Women and Physics

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To Kelly, with much love, and with pleasure in being able to reciprocate a dedication

Contents

Preface

This book addresses some of the issues that women in physics face right now in the Anglophone world, through a review of the most recent research. It begins with an examination of the numbers of women in physics in English-speaking countries, at all levels of the educational ladder. It moves on to examine factors that affect girls and their decision to continue in science, the issues those girls face as young women in their pre-college physics courses, and the problems they will encounter during undergraduate and graduate studies as they grow older. Moving on from the world of the student, the book outlines the problems that women in physics careers face. The book looks at all of these topics with one eye on the progress the field has made in the past few years and another on those things that we have yet to address. In service of the latter goal, the book surveys the most current research as it tries to identify those strategies and topics that have a significant impact on women's issues in the field with a special emphasis on our biases and stereotypes as physicists and how they can affect they way all of us interact with women both individually and collectively.

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Author biography

Laura McCullough

Laura McCullough is a Professor of Physics at the University of Wisconsin-Stout. She has a BA in physics from Hamline University, and a MS in physics from the University of Minnesota. Her PhD from the University of Minnesota is in Science Education with a focus on Physics Education Research. Her primary research area is gender in science and surrounding issues, a topic on which she is frequently asked to speak, especially on gender and context issues in assessment. She has also done significant work on women in leadership, and on students with disabilities, where she was involved with a major grant from the NSF. She has had articles published in the *Journal of College Science Teaching*, the *Journal of International Women's Studies*, and *The Physics Teacher*, among others.

Chapter 1

Introduction

A little girl waits patiently at a science exhibit for another child to finish. Her brother butts in when he comes over to see it and she never gets her turn.

A young woman in high school physics is always relegated to be the record keeper and never gets a chance to play with the equipment.

A woman walks into her first day of physics graduate school and sees twenty four men and no other women.

A physics professor is called 'Mrs' by her students instead of 'Dr'.

An assistant professor is placed on every departmental committee in order to have female representation.

A woman makes a suggestion at her weekly research group meeting. Her idea is ignored. Three minutes later, a man makes the same suggestion and is applauded.

Women have been doing physics, and loving physics, for hundreds of years. Yet there is still a significant under-representation in the field at every level in the English-speaking world. Why have we not yet reached parity? What issues do women who want to enter physics face? What hurdles do they encounter as they move through university and graduate work? What holds them back in research positions and teaching positions? Why do they leave? These questions have fascinated researchers and scholars for decades.

Why is this such an issue? Should it even matter if there aren't many women in physics?

Yes. For so many reasons.

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The presidents of Stanford, MIT, and Princeton know how important it is: 'Until women can feel as much at home in math, science and engineering as men, our nation will be considerably less than the sum of its parts. If we do not draw on the entire talent pool that is capable of making a contribution to science, the enterprise will inevitably be underperforming its potential' [1]. Technology and engineering are key areas our nations need to be developing to thrive in the twenty-first century. We should be encouraging every interested child to explore, study, and make a career in physics.

The field of biology tells us that a more diverse ecosystem is a stronger ecosystem. 'Diversity within and between groups helps a whole population to survive and adapt to the changing demands of the environment' [2]. By encouraging more women to enter and stay in physics, we are helping to make our field stronger.

This volume will explore the participation rates of women in physics, the challenges and hurdles they face, and the things that can encourage and support them in pursing physics. This book is primarily intended as an introduction to the topic for both the general audience and academics who may not be familiar with this area, though it is the hope of the author that those with some knowledge of these issues will also find material of interest here. Ideally this book will help promote awareness of the barriers women face in entering and remaining in physics, and highlight the importance of pursuing further study on the subject of women's participation in physics.

Notes about this volume:

In this book, the words 'female' and 'woman' are used interchangeably. There is an important semantic difference between these terms, and there is an important psychological difference as well, but for the purposes of this book they will both refer to the gender construction. Similarly, though the book presents information mainly in terms of two sexes, readers are encouraged to remember that today's research tells us that gender and biological sex are not dichotomous, but are more fluid [3]. Until we develop and widely adopt appropriate language for the range of genders and sexes, we are limited by our standard 'male/female' and 'woman/man' word choices when trying to speak clearly to a general audience. In matters where the technical language of the researcher or content expert is divergent from the common usage of the general audience, the author has chosen to use the less precise but more easily understood vocabulary of the layperson.

It also should be noted that wherever possible, the focus has been on recent research, English-speaking countries, and physics research rather than science overall. One of the problems in studying women and physics is that the situation in the real world is in a constant state of change. As our greater society has moved slowly closer to gender equity, some of the issues in classrooms and laboratories that were important twenty years ago have become less relevant to the issues that women and girls are facing today. The long and deep history of research into this topic is still vitally important, because it chronicles the struggles women have faced over the decades, which is a vital part of the moral case for ongoing efforts to move toward equity in physics, the sciences, and society in general. But for the purposes of this volume, the focus will be on current issues, and research on the present day struggles that women in physics face.

Throughout the book the emphasis will be on those places where gender is known to cause a difference of some sort. While a few topics will include discussion on gender parity or gender equity, for the most part, it is the differences that are of interest here. Some people argue that focusing on gender differences carries inherent biases of its own with the male viewed as the standard [4], and women's experiences or performance judged against that norm. Wherever possible, gender differences in this volume will be noted as just that: a difference. Assigning value to the difference is an individual decision, and readers are encouraged to consider how they approach gender differences in their own minds.

One of the problems facing those who study gender differences is the distinction between statistical significance and perceived significance. While 'men' and 'women' may be statistically different on a certain variable, unless the statistical effect size [5] is reasonably large, that difference is not likely to be explained only or primarily by the difference in their genders. Typically, the variability on a characteristic is much more variable *within* gender than *between* genders [6].

The issues facing women in physics are well researched. Similar issues face racial and ethnic minorities in physics, and are compounded for people in more than one category. The focus of this book is squarely on the gender aspects of under-representation, but it is important to remember that the problems are intersectional. For those women who are members of multiple minority groups, the barriers are higher and stronger. There are good resources for those interested in hearing about what it is like for a woman of color in science, and I encourage readers interested in these issues to seek them out.

It is my intent to present the main issues and topics of women and physics as an overview with enough support to demonstrate their validity. Many of the topics I discuss could be (and have been) the subject of chapters or even whole books. As I was working on this book I was repeatedly tempted to follow the research into a deep exploration of various subtopics, but I had to remind myself that my goal for this volume was to give readers enough to pique their interest, and start them on their own paths of study.

I hope that this book inspires reflection and action in its readers. We all have a role to play in promoting a more diverse and representative field. Physics needs and deserves the best students and researchers. I want the physicists in generations ahead to be free to spend all their creativity and intelligence on the problems of the day, instead of wasting energy worrying about if they will be safe, respected, and valued in their chosen field.

'I do not mind that you are a girl, but the main thing is that you yourself do not mind. There is no reason for it' [7]. Einstein, to a young girl he corresponded with.

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Chapter 2

How many women are in physics?

> 'Science is not a boy's game, it's not a girl's game. It's everyone's game. It's about where we are and where we're going'.
>
> Nichelle Nichols (Lt. Uhura from Star Trek)

Across the globe, girls and young women get excited about physics. Yet as they move forward with their chosen field, they will encounter fewer and fewer 'fellow' women. In this chapter we are going to explore the representation of women in physics from secondary school through graduate education. How many women are studying physics and choosing physics as their career?

2.1 Historical women in physics

A good start is to take a brief look back through the years, to remind ourselves that women have been doing physics for centuries [1]. There are numerous biographies recounting the lives of women in physics. The most famous female physicist is, of course, Marie Curie. But if you ask someone to name a second female physicist, they are likely to draw a blank. Yet women in physics and astronomy have made many significant contributions to the field. Increasing awareness of the work that women have done in physics is a worthwhile goal, and many websites are working to address this [2].

The issues that women in physics faced through the twentieth century were quite different than what women face today. It was a very difficult time. They weren't allowed in universities, tutors would often refuse to teach women, and women had no right to own property until the nineteenth century in many countries. So how did women succeed? Usually by working with a male scientist.

Doing formal physics research typically requires access to journals, equipment, and lab space. Supportive males, often a parent or spouse, allowed women access to the labs and equipment that they needed to do their physics. Marie Curie worked with her husband and her daughter. Caroline Herschel worked alongside her

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brother, Sir William Herschel. Mileva Einstein-Marić was a physicist in her own right before she married Albert Einstein. Lise Meitner worked as an unpaid assistant before collaborating with Otto Hahn. Having a supportive husband has helped several famous physicists, and yet it stood in the way sometimes too: anti-nepotism laws prevented Nobel Prize winner Maria Goeppert Mayer from being paid to work at the same university at which her husband worked [3].

