conducting gender equity education research in other domains where gender equitable education is a goal. Additionally, the methods used in this study, particularly the Delphi technique, may be applied to PER fields elsewhere in the world or to other higher education research fields as a step toward identifying research issues and priorities and developing a guide to ongoing research programs.

Importantly, this study was framed around the concepts of gender and equity pertaining to women and the goal for women’s experiences and opportunities in physics education to be free of bias on the basis of gender. While the implications of this work are for gender equity-related PER to improve women’s experiences, it is expected that the effects of increased gender equity in physics education will benefit all gender minoritized students. This is expected because when physics education is free of gender-based bias and welcoming to all, all students are more likely to thrive.

As the participants and findings of this research suggest, funding for PER in Canada is a gatekeeper to conducting much needed research and is very limited. A key policy priority should therefore be to create accessible and stable funding structures for Canadian PER, both within
universities and schools as well as through federal, provincial, and local organizations that support improved physics education. While PER activities like informal PER group operation and knowledge mobilization may occur gradually with limited or no funding, these activities and others such as the development of a network of Canadian PER engagers or a Canadian PER conference or publication are unlikely to occur.

**Implications for Methodology**

A few benefits and drawbacks of the Delphi technique are noted here for consideration of the implications of its use. As the topic of gender equity in physics education is a highly complex problem with controversy, debate, and lack of clarity, the Delphi technique was an ideal method for facilitating structured communication among participants (Iqbal & Pipon-Young, 2009). Benefits of this method included its compatibility with digital communication and connecting a participant pool spread across wide geography (Donohoe & Needham, 2009). In addition, the Delphi maintained participant confidentiality and therefore encouraged honesty and openness in communication while reducing effects of group dynamics (Linstone & Turoff, 1975).

Methodologically, the Delphi straddles qualitative and quantitative methods and is able to provide a holistic picture of participant perspectives (Iqbal & Pipon-Young, 2009). Lastly, results can be considered verifiable and valid since participants contribute their own ideas and consider the problem and their perspectives over several rounds of questionnaires (Donohoe & Needham, 2009; Iqbal & Pipon-Young, 2009).

Drawbacks of the Delphi technique include a lack of universal standards for its use, interpretation of results, and participant selection (Fink-Hafner et al., 2019). This method also requires a high level of commitment of time and effort on the part of both researcher and participants. Methodologically, limitations include the difficulty of generalizing results because of a small sample size (Hartman & Jugdev, 1998) and potential limited views if participants are too narrowly or too widely spread in terms of agenda, geographic, and/or cultural location.
(Nambisan et al., 1999). Overall, this method was found to be highly useful in this research for facilitating communication, but it required careful consideration at every stage of recruitment, design and timing of questionnaires, and communication with participants.

**Limitations**

This section acknowledges the limitations and potential weaknesses of this research. The first limitation is in its conceptual framing; the research was framed through the lens of gender equity as focused on women’s situations and problematizing these for the justification of change. A broader concept of gender equity, including all gender minorities in physics education, or of equity in general, including all minorities in physics education, could have expanded the applicability of the study’s findings. However, the recommendations for increased gender equity made in this work are expected to benefit all gender minorities.

Some demographic data, specifically gender and race for the international PER experts, and race for Canadian PER engagers, were not collected. The studies may have had more credibility if the researchers were found to represent broad demographics in terms of gender and race.

Methodological choices posed limitations to the research as well. Canadian researchers who participated in the phase two survey of PER engagement in Canada were asked for permission to be contacted for future research activities. These included a follow-up interview about their PER engagement based on their survey responses, and potential participation in the phase three Delphi study with other Canadian PER engagers. Asking for their consent was an action taken to comply with ethical research recommendations, and provided a measure of interest in future participation. While useful and ethical, this methodological decision potentially limited participation in the interviews and Delphi study because some survey respondents were ideal participants for future research activities but did not give permission to be invited to participate in these in the future.
Additionally, the Canadian PER engagement survey did not have a particularly high response rate at 36.6%. Of 150 possible Canadian PER engagers, only 42 were confirmed to engage in PER based on their survey responses. Based on knowledge of Canadian physics education researchers from their publications, conference attendance, and general PER activity, some known Canadian PER engagers did not complete the survey. It was a disappointing result of the survey to have not captured some prominent Canadian PER engagers. Despite not capturing the most expert-like or fullest possible picture of PER in Canada, the survey and Delphi study still contribute the first data of this kind to the field and lay the groundwork for further investigation.

