Why Women Are Underrepresented in Science, Technology, Engineering and Mathematics (STEM) Fields in the United States

by

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Submitted to the Institute for Data, Systems, and Society
in partial fulfillment of the requirements for the degree of

Master of Science in Technology and Policy

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2018

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Abstract

The issue of women’s underrepresentation in science, technology, engineering and mathematics (STEM) fields in the United States has recently gained significant interest and accordingly, a great increase in the body of literature on this topic. A review of the literature reveals that the issue is a complex phenomenon with a myriad number of causes. These causes may be socioeconomic or cultural influences, or they may be specific events in women’s educational or occupational timeline such as first-year college and university STEM classes. This thesis will use the following two themes to weave through and present the existing body of research: (1) STEM fields are riddled with gender stereotypes, which make many women uncomfortable and feel like they do not belong; (2) a gender confidence gap exists in STEM fields and discourages women from entering or further pursuing STEM. An examination of gender composition of STEM fields across different countries validates these two themes as well. Finally, this thesis will end with a discussion of several potential strategies for increasing the representation of women in STEM.

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Acknowledgements

I would first like to thank my thesis supervisor Professor Richard Larson, for this thesis would not have been possible without his guidance. Professor Larson was always patient with me, pushing me to think outside my comfort zone and steering me in the right direction when I needed it. He was just as passionate about my thesis as I was, and he provided valuable insights and advice throughout the whole process.

I am also grateful to MIT and TPP for offering me this wonderful opportunity of personal growth and academic development. A special acknowledgement goes to Barbara DeLaBarre for always being a friendly face and lending her ear to my questions and concerns.

I would also like to thank my parents and my sister, for they are my fiercest fans and advocates, who cheer me on with whatever I pursue. Finally, I want to thank my husband, Jae Yeon, for being my anchor during my two years at MIT. We are expecting a baby girl in less than two months, and writing this thesis has helped the two of us envision a future for our daughter, in which she is truly free and empowered to study and excel in whatever field she chooses, including science, technology, engineering or mathematics.
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I. Introduction

a. First Realization

Any scholar that studies the issue of women’s representation in science, technology, engineering and mathematics (STEM) fields in the United States will soon come upon three overarching realizations. One, women’s underrepresentation in STEM fields is a complex phenomenon with an innumerable number of causes, further complicated by the intertwining of the various factors. At times, it is difficult to distinguish cause and effect, to differentiate causation from correlation, and to separate the effects of one factor from the effects from another. There are also no such things as simple statistics. When one digs deeper, each statistic carries with it a story or another dimension that we should consider.

For example, we have recently seen some positive and promising headlines regarding the issue of women’s representation in STEM fields: women compose about half of all science and engineering bachelor’s degree recipients (National Science Board, 2016); in 2016, 46.3% of medical school graduates were females (Association of American Medical Colleges, 2016); and Harvey Mudd, which is one of the most renowned math, science and engineering undergraduate colleges, for the first time in 2016 witnessed more women than men graduating with a degree in computer science (Staley, 2016). These statistics, as encouraging as they may be, can be misrepresentative on their own and therefore need to be fleshed out with more information and context.

The first statistic is too broad, for instance. Women do receive about half of science and engineering degrees at the bachelor’s level, but the idea of gender parity at the college or university level is still illusory. When one digs deeper and examines each field of study, there is actually a significant gender imbalance. In 2015, women earned 49.7% of science and
engineering bachelor’s degrees, but gender parity was achieved in only select life sciences fields such as biological sciences and chemistry (59.5% and 48.5%, respectively) (National Science Board, 2018). Meanwhile, in engineering, women composed only 20.1%, dipping as low as 11.9% in electrical engineering, 12.9% in mechanical engineering and 13.3% in aerospace engineering. Women also composed only 18% of computer sciences and physics bachelor’s degree recipients. Worse, the fraction of women receiving bachelor’s degrees in these underrepresented fields has been on the decline since 2000: the percentages have gone down in computer sciences, mathematics and statistics, physics and engineering by 10%, 5%, 3% and 1%, respectively (National Science Board, 2016). Evidently, women remain a significant minority in many of the STEM fields at the college level.

The second statistic, that almost 50% of medical school graduates are now females, also has the potential to mislead us that a sustainable gender balance has been reached in at least some STEM fields. However, the gender parity we observe in life sciences fields at the college or university level is rather fleeting and does not last as women progress throughout their careers. Biological sciences and medicine become subject to significant female attrition as we climb up the academic ladder. Although we see a fifty-fifty women representation among medical school applicants, matriculants and graduates, the representation percentage quickly dwindles to 34% for associate professors, 21% for full professors, 15% for department chairs and 16% for deans at these medical schools, as demonstrated in Figure 1.1 below (Association of American Medical Colleges, 2014). Therefore, even the STEM fields that start out with a healthy gender balance, over time, appear to lose women at a faster rate than men.
b. Second Realization

Accordingly, the second realization is of the need to segment and add different dimensions when studying the issue of underrepresentation of women in STEM fields. The various STEM fields as well as all junctures throughout a woman’s educational and vocational timeline deserve an examination on their own. Why are young girls interested in biological sciences and chemistry but not in computer science and engineering? At what ages do females tend to lose interest in the latter fields then? What are the barriers and obstacles hindering women in STEM fields, and how do they differ by field or by age?