Because women working in physics were often treated as unpaid assistants, few ever received recognition for their work. It wasn't until women were allowed to enter universities and scientific societies in their own right that they began to be generally credited for their work.

There are untold numbers of women who have loved physics and contributed to the field, yet many of them are lost to history because they were never acknowledged in their time. One place where progress has been made is that it is now expected that anyone who works on a project will be credited for their work. This helps us develop a picture of how many women are working in physics currently. By looking at national data sources, we can now get a strong sense of the participation of women in physics today. Let's start by looking at the earliest formal physics instruction, which usually happens in high school/upper secondary education.

2.2 High school physics/upper secondary physics

Most people likely believe that science education has always been a male domain. Yet there was a period of time where science was viewed more as something to teach young women, while young men needed to learn the more important classical education of Greek, Latin, mathematics, history and rhetoric.

During the last half of the nineteenth century, schools across America and the United Kingdom were focusing the education of young women on science, typically considered 'domestic science' or 'household science'. Since women were the homemakers and in charge of the health and cleanliness of the home, they were encouraged to learn the basics of science [4]. Science was also purported to develop strong thinking skills for women [5], in the same way that learning the classics did for men.

Ironically, at the same time, women were discouraged from higher education because of fears that such education would create 'pale, weak, neuralgic, dyspeptic, hysterical, menorraghic, dysmenorrhoeic girls and women' [6]. Much medical research at the time focused on proving that education was harmful to women, particularly that the brain will pull essential energy and nutrients away from the uterus [7]. One writer in 1735 argued *for* the education of women, including this rationale: 'If the female Tongue will be in Motion, why should it not be set to go right? Could they discourse about the Spots in the Sun, it might divert them from publishing the Faults of their Neighbours. . .' [8] Science can prevent gossiping? If only the author could see scientists' social media today.

Physics education was slowly developing at the same time. By the late nineteenth century, educators were worried about the lack of standardization of education in the US, and the 'Committee of Ten' was formed in 1892 [9]. This committee pulled together science educators and scientists, who recommended the now-common order of high school science as biology, then chemistry, then physics. The committee itself recommended chemistry after physics, but the scientists' recommendation was more generally accepted. And thus began more than a century of physics being last in the high school science curriculum [10].

2.3 Current trends in women's participation in physics

The slow drain of women leaving physics and other sciences as they move into higher levels of the field, or—too often—don't, has often been referred to as the leaky pipeline problem. The analogy works well in some ways, with the initial talent pool of physicists being the initial flow of water into a pipe. But along the way, at each of the major junctures (high school to college, college to graduate school, etc) the field loses women at a higher rate than it loses men. Though the pipeline analogy has its problems [11], it is a common and useful way to visualize the issue of women dropping away from physics as they move through their education and careers.

Whereas we can look at many of the problems women encounter in physics in a more qualitative way, the issue of falling participation at higher levels in the Anglophone countries is best approached by looking at the statistics. So, we're going to do just that, following the leaky pipeline as it moves upward, starting with the educational levels where most students first encounter physics as a standalone topic.

In the US most schools do not have a separate physics class until high school. Most other Anglophone countries are similar. Science is considered an important subject to take as preparation for college (tertiary education), so most young men and women in the US are encouraged to take a physics class in high school though most are not required to do so.

In the US, the number of high school students taking physics is approaching 40%, a very respectable number. The number of women in high school physics classes as a percentage of the total is about 47% and has stayed consistent over the last decade—near parity [12].

We find less encouraging numbers in the UK, where only around 20% of boys and fewer than 5% of girls choose to take A-level physics [13]. That means that only one in five A-level physics students were female compared to the US one-to-one ratio. Interestingly, single-sex schools do a better job of sending girls on to physics [14].

New Zealand is in line with the US for participation rates, with girls making up 40% of the population of the average physics classes in Year 12 or 13 [15]. Australia's percentages are closer to the UK, with about 22% of girls choosing physical science in Year 12 compared with 36% for boys which makes for a participation rate of about one in three for the girls [16].

Canada also has fewer girls in high school physics across most of the provinces, where they are participating at about half the number of boys. The exception to this rule is Quebec and Saskatchewan which have near equal numbers of boys and girls in physics [17].

With the ratio so variable across countries and even provinces it can be hard to make exact statements about the exact magnitude of the problem, but it is clear that work needs to be done at the pre-high school level if we want to see parity in students beginning formal education in physics. Chapter 3 will discuss ways to encourage young girls to take physics.

2.4 College/tertiary education

Students often have very limited choices in which courses they will take in high school, so it is not until they enter university that we see them taking full charge of their educational destiny. Unfortunately, one of the choices that young women often make at this point is to move away from physics. This is where we see our first significant drop in the number of young women choosing to pursue physics as they opt out of taking physics classes and majoring in physics.

In the US only 1 in 5 physics bachelor's degrees go to a woman. There has been a very slow growth in that number over the last forty years, since only about 10% of bachelor's degrees went to women in 1981 but at that rate parity is a long way in the future [6].

Interestingly, despite the significant difference in participation at the high school levels the current US number of approximately 20% is quite similar to the UK, where women make up around 22% of the undergraduate physics population [18].

Other Anglophone countries show significant variation in women's participation in physics at the undergraduate level. An Irish study of physics departments reported a dismal 7% female participation rate for undergraduate physics at one department [19]. Australian physics enrollments have proved difficult to find, but engineering enrollments are currently at approximately 15% [20].

2.5 Postgraduate education

For women in the US, the percentage receiving masters degrees in physics runs at about 22% and then drops back to 20% for doctoral degrees going to women (2012 data) [21]. This is following the general upward trend we see in bachelor's degrees, with a steady but slow climb over time in the participation of women in graduate physics.

Canadian enrollment for math and physical sciences shows about 35% women at the masters level, and 30% for doctorates. Though they do not break out the numbers for the two fields individually we can look at the general pattern of higher percentages of women in math, and infer that the physics numbers are likely significantly less than 30% [9].

While we see relatively static numbers in the US between degree levels and a small drop off in Canada, in the UK we see a small rise in the proportion of women in physics at higher degree levels with postgraduate physics participation rising to 26.5% from the 21.7% at the undergraduate level [22]. It is not clear what causes this increase, and more research in this area might prove very fruitful in service of the goal of promoting similar increases elsewhere in the English-speaking world.

2.6 Conclusion

In this chapter, we have shown that women participate in physics at much lower rates than men do in English-speaking countries, though the numbers are slowly climbing. For over fifty years, scholars have asked what the reason for this lower participation

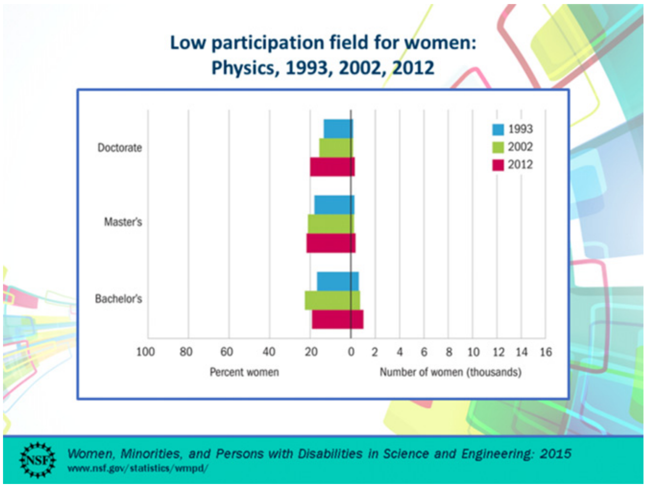

Figure 2.1. US Women's participation rates in physics. From [23].

is, and many ideas have been put forth to explain the discrepancy. One excellent review of the women and science literature by Blickenstaff [24] lists nine broad themes attempting to explain why women do not pursue science and engineering, and anyone who is interested in the topic should consider these carefully:

1. Biological differences between men and women.
2. Girls' lack of academic preparation for a science major/career.
3. Girls' poor attitude toward science and lack of positive experiences with science in childhood.
4. The absence of female scientists/engineers as role models.
5. Science curricula are irrelevant to many girls.
6. The pedagogy of science classes favors male students.
7. A 'chilly climate' exists for girls/women in science classes.
8. Cultural pressure on girls/women to conform to traditional gender roles.
9. An inherent masculine worldview in scientific epistemology.