Finally, this research is limited by the present challenge of putting the resulting framework into action. While all attempts were made to develop a highly useable, scalable, and adaptable framework for all people who engage in PER and especially on gender equity, its uptake, use, and impacts are yet to be determined.

**Moving Forward**

Following the limitations of this research, future studies are recommended to establish specific PER needs and priorities for the benefit of minorities including gender, sexuality, race, ability, and more. Building on this research, interviews with participants of the Delphi study might obtain a deeper understanding of the interesting commentary present during that process. Similarly, continued investigation of what supports are needed for PER in Canada and internationally to tackle gender inequities in physics education are important. Evaluations of Canadian PER’s impact on gender equity in physics education would prove useful to adapt and evolve programs of research to achieve their desired effects. Two questions raised by this study are how do physicists and physics educators understand their responsibility in fostering an equitable field? and what is the uptake of PER among physicists and physics educators? Finally, research and policy work needs to be done both within and alongside the PER community to
endorse activities such as the establishment of Canadian PER funding structures, conferences, and publications.
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February 25, 2020

Mrs. Lindsay Mainhood
Ph.D. Candidate
Faculty of Education
Queen’s University
Duncan McArthur Hall
511 Union Street West
Kingston, ON, K7M 5R7

GREB Ref #: GEDUC-995 20; TRAQ #: 002885
Title: "GEDUC-995 20 Gender equity in physics education: Modeling a future for physics education research in Canada"

Dear Mrs. Mainhood:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled "GEDUC-995 20 Gender equity in physics education: Modeling a future for physics education research in Canada" for ethical compliance with the Tri-Council Guidelines (TCPR 2 (2016)) and Queen’s ethics policies. In accordance with the Tri-Council Guidelines (Article 6.14) and Standard Operating Procedures (405.001), your project has been cleared for one year. You are reminded of your obligation to submit an annual renewal form prior to the annual renewal due date (access this form at http://www.queens.ca/traq/signoff.html; click on "Events;" under “Create New Event” click on "General Research Ethics Board Annual Renewal/Closure Form for Cleared Studies"). Please note that when your research project is completed, you need to submit an Annual Renewal/Closure Form in Romeo/traq indicating that the project is ‘completed’ so that the file can be closed. This should be submitted at the time of completion; there is no need to wait until the annual renewal due date.

You are reminded of your obligation to advise the GREB of any adverse event(s) that occur during this one-year period (access this form at http://www.queens.ca/traq/signoff.html; click on “Events;” under “Create New Event” click on “General Research Ethics Board Adverse Event Form”). An adverse event includes, but is not limited to, a complaint, a change or an unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example, you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To submit an amendment form, access the application by at http://www.queens.ca/traq/signoff.html; click on “Events;” under “Create New Event” click on “General Research Ethics Board Request for the Amendment of Approved Studies.” Once submitted, these changes will automatically be sent to the Ethics Coordinator, Ms. Gail Irving, at University Research Services for further review and clearance by the GREB or Chair, GREB.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Sincerely,

Chair, General Research Ethics Board (GREB)
Professor Dean A. Tripp, PhD
Departments of Psychology, Anesthesiology & Urology Queen’s University

C Dr. Lynda Colgan, Supervisor
Dr. Pamela Beach, Chair, Unit REB
Haven Jerreat-Poole, Dept. Admin.