Several of these have been disproved as further work has been done in this area. But some of these explanations have staying power. In the next two chapters, we will explore the current theories and explanations for women's under-representation in physics.

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Chapter 3

What helps, what hurts: family and education

> 'I have no dress except the one I wear every day. If you are going to be kind enough to give me one, please let it be practical and dark so that I can put it on afterwards to go to the laboratory.'
>
> —Marie Curie [1]

We have seen that the proportion of women in physics in the English-speaking world is much lower than 50% at nearly every stage of education and career. What factors are causing this? Research on women and science has been conducted for over fifty years, and despite all we have learned, we are still discovering important new factors that play into this under-representation.

The data presented in the previous chapter support the idea that the split between girls' and boys' participation levels in physics happens very early, prior to college. The research literature supports this conclusion. This chapter will explore some of the factors in early life and education that start to differentiate the genders in their attitude towards physics. Readers are encouraged to remember that gender differences which are noted are simply that, and not a statement of value. Whether a difference preferences or advantages one group over another is something readers should consider for themselves, along with the underlying biases and beliefs that lead us to these conclusions.

For those women who have managed to stick with it and become physicists, many have had the support of their family. Even a single family member (or close family friend) who is an advocate for a young woman can be a major help to her. This support does not need to come from family in the sciences [2]; any family support will help with the motivation to study and work in science [3]. 'Twenty-one percent of girls said their parents encouraged them to be actresses and only 10 percent were encouraged to be engineers' [4], writes Karen Purcell. Without encouragement, and without ever being exposed to scientists, how are young girls and boys to learn that

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physics is a fun and satisfying career choice? 'Young girls cannot possibly consider opportunities they do not know exist' [5]. Teachers, parents and family members should show children that many science fields exist and are possibilities for *every* child.

Alexander *et al* [6] report that even at ages 4–7 there are gender differences in science interest and how families respond to their children's interest in science. And the source of science encouragement can be different for girls and boys: one study notes that females were more likely to be encouraged by teachers than parents, while males were encouraged by both approximately equally [7]. Many female physicists report becoming interested in a physics career before they graduated from high school [8], demonstrating that encouragement during the teenage years can be very important to future career paths. Yet parents don't always know best: 'Parents are the primary influencers but have difficulty advising their daughters on STEM-related career choices' [9].

3.1 Extra-curricular and informal science activities

Science camps are prevalent across most Anglophone countries, and science camps for girls are growing in number. Why the push for such opportunities for girls? Because having experiences with science as a child can change attitudes towards science and motivation to choose science as a career later in life. While the research on these programs is mixed [10], most are providing important pieces [11, 12] in the larger puzzle of attracting girls to science. These camps often bring such factors to bear on the issue as mentors or counselors who work with the girls, a sensitivity to the cultural background of the girls being recruited, and peer social interactions. These camps target girls ranging from young elementary school to high school (see Valla and Williams [12] for a thorough listing of articles on this topic). Another advantage of non-school science activities like camps is that girls can start to see science in their world, and their world as full of science [13].

3.2 Early science education

One of the problems facing US science education and female participation is the lack of good science in elementary schools. Many elementary teachers are afraid of science [14], and will avoid it where possible. Only about one-third of K-5 teachers have any coursework in physics, and only 17% felt well prepared to teach physical science [15]. When they do teach it, their attitudes are communicated to the children they are teaching, with sometimes negative consequences [16, 17]. Standards at the state and national level can help somewhat [18], but if the teachers are uncomfortable with, afraid of, or poorly educated in science, they are not serving the best interests of their students, or of our society in general. One study [17] notes that female elementary science teachers' fear of math is transferred to the girls in their class, though not to the boys. Since most primary school teachers are women, this presents a major problem.

A related issue is that when teachers are uncomfortable with science, they tend to fall back on lecturing and rote learning, which is what they likely experienced in their college science courses [19]. They also may or may not have experienced a science methods course that focused on active learning. If primary teachers use an active, engaged teaching style for most topics, but a more rote and passive style for science, they will likely be creating negative attitudes towards science in their students.

A fascinating task that has been used for decades to determine ideas about scientists is the Draw A Scientist Test [20]. Participants are asked to take a few minutes to draw a scientist—usually no other information is given. Milford and Tippett [21] found that pre-service elementary teachers were likely to draw highly stereotypical scientists: male, lab coat, glasses, crazy hair. These stereotypes of what a scientist looks like are likely to be transferred to their students. This test has been very consistent over the last few decades in drawing out stereotypes of scientists, from elementary students to university students [22].

One of the sad ironies of elementary school science teachers who are afraid of science is that they serve as such an important role model for both the girls and boys in their classrooms. But this also represents an opportunity. By combating negative attitudes towards science among these teachers, we can not only help in the transfer of more positive attitudes, but also create better role models for females who like science.

3.3 High school physics education

High school physics is one of the first places where students have the option to drop out of physics. Because physics is commonly taught in the US during the last year of high school, it is often elective (as with A-level physics), with many students allowed to skip senior year science altogether, or choose another science instead of physics. This is a major point of leakage in the pipeline. Now for those that do choose to take a physics course in high school, what experiences are young women having in those classes? And what impacts those experiences?

In the US, only about a third of high school students will have a female physics teacher [23]. This number is rising, but very slowly. In New Zealand the ratio is similar, with about 200 female physics teachers and 500 male physics teachers [24]. Ireland's ratio is slightly higher at 40% [25]. Wales and Scotland have between one quarter and one third female physics teachers [26]. In Australia only about a quarter of physics teachers are women [27]. Young women have no guarantee of seeing a female role model in their secondary physics courses.

The gender of one's high school physics teacher can have interesting effects, though the data on exactly how those effects play out are open to interpretation. Students in high school physics classes are more likely to rate the performance of a female physics teacher lower than a male physics teacher. This was true for both the young men and young women in the class [28]. Using different criteria, Gilmartin *et al* [29] found that the percentage of female faculty in high school science classrooms in a small study did not correlate to how the students talked about their teachers, nor did students refer to teachers as role models.

College students also share a bias against female physics teachers, as demonstrated in an experiment [30] where four professors delivered identical videotaped lectures. Students watched one of the videos, then rated the teachers. Male students showed a significant bias in favor of male teachers. Female students were more equitable in their evaluations except for rating female teachers higher in communication skills and *lower* in scientific skills.

Too few teachers encourage students to study physics. A Canadian research study [31] of undergraduate students with research awards shows that only 32% of the women in this population had a high school teacher who encouraged them to continue in science and engineering, and the males were only slightly higher at 37%. And these were students with research awards in science and engineering! Imagine what it is like for less obviously science-inclined students. And it's true across many countries. Mujtaba and Reiss [32] note that 'girls are less likely to be encouraged to continue with physics' after it is no longer compulsory in the UK.

While we are in the process of moving past much of the most explicit discouragement of girls, we still regularly hear about blatant sexism in high school classes and counseling rooms [33]. Without encouragement from academic advisors and teachers, it is difficult for young women to push through the barriers and move into science. '(I)t is crucial for career counselors to develop interventions that build minority and female students' confidence and increase their self-understanding.' [34]

For decades, single-sex classrooms [35] have been proposed as one solution to the gender divide in science. The literature on this subject has been quite variable [36] over the years, and remains so. Recent articles suggest 'that girls in single-sex classes have a better self-concept of ability in masculine school subjects than the girls in mixed-sex classes because gender-related self-knowledge is less accessible once the opposite sex is absent' [37], but also '(w)hile girls-only schools appear to foster more participation in physical science courses or to encourage more interest in physical careers among their students, these differences are attributable to factors other than gender compositions of schools' [38]. The Institute of Physics (IOP) in the UK did find that single-sex classrooms were better at countering gender differences in progression to A-level physics [39].

One common critique of single-sex classes is that they can serve to falsely insulate women from the harshness of the broader science community, thus putting them at a disadvantage later when they enter the world beyond the classroom. As Gertrude Elion noted: 'I hadn't been aware that there were doors closed to me until I started knocking on them. I went to an all-girls school. There were 75 chemistry majors in that class, but most were going to teach it … When I got out and they didn't want women in the laboratory, it was a shock … It was the Depression and nobody was getting jobs. But I had taken that to mean nobody was getting jobs … (when I heard) "You're qualified. But we've never had a woman in the laboratory before, and we think you'd be a distracting influence" ' [40].

Perhaps the best comment on single sex classrooms comes from Michael Neuschatz, at the American Institute of Physics in 1995: 'single sex classrooms cannot substitute for confronting head-on gender prejudice in physics education' [41].

One very promising educational approach to the gender gap in many areas is found in the research on intellectual mindset [42]. Some people believe that intelligence is a fixed trait: that a person is smart or not. Others believe that intelligence is malleable, and one can change and develop how smart you are. Fixed-mindset students tend to stop trying when they fail at a task, saying 'I am not good at physics'. Growth-mindset students will continue to try, believing that they can *become* good at physics [43]. What makes this so important as a tool is evidence that you can teach students to shift to a growth mindset [44]. This is especially hopeful, when the main researcher for mindset has stated that a growth mindset can help increase girls' confidence in STEM areas [45].

Readers should keep in mind that the majority of this research was conducted on and with white girls, and that has the potential to create impressions that may not be generalizable to all female populations. 'Developmental models that may be appropriate in certain white, middle- and upper-middle-class settings cannot be generalized to all girls in all contexts' [46]. We also need to remember that every human is individual, and the differences among women are usually bigger than the differences between genders [47].

3.4 Undergraduate physics education

At the undergraduate level, physics is an elective course, unlike math or English for most students. Aside from a very small number taking the course for general education/distribution credits, only those with an interest in science or a career choice related to science will take physics classes. This creates an environment in which women are only about 25% of college physics students—so one of the first things a young woman might notice when she take physics is the relative lack of fellow women in her classes.

The next thing a young woman in physics might notice is how few female faculty members there are. Only 14% of physics faculty in the US are women, and with only about 20% of graduate students being women, if they have a Teaching Assistant, there is only a 1 in 5 chance of that TA being female [48]. As with the high school classes, this lack of role models is a subtle, often subconscious, message that physics may not be a welcoming place for women. In the UK the numbers are lower still, with only 9% at the professor level and 19% at lecturer level [49].

The physics classroom itself can promote or hinder women's participation in physics. Women's self-confidence [50] and self-efficacy [51] are often lower or different than men's in the physics classroom. This confidence can affect persistence in pursuing physics [52] and career choices: 'Women, more often, and I saw that very much true in terms of when I was a graduate student, left grad school because they lacked the self-confidence … They always questioned themselves, inherently' [53].

The way that women and men interact with the physics classroom is quite different. Even online homework can be approached differently [54]. There is so much affecting how women interact with the physics classroom that it is hard to identify the individual factors which are causing the most differences in performance; instead, we see a 'smog of bias' [55]. Nor are solutions obvious. Active learning in the classroom can help [56], but not in all cases [57].

One of the issues that has been problematic for girls and women in physics classes is the historical practice of using contexts that are more stereotypically or historically male than female. Projectile motion might include baseball, while a frictionless surface might be ice on a hockey rink. Ballistics and military contexts, torque wrenches [58], and footballs can serve as subtle messages that physics is a man's field.

Rennie and Parker studied the effects of context on gender and performance for several years [59]. They found that the context of a question can affect how boys and girls perform on a problem. In physics the effect of context on the problems of the Force Concept Inventory [60] has been studied, and it has been shown that men and women perform differently with different contexts [61]. A British head of physics at a girls' school notes: 'Girls love practical work. They engage with everyday examples, but it depends on the context because topics such as cars might switch them off. The teacher should let them construct the relationship with the topic, themselves, from practical work' [62]. Being conscious of the contexts we use can help promote a more welcoming environment for the young women and girls that are engaging with physics.

Another point to remember is that many of the tests and assessments used in our educational system were only pilot tested on classrooms of boys or men. From the SAT to the GRE to many commonly used tests of physics, if women perform more poorly than men, we cannot know without careful study if that is a fault of the women's understanding of the material, or if the design of the system and of tests and classes is *actually* biased towards men. As mentioned in the introduction, we need to be careful not to set men's performance as the standard and measure women against an inappropriate measuring stick. Jane Austen notes in her book *Persuasion*: 'I do not think I ever opened a book in my life which had not something to say upon woman's inconstancy. Songs and proverbs all talk of women's fickleness. But…these were all written by men'. If women underperform on an exam that was written by men, tested on men, and optimized for men, we should not immediately blame the women.

One thing that has improved over the last few decades is diversity of representation of people in physics textbooks [63]. As recently as twenty years ago, if there were people pictured, those people were likely to be (a) male, and (b) doing something stereotypically male. Today's texts are much more diverse in their pictures, both in terms of people and activities. Larsen [64] studied four decades of gender inclusive pictures in astronomy texts and found a significant increase in the number of women included over time. For interested readers, UNESCO [65] has produced a guide to gender equality and textbooks.

As one reaches tertiary education, the role of the advisor grows in importance. And just as with secondary school advisors, college advisors often (knowingly or unknowingly) discourage women from physics and other STEM majors [66]. Though we no longer expect to hear 'Why do they expect me to teach calculus to girls?' [67], we still have to work against unconscious biases where young women are told to take biology instead of physics, or to stop taking math classes. More obvious sexism, while rarer, still exists, such as the comment from Nobel Prize awardee Tim Hunt in June 2015, that he has problems when 'girls' are in the lab: 'You fall in love with them, they fall in love with you and when you criticize them, they cry' [68].

While he did apologize somewhat for this statement, that anyone feels this is an appropriate thing to say in 2015 shows how much work we have to do.

Along with outright sexism, sexual harassment is still a factor for some women in physics classrooms and laboratories. Recent news articles [69] about sexual harassment in the sciences demonstrate how common this problem still is. Most universities and many large departments (e.g. MIT's Department of Physics) [70] now have policies on sexual harassment, and there are some universities [71] with online training programs to help prevent sexual harassment. Some schools have new students take training on sexual consent [72]. Despite these advances, it's clear that we still need to be aware of this issue, and all schools need to have programs in place to support victims of sexual harassment and sexual abuse. Firm statements from agencies such as the US National Science Foundation [73] can also help move the culture forward.

Getting involved in research as an undergraduate can be an extremely rewarding experience [74], and makes a student more attractive to graduate schools. (And isn't it interesting how we use sexualized language in this context?) Because of the high value of undergraduate research, there are conferences devoted to supporting undergraduate women's research. The Conferences for Undergraduate Women in Physics are run by the American Physical Society (APS) [75]. Their purpose is 'to help undergraduate women continue in physics by providing them with the opportunity to experience a professional conference, information about graduate school and professions in physics, and access to other women in physics of all ages with whom they can share experiences, advice, and ideas'. A similar conference has been developed in the UK by the Oxford Department of Physics [76]. The second conference in the UK is taking place in 2016.

Research can help us move forward in our goal. Along with countering bias and stereotypes, we can look at how women enter science rather than just what causes them to leave. A study that focused on the life course of scientists encourages policies and efforts to 'facilitate the flow of high school students who expected non-S/E (science/engineering) college majors into S/E majors during the first year of college' [77].

3.5 Postgraduate physics education

The experiences that women have in postgraduate physics tend to be harsher and more hostile than during their undergraduate years [78]. Despite this, there is only a small drop in participation from master's degrees to doctoral degrees, possibly because the women who have made it this far are solidly committed to the field. While some women who go in for a PhD do drop out with a master's degree, this happens at a similar rate to men leaving the field, at least in the US.

The issues facing female graduate students are broadly similar to those of undergraduates, but with some additional areas where bias can enter into the process. Because graduate school is focused so strongly on research, the relationship a student has with their advisor is extremely important [79]. 'Without an advisor who is willing to encourage and direct, women are often unable to puzzle out the strategies necessary to get through graduate school' [79] (page 79). Some advisors are not good at advising and mentoring women, while others simply don't want to work with women at all [80].

Here's what one female graduate student had to say about her first advisor, who never let her finish a sentence. She felt that his message was 'I'm going to regard you, graduate student, as nothing' [80] (page 134). Such messages are not exclusive to male advisors. Female advisors can be just as poor at encouraging women as men. Informal networks can be very helpful for female graduate students in these situations, allowing information to be passed along to new graduate students about who is a good or bad advisor [81]. I benefited from this in my own career, as second- and third-year female students told the first-year female students whom to avoid when I was in graduate school.