177
Appendix B Physics Education Research in Canada Questionnaire

Physics Education Research in Canada Questionnaire

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**Letter of Information and Consent Form**

**Study Title:** Gender Equity in Physics Education: Modeling a Future for Physics Education Research in Canada

**Principal Investigator:** Lindsay Mainhood (PhD candidate), Faculty of Education, Queen’s University

**Supervisor:** Dr. Lynda Colgan

I am inviting faculty members working in Education or Physics departments at Canadian universities to take part in a research study. The purpose of this study is two-fold: 1) to determine how physics education researchers are working to address the issue of gender inequity in physics education, and 2) develop an expert knowledge-based model to guide physics education research in Canada to achieve gender-equitable physics education. You are invited to complete this electronic questionnaire (it will take **under 10 minutes**) asking about your research interests and areas of focus. If you agree to complete the questionnaire, please check the consent box at the end of this letter, indicating you have read the Letter of Information and all of your questions have been answered. Based on your responses to the questionnaire, you may be invited to participate in further study activities: one interview and/or three additional questionnaires as part of a Delphi study (a series of questionnaire rounds with the purpose of developing consensus on an issue). If at the end of this letter you agree to being contacted in the future, you will be provided separate letters of information and asked to provide consent at the time of future contact.

By completing this questionnaire and by any potential further participation in this study, you will be contributing your input on issues related to gender equity in physics education and research on this topic. You may decline to continue participation at any time. If you are invited for an interview, I will interview you for one hour by telephone. The interview will be audio-recorded and later transcribed. There are no known risks to participating in the interview. If you are invited...
to complete subsequent questionnaires as part of the Delphi study, each will take less than 30 minutes to complete, for a maximum of 90 minutes. There are no direct benefits to you as a participant from the first questionnaire; however, there may be benefits to participating in the interview or later questionnaires. Benefits to participation in these activities may include learning about best practices for gender-equitable physics education. Study results will help inform the Canadian physics education research field about how gender equity may be achieved. You will not be paid for taking part in this study.

Participation is voluntary. You do not have to answer any questions you do not want to. You can stop your participation at any time by telling the researcher(s). You may request to have your data withdrawn from the study within 30 days following your participation by contacting me at lindsay.mainhood@queensu.ca.

Your confidentiality will be protected to the extent possible. Your name will be replaced with a pseudonym in all publications and a study ID number in all study records. The study data will be stored on a password-protected computer and an encrypted hard drive. The code file that links real names with pseudonyms and study ID numbers will be stored securely and separately from the data on an encrypted USB key. Access to study data is limited to Lindsay Mainhood, Dr. Lynda Colgan, and a transcriber (who will sign a confidentiality agreement). The Queen's General Research Ethics Board (GREB) may request access to study data to ensure that the researcher(s) have or are meeting their ethical obligations in conducting this research. GREB is bound by confidentiality and will not disclose any personal information. All data collected in the study will be retained on an encrypted hard drive for five years after study closure. The code file identifying your pseudonym and study ID number will be destroyed five years after study closure.

I plan to publish the results of this study in academic journals and present them at conferences. It will not be possible to remove your data after study publication or after participation in the confidential Delphi phase. I will not include any quotes with personally identifying information from interviews when presenting my findings. I will never include any real names with quotes. I will do my best to make sure quotes do not identify participants. If applicable, during the interview, please let me know if you say anything you do not want me to quote. Despite these efforts to protect your identity, it is not possible to eliminate entirely the risk of readers inferring your identity.

If you have any ethics concerns please contact the General Research Ethics Board (GREB) at 1-844-535-2988 (Toll free in North America) or chair.GREB@queensu.ca. You may call 1-613-533-2988 if outside North America. Please note that GREB communicates in English only.
If you have any questions about the research, please contact me at lindsay.mainhood@queensu.ca or contact my supervisor, Dr. Lynda Colgan, at lynda.colgan@queensu.ca.

This Letter of Information provides you with the details to help you make an informed choice about your participation. All your questions should be answered to your satisfaction before you decide whether or not to participate in this research study. Please keep one copy of the Letter of Information for your records. By completing the questionnaire, a copy will be sent to the Researcher, Lindsay Mainhood.