Advisors also determine how much a graduate student does in the lab. A poor advisor may give too much work, provide too little support, or use very poor communication. Students who are poorly served in this way will not acquire many of the skills that the PhD system is intended to develop. On the other hand, some advisors may be over-protective of their students [82]. These advisors are likely to spoon-feed their students, to fail to challenge them, and to limit the opportunities they allow their students. The strongest PhD candidates on the job market are those with a breadth of experience.

Good advisors will encourage and challenge their students, while providing enough support to let the students succeed. Having graduate students assist in grant writing, serve as first author on papers, give conference presentations, and participate in professional development such as workshops and summer schools are all things that will help not just women but all students. A supportive advisor can be male or female [83]: 'Women and men faculty do not, simply by virtue of their gender, automatically make good or poor mentors for female students' [84].

Having a supportive advisor or mentor can have long-reaching consequences. Louis Leakey (who worked with his wife Mary) believed that women would be better at studying primates in their natural habitat, and from this were born the leaders of three fields of primatology: Jane Goodall, Dian Fossey, and Birute Galdikas [85].

Graduate students are also more sensitive to the climate and culture of a department, because unlike an undergraduate, their whole education is now confined to one department, often to one building. The term 'chilly climate' has been around since the 1980s [86], and it is particularly appropriate to apply in a graduate school environment.

Luckily, women entering physics graduate school today have several resources to help determine the climate of a department they are considering. Project JUNO, part of the IOP, has a goal 'to recognise and reward departments that can demonstrate they have taken action to address the under-representation of women in university physics and to encourage better practice for both women and men' [87]. In the US, the APS has a site visit program [88] to help departments find out how to better the climate for their female colleagues. A similar site visit program was conducted by the IOP in the UK [89]. The APS also has a website with information on over 150 graduate programs [90] appropriate to helping women decide where to go.

A related issue for graduate schools has to do with the Physics GRE, the standardized test in the US for graduate school. It came under attack in the 1990s as detrimental to the field's gender diversity [91]. The APS newsletter carried an editorial on the issue, stating that while there is a gender gap on standardized tests such as the SAT and GRE, these tests are very poor predictors of student success in physics, and should not be a main criterion for choosing graduate students [92].

In terms of climate, women in post-graduate education have to be careful of how they dress, how they speak, where they hang out [93]. Graduate school is about becoming a physicist, in many ways. 'Break down the ego…until it is a barely visible puddle on the floor, then build it up again in the image of the professor' [94]. Do physicists wear dresses? 'I know a girl who dresses in skirts and heels when at summer schools, but told me she never dresses up around her supervisor, so that he will think she is always working' [95]. For some reason there is an idea that wearing nice dresses means you are a bad scientist. As one graduate student shares: 'At a conference, (my advisor) pointed out another student presenter to us who was wearing a pretty dress. He said "look at what that chick's wearing, she obviously doesn't know what she's talking about!"' [96] (page 512).

In my own experience as a graduate student, I was walking up the stairs in the physics building, holding my long skirt in my hand so as not to trip. A male faculty member stopped in the middle of the stairs, looked puzzled, and told me that he didn't think he had ever seen such behavior in that building before. The message this sent was quite clear, even if the professor in question did not intend it explicitly: skirt $\neq$ physicist.

From the home hearth to the classroom seat to the lab bench, women experience physics differently than men do. These differentiated experiences lead to different attitudes and beliefs about their relationship to physics. For some women, this difference is enough to make them leave physics altogether. Other women stick it out, and move on to PhDs and jobs. They are the successes of the educational system. In the next chapter we will explore how working women encounter the culture of physics.

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Chapter 4

What helps, what hurts: family and career

> 'I'm excited because earlier I didn't think about the issues between females and males in science. I see now that there's so much that can stop a woman from getting a career compared to a man. With men you're expected to do well and get the support, but for females, you have to sacrifice something in a different way from men, and I didn't realize that earlier. I think it's very important for other woman to see that I have had success.'
>
> — May-Britt Moser, 2014 Nobel Prize in Physiology/Medicine

Once a woman has a degree or two in physics, what are her options? Does she choose a job in industry, academia, government? Does she stay in a physics-related position? Does she stay in the workforce at all? In this chapter we will explore what happens to women in physics as they graduate and head into the workplace.

4.1 Choosing a job in physics

For those with a physics PhD in the US, nearly half go into academia. Approximately one-third end up in the private sector, and 15% head into government employment [1]. In Canada, two-thirds of the research positions are in academia, with one-fifth in the private sector and 15% in government [2]. In a UK survey of physics postdoctoral scholars, three-quarters were headed to academia, with only 9 of 48 choosing industry [3]. An interesting note from the UK survey is that 'female physicists' knowledge of opportunities outside academia improves after their first postdoctoral research contract' [3] (page 45).

With so much of the PhD pool heading to academia, much of the research focuses on the lives of academic women in physics. There is significantly less research on how women physicists fare in industry and government positions. Yet there are certain common hurdles that women face, no matter if they are in a lab, a classroom, or a research group. Some of these are discussed below.

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Bias in hiring has been an active research area for several years. Recent works [4] show that women are rated lower than men with the same qualifications, are less likely to be hired, and are less likely to be offered mentoring. Recommendation letters for women tend to be shorter and use less active and agentic language [5]. These many small effects add up to a big effect for women. Over the course of a career, it can cause quite extensive differences [6].

When a woman enters a physics career, she should be able to expect to be given the same resources and opportunities that her male counterparts receive. She will not get them, as things stand currently. In a study of 15 000 physicists across the globe, women in physics were less likely than men to receive important career resources such as funding, office and lab space, equipment, and travel money [7]. Whatever the cause, such disparity means that female physicists are going to be more likely to take longer to do research, have fewer students, write fewer papers and attend fewer conferences. This will slow a woman's career progression compared to the men around her. It also makes women more prone to leaving their STEM career [8].

A related topic is the idea of negotiation. Women have been culturally trained to please others and not make waves. So, 'women don't ask' [9]. By not negotiating, especially at the hiring stage, women often lose out on things that men ask for without hesitation: higher salary, bigger start-up funds, more space, more help. We don't know how much of the difference in resources may be due to negotiation discrepancies, but we can help women learn to start asking [10].

Along with demonstrated biases in evaluating potential hires as discussed above, there is evidence of gender bias in ongoing evaluations of women as well. Female physicists in postdoc positions in the UK were less likely than men to be evaluated by their own supervisor, which could affect how their supervisor advises them or promotes their work, and may also cause the women to feel that the evaluation was not useful [11]. Women are often required to be better than men to achieve the same level of evaluation, having to prove themselves over and over again [12]. When mistakes are made, men may get away without negative consequences where women are likely to be taken to task for their involvement [13].

4.2 Leadership

Women are expected to be warm, nurturing, communal creatures. When women move outside this expectation, they are likely to be viewed negatively [14]. Such bias can affect how women are evaluated in their jobs. Similarly, leaders are supposed to be agentic and forthright while women are not supposed to be. When a woman acts as a leader, she is seen as not acting as a woman. When she acts as a woman, she is seen as not acting as a leader. This is a huge problem. The research on leadership is itself interestingly biased. We often talk about 'leadership' in contrast to 'women's leadership' suggesting that leadership is inherently male and therefore we need to add the descriptor. We compare women to an ideal standard of leadership, which is male [15]. It makes the road to leadership very difficult for women [16]. And it can be particularly difficult in STEM fields: 'Resistance to women's leadership is strongest in highly masculine domains…' [14].

There is very little literature on women and leadership in STEM fields, particularly physics and engineering [17]. Because being a department chair or the head of a laboratory is often a limited time position, it is difficult to capture data for women in leadership positions. One study found that in physical sciences and mathematics only 5.5% of department chairs were women, and in engineering it was a sad 2.5% [18]. A positive trend can be seen in the increasing number of women in leadership positions in governmental agencies in the US [19], which is definitely pushing society in the right direction, if slowly.

Arguments have been made to improve the number of women in physics leadership positions [20]. Suggestions for how to do so have also been put forth [21]. Yet we have little actual data on this important topic.

4.3 Family and work/the balancing act

The international study of physicists [22] also asked about housework and expectations in the home. Regardless of country (and cultural gender roles) female physicists do more housework than their male colleagues. This pattern is true in general, even in 2015 [23]. Spending more time with housework obviously means less time for research and work.

An interesting difference for male and female scientists is that having a child typically slows a woman's career progression, while it can have no effect [22] or a small positive effect [24] on a man's career. It is very difficult for women to have their cake and eat it too [25]. Family-friendly policies such as stopping the tenure clock can help, but many women do not take advantage of stopping the tenure clock because of entirely reasonable fears of repercussions: 'I saw the two other women with young children get punished on reviews for not getting enough published even though they "had time off and had more time to write". I wasn't going to risk it' [26]. The impact of having a child is big enough that some women decide to have fewer children than they wanted, in order to keep their career going [27]. The decision to have fewer or no children can even have recruitment effects: during an 8th grade girls' science day a young girl asked how many of the present female scientists had kids. 'Not a single one of us did.…You could see the smiles on the girl's (sic) faces just dissolve' [28].

Our society still views motherhood as a key component to women's fulfillment in life. Even at the end of the twentieth century, it was believed that in order to truly succeed, a woman had to achieve domestic perfection as well as professional accomplishments to be considered a complete person: 'All women scientists should marry, rear children, cook, and clean in order to achieve fulfillment, to be a complete woman' [29]. This quote from Nobel-winning medical physicist Rosalyn Yalow (1921–2011) demonstrates that it's not just men who set unreasonable expectations of women.

When women in science achieve greatness, the attention they receive is often heavily focused on their gender. Upon being awarded a Nobel Prize in Physics in 1963, Maria Goeppart Mayer's success was announced 'S.D. MOTHER WINS NOBEL PHYSICS PRIZE' in a San Diego newspaper [30]. Mayer was interviewed for *McCall's* magazine (which remarked on the dress she wore to the Nobel ceremony), and *Science Digest* noted her beauty and how good a wife she was [31].

The two-body problem—the issue of prioritizing where to live, which opportunities to pursue, and other important decisions necessitated by having a two-career household—is also a particular difficulty for women. Having a working spouse is a different experience for men and women in heterosexual relationships. A woman is more likely to be a 'trailing spouse' and pause or end her career in order to promote her husband's [32]. An older survey found that female physicists are more likely to be married to another physicist than male physicists are [33].

More recent research shows that among scientists in general, female scientists are more likely to be married to other scientists [34], making this a much more common problem for women in physics than for men, though there can be advantages to marrying another scientist: 'In my department, the most successful women are married to men who are also in the department' [28]. Spousal relationships can help women and men: 'one route for women into the sciences is through connections to high status men' [28].

Historically there have been several famous physicist couples [35], proof that it is possible to succeed in such a relationship. While this can be a positive, it can also be a sign of deeply set issues of discrimination or bias, forcing women pursuing science in hostile environments or times into collaborations they might not have needed if their work were allowed to be evaluated solely on its own merits.

While companies and universities sometimes have spousal hiring programs [36], they are only useful in limited situations and often provide only temporary employment to the spouse. As one advice writer notes in regards to double hires in a single department: 'If you want to achieve this unbelievably difficult goal, you both should be rock stars' [37]. And even if you manage it, there are still burdens, particularly on the trailing spouse [38]. The difficulties are even greater for those in same-sex marriages [39].

When a physicist publishes a paper, they must choose how to list themselves as an author. Does a woman include her full name, often making it clear that she is female? If she does, she may set herself up for potential bias on the part of reviewers or those who might choose to cite the article, whether the bias is explicit or implicit. Or she may choose to limit herself to a first initial [28]. While this may subject her personally to less bias, it removes an important cultural reminder that *women do physics*, which may make things more difficult for women who follow her. This is one of many issues and hard choices that men in the same position are spared. Another publishing dilemma that is primarily a woman's issue comes from the fact that many women change their last name upon marriage or divorce. When you've changed your name, how do you let people know that the Jane Doe who has published six condensed matter papers is the same Jane Smith that is now submitting another condensed matter manuscript? How do you let grant reviewers know that your bibliography has ten papers, not just two? There is very little research on how this affects female authors [40].

4.4 Resources

Many professional organizations provide support for physicists in academia and industry. Most of the physics professional organizations not only have groups focused on women in physics, many of them have programs specifically designed to help women's careers. From child-care grants for conferences [41] to seminars and directories [42], professional physics organizations have realized that supporting women is an important part of their job. Similar support can be found in the numerous women and science organizations around the world [43]. General science organizations also support women in science with funds and programs [44].

Other forms of support for women in physics include listservs [45] which can provide connections to other women that may not be available locally if you are the only female in your department. Mentoring programs [46] serve to help women deal with day-to-day issues as well as larger career questions. Some women find support by forming groups with other women in similar situations. One long-standing group for women in science feels that 'a primary source of the power of the group process is that groups bring together people with shared concerns who might otherwise be isolated from one another' [47]. All of these can provide help, answers, and companionship to women who may be in the minority or alone in their lab or department.

When one is the sole minority in a group, it has effects both on the individual and the group. Women in male-dominated academic departments may find themselves asked to serve on many committees to provide 'female representation', disproportionately increasing their workload and putting them in the position of serving as a sort of voice for all women, among other issues [48]. 'I notice that while women make up less than half the faculty at the associate/full rank, they frequently represent two thirds or more of committee members on committees' [49]. Others in the group may make the assumption that a woman must be interested in activities promoting women or girls, when that is likely not a primary focus for them. Such isolation at its worst can cause feelings of tokenism in a female physicist: a sense that a woman was hired or chosen simply to give lip service to the idea of diversity rather than for her value as an individual scientist.

The woman who feels she is a token will often suffer a loss of self-confidence. Was she chosen simply because she was a woman? Was she a 'diversity' hire instead of a merit hire? Were her accomplishments or her gender more important to the hiring body? Since women often don't speak of these things for a variety of reasons, a lone woman may harbor such self-doubts for years. The marginalization she likely encounters [48] often strengthens these fears. And fear of retaliation often keeps her from speaking up when there are problems or when she has ideas that are counterculture in relation to her workplace [50].

'To the statistician a token is something you can write off as being insignificant because it is not big enough. But when you are talking about revolutionary change, tokens and rituals are often more important than huge quantities' [51]. While feeling that one is a token can be destructive to the individual, the goal of diversity is worthwhile for any organization. Being the *first* or *only* is difficult, but very important.

We are now ten years past the day when then-Harvard-president Larry Summers claimed that the three likely reasons women aren't in science are (i) status related ('high-powered job'), (ii) differential ability at the high-aptitude end, and (iii) patterns of discrimination [52]. His remarks set off a national and international furor. The number of women in physics careers has improved very little since then. And it's still a hot-button issue with a lot of sexism surrounding it. In 2014 Neil deGrasse Tyson was asked at a conference: 'The Larry Summers question: What's up with chicks and science?' [53]. Tyson responded well, speaking about bias and assumptions. But just the phrasing of the question is enough to make many people flinch. That anyone could use such language today in a public forum is a perfect example of the continuing need to fight sexism.

Despite the numerous problems and barriers that women in physics face, it is reassuring to know that we have made many gains in the last century. While the 'problem' of women in science is not yet solved, there are many things that today's women don't need to deal with. The next chapter will focus on the positive changes that have been made for women in physics.

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Chapter 5

The view through rose-colored glasses

> 'A generation later progress for women throughout the academic world is measurably improved…But other…forms of inequities linger and obstacles still exist.' [1]
>
> Donna Shalala

Despite the many hurdles and barriers that women face, we do have successful women in physics. Many websites and other venues promote women in physics as role models, and these sites also serve to educate and remind the public that women can do physics.

How have things gotten better for women? What barriers did our mothers and grandmothers face that our sisters and daughters will not? This chapter explores the progress made and the hurdles dismantled for women in physics.

For women raised in the last half of the twentieth century, it was not uncommon to hear that women don't or can't do science. High school girls were advised away from science by teachers and counselors. College professors and advisors were often worse: 'What makes you think you're worth educating? You're a woman, and you're already married' [2]. Today such overt discrimination is rare, though not entirely extinct. Witness the quote in 2015 from Nobel Laureate Tim Hunt [3] about why he doesn't like having 'girls' in the lab. On the plus side, he got a great deal of push back. Even twenty years ago, it probably would have gone mostly unremarked.

Gender bias in three areas has been reduced for women in science: grant funding, journal reviewing, and hiring [4]. The authors of the paper find that given similar resources, women and men do equally well in these areas. These same authors have published other articles [5] claiming either no bias or bias in favor of women, though not without rebuttals [6]. The oft-cited article by Wenneras and Wold [7] from 1997 showing gender bias in Swedish grant awards has shed some of its currency in terms of award bias, as Sweden's male-female difference in grant success has been

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significantly reduced [8]. However it is not gone: a meta-analysis shows a 7% gap still favoring men in grant success [9]. So we have removed a lot of the explicit discrimination [10], and things are shifting in a good direction in terms of bias in grants and reviewing.