You have not waived any legal rights by consenting to participate in this study.

Please check all that apply:

☐ Yes, I consent to complete this questionnaire. I have read the Letter of Information and all of my questions have been answered.

☐ Yes, you have my permission to contact me in the future about participating in further activities for this study.

End of Block: Letter of Information and Consent Form

Start of Block: Demographics

The questions in this section ask about your demographics.

Please enter your name and contact information.

☐ Name: ________________________________________________

☐ Email: ________________________________________________

☐ Phone number: __________________________________________
What is your gender identity?

- Man
- Woman
- Nonbinary

Gender identity(ies) not listed above (please specify):

I prefer not to answer

What is your age?

- 20 - 29
- 30 - 39
- 40 - 49
- 50 - 59
- 60 - 69
- 70 or older
In what province or territory do you currently work?

- Alberta
- British Columbia
- Manitoba
- New Brunswick
- Newfoundland and Labrador
- Northwest Territories
- Nova Scotia
- Nunavut
- Ontario
- Prince Edward Island
- Quebec
- Saskatchewan
- Yukon

With what academic institution are you currently affiliated?

__________________________________________________________________________

__________________________________________________________________________
In what department or faculty do you currently work?

☐ Physics
☐ Education
☐ Other (please specify):
________________________________________________

End of Block: Demographics

Start of Block: Areas of Research

The questions in this section ask about your areas of research focus.

What are your areas of research focus? Please list. (E.g., science education, literacy)
________________________________________________

Have you conducted or been involved in physics education research? (For the purpose of this study, physics education research is defined as research related to the teaching and learning of physics).

☐ Yes
☐ No
☐ Not sure (please explain below)
________________________________________________

Skip To: End of Block if Have you conducted or been involved in physics education research? (For the purpose of this study... = No
For how many years have you conducted or been involved in physics education research?

○ Number of years: ________________________________________________

How would you describe your level of expertise in physics education research (PER)?

<table>
<thead>
<tr>
<th></th>
<th>No expertise</th>
<th>Limited expertise</th>
<th>Moderate expertise</th>
<th>High expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>In PER, I have:</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>


On what topics do you conduct physics education research? Select all that apply.

☐ Cognitive mechanism
☐ Curriculum and instruction
☐ Epistemology and attitudes
☐ Gender equity
☐ Identity
☐ Institutional change
☐ Problem solving and reasoning
☐ Research methods
☐ Socio-cultural mechanisms
☐ Student conceptions
☐ Teacher education and TA training
☐ Effective use of technology in teaching
☐ Other topic(s) (please specify):

______________________________

Display This Question:

If On what topics do you conduct physics education research? Select all that apply. = Gender equity
Or On what topics do you conduct physics education research? Select all that apply. = Identity
Or On what topics do you conduct physics education research? Select all that apply. = Socio-cultural mechanisms
If you conduct physics education research related to the topic of gender equity, what is its focus? Please list. (E.g., girls' high school physics experiences, gender-biased assessments)

________________________________________________________________

How many physics education research publications have you produced or co-produced? Please enter a number for each applicable category.

○ Estimated total ________________________________________________

○ Academic journal papers __________________________________________

○ Practitioner journal papers _________________________________________

○ Conference presentations (including paper, poster, roundtable) __________

○ Other ____________________________________________________________

Display This Question:

If On what topics do you conduct physics education research? Select all that apply. = Gender equity
Or On what topics do you conduct physics education research? Select all that apply. = Identity
Or On what topics do you conduct physics education research? Select all that apply. = Socio-cultural mechanisms
Of your physics education research publications, how many publications are related to **gender equity**? Please enter a number for each applicable category.

- Estimated total ________________________________
- Academic journal papers ________________________________
- Practitioner journal papers ________________________________
- Conference presentations (including paper, poster, roundtable) ________________________________
- Other ________________________________

End of Block: Areas of Research

Start of Block: Block 3

Clicking on the next button will submit your responses.

End of Block: Block 3