Any discussion of women's progress in the US must acknowledge the positive effects of Title IX [11] of the Education Amendments of 1972: 'No person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any education program or activity receiving Federal financial assistance'. Under Title IX, any class, program, or activity that receives federal money cannot deny access because of a person's sex. While the link to physics is less direct than the link to athletics or school programs, Title IX moved the US significantly forward on the path towards gender equality in our schools. This progress has helped promote girls' participation in physics in more ways than can be easily traced back to the legislation. For example, by increasing female participation in sports it may have given them better grounding in some of the contexts used in physics examples that used to favor male contextual knowledge and identification. The Women's Educational Equity Act a few years later had a specific focus on girls' participation in science and math, and a 1992 report on the WEEA noted that 'there has been increased interest in mentoring and materials in the area of math and science' [12].

In the UK, the 1988 Education Reform Act [13] served to help girls' education because of its focus on maths and science as a core curriculum for all students in every school. As with the American Title IX, though the focus was not specifically on STEM education, it has had a far-reaching impact on how girls were educated in science. Teaching girls science content is necessary. Teaching about successful women in science should also be a part of our curriculum.

One way to learn about and acknowledge the work that women do in physics is to note the ground-breakers, the women who were the first to succeed at certain tasks. The American Institute of Physics has developed a timeline of important events for women in physics and astronomy [14]. We need to acknowledge those who have gone before.

In 1959 Edna Yost wrote: 'Very little biographical material is available about women who are scientists' [15]. Today, there are a great many resources listing successful women in physics and science in general [16]. Biographies abound of famous and less known women who loved physics and made significant contributions. There is even a book specifically written to introduce children to important female scientists [17]. There are resources that provide people with lists [18] of possible role models for our young women and men. It is now easy to look up and find out interesting facts about female physicists. I believe a day will come when you ask a person to name a female physicist [19] and they can come up with someone other than Madame Curie.

Another sign of how things have improved is the awareness of women's issues in science in the general public. There are hundreds of books available if one searches for 'women and science'. A web search can find videos, articles, books, blogs, and conferences on the topic. In order to truly solve a problem, one must first recognize that there is a problem. We are solidly at this point now, with more and more general societal awareness and press attention on the issues that women in science face.

An interesting way to look at the general public's view of women in physics comes from the popular US television show *The Big Bang Theory*. Who could imagine that a TV sitcom about physicists would be big enough to last ten seasons? What great news, right? And yet…. The portrayal of women in science in the show can be quite negative. Shrill. Dowdy. No fashion sense. Admittedly smart, but most often socially awkward. This mirrors the portrayal of male scientists on the show in many ways, but may play differently with the potential audience of young women interested in science. Especially with a pretty, socially adept woman as a comparison in the show. Are these role models that our young women will connect with, or aspire to?

Issues of women and physics have been recognized by our professional organizations for many years. Most of the professional organizations for physicists in the English-speaking world have a committee or a special topical group on women in physics. One of these committees has been around since 1972! [20]

http://www.aip.org.au/info/?q=content/women-physics-wip (Australian Institute of Physics)

http://www.aps.org/programs/women/ (American Physical Society)

http://www.aapt.org/aboutaapt/organization/women.cfm (American Association of Physics Teachers)

https://www.iop.org/activity/groups/subject/wip/index.html (UK Institute of Physics)

http://www.stfc.ac.uk/about-us/how-we-are-governed/advisory-boards-panels-committees/women-in-science-engineering-and-technology/ (UK Science and Technology Facilities Council)

http://iupap.org/working-groups/wg5-women-in-physics/ (International Union of Pure and Applied Physics)

In the US, the APS maintains a list of women in physics for recruitment and dissemination purposes, the Roster of Women & Minorities in Physics [21]. They also host a Women Speakers List, of women in physics willing to give talks on a wide range of topics [22]. The Australian Institute of Physics supports a 'Women in Physics Lecturer' program [23].

The IOP in the UK has created a project focused on encouraging physics departments to become more female friendly, Project JUNO [24]. Similarly, the US has a site visit program to encourage departments to improve the climate for women [25].

Such programs and initiatives did not exist thirty years ago, and their presence today suggests that we have indeed come a long way. Though we still have under-representation of women in physics, it is worth celebrating our progress as we reach for more. So that's the case for how things are better; what are the barriers and hurdles that remain? What do we still need to work on? The next chapter looks at what issues are currently being faced by female physicists.

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IOP Concise Physics

Women and Physics

Laura McCullough

Chapter 6

The glass is half-empty

> 'I have always believed that contemporary gender discrimination within universities is part reality and part perception, but I now understand that reality is by far the greater part of the balance.' [1]
>
> Charles Vest, when president of MIT.

We have many examples of productive and successful women in physics; things have definitely gotten better. And yet, the percentage of women in physics currently continues to hover around 20%. Why is this number not increasing? What is keeping more girls and women from choosing physics, and staying in physics? The ongoing challenges and barriers to women in physics will be explored in this chapter.

A good overview of the issues women face comes from an international survey of physicists [2], where 3000 women from around the world shared what helps and hurts them as physicists. Access to resources, demands from family and home, chances to travel to conferences; all these affect how successful women are in physics. Chapter 4 goes into more detail of the issues facing career women in physics.

6.1 The nature of science

There is an active field exploring the idea of a feminist or masculinist nature of science. Is science as we have created it an inherently masculine field? Examples abound in the literature of ways that science shows off its male side. The first atomic bombs were named Fat Man and Little Boy [3], an example of the idea of male birth analogies in science [4]. Many histories of science and scientists speak of science as 'a woman to be unveiled, unclothed, and penetrated by masculine science' [5]. Nature is a woman, a harsh mistress, something one falls in love with, even marries. To quote Richard Feynman: 'That was the beginning, and the idea seemed so obvious to me and so elegant that I fell deeply in love with it. And, like falling in love with a woman, it is only possible if you do not know much about her, so you cannot see her faults.

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The faults will become apparent later, but after the love is strong enough to hold you to her' [6]. Helen Longino has argued that science cannot be truly objective since it is always undertaken in a social setting, and so we should make sure that the biases and values we attach to science are not purely masculine in nature [7].

6.2 Covert discrimination

As we saw in the last chapter, overt discrimination has diminished greatly and is no longer an expected or accepted practice. But in moving forward, we find a new challenge: the discrimination that hides under the surface. Covert discrimination takes many forms and is often much harder to combat because of this.

A stunning exposure of covert discrimination comes in the 1999 Massachusetts Institute of Technology women faculty study [7]. They note how surprised they were to discover the many forms of discrimination: 'Most of us thought that the Civil Rights laws and Affirmative Action had solved gender "discrimination". But gender discrimination turns out to take many forms and many of these are not simple to recognize.' The MIT study authors report that in some science departments '(i)nequitable distributions were found involving space, amount of nine-month salary paid from individual research grants, teaching assignments, awards and distinctions, inclusion on important committees and assignments within the department'. Working from this study, MIT's School of Science made recommendations designed to address the inequities, and an updated report in 2011 suggests that much progress had been made, though tensions and issues remain that impact the professional work of women in science and engineering at MIT.

When discrimination goes underground, it becomes much more difficult to expose and correct. Those who are discriminated against may be unlikely to realize what is going on, while those doing the discriminating may not even be doing so in a deliberate manner. One of the reasons for this nearly invisible discrimination is unconscious belief structures affecting actions.

The last two decades have produced a great deal of research on the effects our unconscious biases may have on our actions. Implicit bias is bias we are unaware of, typically a product of our society and upbringing.

A fascinating series of tests are available from the Project Implicit website (https://implicit.harvard.edu/implicit/index.jsp). These tests have been shown to uncover the unknown, implicit biases that we all carry. One of these implicit biases is the connection between science and men. The unconscious connection between science and men, not women, can affect not only a person's decision whether or not to go into science [8] but can also affect achievement in science. Countries with a stronger correlation between men and science on the implicit bias test exhibit higher scores by boys on the TIMSS 8th grade science tests [9]. Higher national gender-science stereotypes also correlate with lower numbers of women in science [10].

The Women In Science and Engineering Leadership Institute (WISELI) group in Wisconsin, USA has an Implicit Association Test for women and leadership, and you can participate in their research by taking the test at http://wiseli.engr.wisc.edu/leaderiat.php. The connections between women and leadership provide one lens for examining the issue of women's participation in science. If science is a high-status field [11], then scientists are viewed as leaders. If women aren't viewed as belonging in science, and they aren't viewed as leaders, they face a double challenge. As one young woman in high school says: 'I guess scientists, you can say, have power. I don't know. And a lot of people don't like the idea of women having power' [12]. WISELI has a brochure on 'Advancing Women in Science and Engineering: Advice to the Top [13]' as well as many other helpful resources [14].

These implicit biases have been carefully studied, and we know that people who profess an unbiased view can still hold these hidden ideas [15]. So what can be done about them? Well, it is possible to reset these biases! Several studies have shown that long-term changes can be made to our hidden beliefs [16]. The first step is to become aware of our biases. Next we need to realize the effects these biases have, and to really care about changing them. Then we need to confront our biases by exposing ourselves to counter-bias information. Pictures of female scientists, research on girls' abilities in science, stories and biographies of women in science, recognition of male failures in science: all of these can help us overcome biases we may have against women in science. (The American Institute of Physics has a resource collection for teaching about women and minorities in the physical sciences [17].) It can be done, but first and critically we need to recognize our biases and feel motivated to change.

Along with our personal implicit biases, as a culture we may be unknowingly harming girls' performance on science tests because of the stereotypes that our society holds regarding girls and women in science. 'That was the double bind that strangled me. If I did poorly, I would prove women never did finish their degrees in science or math; if I succeeded, I would be even more unpopular than before. Bad enough to be a girl who had gotten all As in high school; how much more of an oddball would I be if I earned all As as a physics major at Yale?' [18] The concept of stereotype threat is another well-studied phenomenon which affects how females experience science.

Claude Steele describes stereotype threat very well in his book *Whistling Vivaldi* [19]. In a seminal experiment, African-American and White students were given a difficult test. One group was told that the test was a good measure of verbal ability; the other group was told it was simply a problem solving exercise and did not diagnose ability. The first group's African-American students performed more poorly than their White counterparts; the second group showed no significant difference. By being subtly reminded of the stereotype that African-Americans are less good at verbal tests, students in the stereotyped group did less well than when they were not reminded of this stereotype.

This experiment has been conducted with women and math tests, with women in the threat condition (they were reminded of the stereotype) doing much worse than both men and women in a non-threat condition [20]. One article claims that by simply waiting to ask about gender until after taking an AP test rather than posing such demographic questions beforehand, women do significantly better [21]. Even so small a thing as writing down your name, major, and gender before a test can trigger a stereotype threat response, and reduce your performance.

Fortunately, just as with implicit bias, there are things we can do to reduce the effects of stereotype threat. http://www.reducingstereotypethreat.org/ is a website with many resources for people interested in learning about and combating stereotype threat. One fascinating idea is employing self-affirmation, with a short exercise in which students are asked to write down values that are important to them and why. This exercise can lead to reduced effects from stereotype threat [22] for women and math tests. In physics, this has been successfully tested at the college level [23] and partially replicated [24]. Women who completed a short self-affirmation exercise performed better on a standard physics test than women who did not, thereby reducing the gender gap on the test.

An important thing to consider when looking at the unconscious and implicit biases we hold is how we may transmit them to others in very subtle forms, with or without any intent to pass them along. One area where this could turn out to be very relevant is in the idea of microaggressions [25], which is gaining ground in the research literature [26]. The evidence is strong that women in science fields experience many subtle slings and arrows throughout their career.

Microaggressions are typically described as 'the everyday verbal, nonverbal, and environmental slights, snubs, or insults, whether intentional or unintentional, which communicate hostile, derogatory, or negative messages to target persons based solely upon their marginalized group membership' [27]. Women are a target for microaggressions simply due to their gender [28] before you bring in the issue of science, and women in science are at an even higher risk of receiving such slights. For example: 'Has anyone ever asked you if you know how to use a wrench?' asks one female physics graduate student to her male interviewer [29]. One study has found that high school students note microaggressions against women and racial minorities [12] so this is a problem that presents early. It can also be quite difficult to address and correct microaggressions because of their subtle nature.

As we continue to do more research into the hidden and subtle biases that women in physics encounter, we will surely develop stronger and more effective ways to remediate and combat these barriers. We also need to remember that women need to be considered as individuals, and each one will inevitably be a part of many groups that may or may not overlap with other women in physics. A woman may define herself first as a scientist, or a Christian, or a lesbian, or a mother. By aggregating all women together, we miss the subtleties of the individual experiences that women of many identities have.

A discussion of women and science cannot be complete without discussion of the pernicious idea of inherent biological weakness of women in the area of science. Most of the time this idea is brought up with the research on gender differences in spatial reasoning (see Benbow and Stanley [30] for a classic paper on this topic). Modern thinking on this idea [31] is that there are brain-based differences in how men and women think and solve problems, but that these differences do not limit how well men or women can do science. Nor do we know if these differences are biological and/or sociological in origin. A short training intervention can raise the spatial abilities of both boys and girls significantly [32], suggesting that biology isn't the only factor at play.

Another argument against the idea of women being biologically disadvantaged when it comes to science is the fact that in some societies women make up a much more significant proportion of physicists. If a double-X chromosome were to blame for the lack of women in science, we would expect very small differences across the globe in women's participation in physics. Instead, we see striking differences between cultures [33], and in many cases the number of women in physics improving greatly [34].

As the low number of women in physics in the English-speaking world suggests, we still have issues to fight and cultural biases to erode. And yet we have come a long way from the first days where women were not even recognized for their work in the lab.

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Chapter 7

Closing thoughts

'If society will not admit of woman's free development, then society must be remodeled.'

Elizabeth Blackwell [1]

Women's interest in science stretches back to Hypatia and beyond. Women have always cared about the way the world works, whether that interest was expressed in a pursuit called natural philosophy or the more modern STEM terminology. What they have not always been allowed to do is to follow that passion. While in the world today we are seeing more and more opportunities for girls and women to learn and do science, the road is long and the end is not yet clear in our sight. Where chemistry, math and biology are nearing gender parity, physics and engineering remain stubbornly male-dominated [2].

When I walked into my physics graduate school on day one and there were twenty-four men and me, I knew that we had a problem. A problem begging for a solution, and because I am a scientist and what I do is solve problems, that moment was the beginning of what has been twenty years of research on gender issues in science for me. I don't know all the answers, and I doubt the problem will be solved in my lifetime, but I know more than I knew then, and sharing that is part of the solution. Hence this book.

From the early days of believing that women's education would cause their uteruses to shrivel up and disappear, to letting women in to some labs but not giving them credit, to saying that women aren't in science because they aren't biologically capable of it, to today's issues of implicit bias and stereotype threat: we have already traveled a long road. Many of the 'hot' women and science topics of the 1980s are antiquated relics to today's researchers. We can only hope that the issues women face in physics today are just as unimaginable to our granddaughters as the idea of telling a little girl that 'physics is only for boys' is to us.

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The women and physics researchers of today and tomorrow need to consider how we go about doing our research as well as how a shifting world will require us to keep shifting our focus to move with the times. We should not view men as *the* standard against which women ought to be judged. Instead, we must determine what is best for physics, and move our field in that direction. As whites are heading towards becoming a minority in many English-speaking countries, the interplay of gender, race, and other identities must become a greater part of our conversation. We also need to study how we view gender and sex, and develop better ways to talk about the fluidity and continuum of these concepts. There is also a great deal to be learned by considering the many identities we all hold. The experience of a white straight cis woman is not the same as that of a trans woman, a Latina, or a lesbian in physics. We need to study the experience of women in a way that addresses *all* of their identities.

Culture is hard to change and slow moving when it does. And yet the evidence points more and more to cultural factors being the main culprits in the lower participation rates of women in science, which means the culture will have to be moved and we will be the ones who have to move it. As researchers continue to study this complicated and fascinating issue, we learn more and more that we couldn't have imagined twenty years ago. For example, who would have guessed that the belief that a field requires innate ability is strongly correlated with the participation of women in that field? The mere fact that physicists believe that physics requires an innate talent has a strong relationship with physics' low numbers of women [3]. What happens if we can move that belief in talent? We don't know, but we should strive to find out.

We now have a history in this area that includes decades of research on women and physics, the growth of programs supporting girls and women in science, and a real societal awareness that this is an issue. All of that points to a rosier future, both for women and for the field. I am optimistic that we can and will solve our remaining problems, because I am a scientist and what we do is solve problems, *and* because I am a woman in science and we have always been here and we always will be.

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