Factors such as ethnicity, race and socioeconomic status can add different dimensions to our analyses as well. African American women, for example, may face a double layer of challenge, one due to their gender and another due to their race. In 2014, African American women composed 11% of all bachelor’s degrees awarded to women but only about 6% in mathematics and statistics and 5% in engineering (National Science Foundation, 2017). African American women struggle worse at higher educational levels: in 2010, they composed less than 1% of STEM doctoral degrees awarded to women (Scriven, 2013), and every year, there are only about 13 African American women receiving a doctorate degree in physics in the whole country.
Some studies and surveys suggest that African American women are more likely to be affected by certain gender-specific biases than other women when it comes to STEM work environments. For example, African American women often find themselves having to prove their competence and worth repeatedly in the face of their colleagues’ skepticism and scrutiny. African American women also have to be more cautious about balancing their ‘feminine’ and ‘masculine’ sides; one cancer biologist claims that she tries to hold back her emotions at lab meetings, in fear of triggering “the ‘angry black woman’ stereotype” (Williams, 2015).

In addition to ethnicity, socioeconomic status is another factor that adds nuances to our analyses and actionable items. Girls from lower socioeconomic classes are less likely to view STEM subjects favorably and eventually less likely to pursue a career in those fields than girls from higher socioeconomic classes (United Nations Educational, Scientific and Cultural Organization, 2017). Some claim that socioeconomic levels have a just as significant, if not greater, impact on educational achievement as gender (Corbett et al., 2008). For example, as demonstrated in Figure 1.2 below, within the higher-income bracket, the differences between girls’ and boys’ scores on the National Assessment of Educational Progress (NAEP) math exam are not significant, especially compared to the differences between scores of students from different income levels. As the authors note, “[b]oys’ advantage in math does not supersede the more substantial advantage of students from higher-income families over students from lower-income families” (Corbett et al., 2008).
In the past few decades, we have witnessed some improvement in increasing the representation of women in STEM fields, but it is unclear whether this progress is applicable to white, privileged women or women of all subtypes and classes. Two encouraging facts and figures representing women’s progress were provided earlier in this piece: half of medical school graduates are now females, and Harvey Mudd witnessed more women than men graduating with a degree in computer science for the first time last year. But do these groups of triumphant
women include those from socioeconomically disadvantaged classes in appropriate proportion? Or are they mostly Caucasian females from families with higher incomes? A statistic reflecting improvement in women’s representation in STEM fields does not necessarily imply such a progress for every group of women.

c. Third Realization

The third and final realization that one will gain upon reviewing the literature and conversing with others on this topic, is that many people hold perceptions and beliefs that are often misleading, neither fully researched nor fully thought out. At times, these perceptions and beliefs oversimplify the problem. And at times they are dismissive, as if they are trying to brush off the problem by putting the blame on women and blaming women’s ‘choices,’ ‘preferences’ or ‘inherent capabilities’ as the primary source of the gender gap in STEM fields.

One of the things I heard repeatedly in my conversations with others was that there aren’t as many women in STEM fields as men, partly because there aren’t enough qualified female candidates to pick from. Many claimed that women weren’t getting the job or women weren’t getting promoted because there were too few qualified women candidates out there. But the people who were making these statements were not aware of the various biases that undermine our perceptions of female competence and therefore make us overlook women when hiring or considering whom to promote.

Moss-Racusin et al.’s study is famous for uncovering widespread bias that science faculty exhibit against female undergraduate students (Moss-Racusin et al., 2012). In the study, the authors sent out to 127 biology, chemistry and physics professors nationwide, resumes of an undergraduate science student who was ostensibly applying for a science laboratory manager
position. These resumes were fictitious, and all the professors received the same resumes with only the names of the student differing: half of the professors received a resume with the name of John while the other half received a resume with the name of Jennifer. The professors were then asked to rate the student’s competence and hireability and to come up with the amount of salary and mentoring they would offer to the student.

The result was surprising. Even though John and Jennifer had the exact same qualifications and experiences, the professors were significantly more likely to view John more competent than Jennifer. The professors were therefore more likely to offer the job to the male candidate as well as to offer a higher salary: $30,238.10 to the male candidate and $26,507.94 to the female candidate, with about a $4000 difference. Finally, the professors offered less career mentoring to the female than to the male candidate. This bias existed regardless of faculty participants’ scientific field, age and tenure status, and interestingly, gender. Female faculty members were just as likely to hold bias against female undergraduate students, suggesting that it’s not just the men who are to blame.

This is not the only study demonstrating the bias – conscious or unconscious – that women in STEM fields face when it comes to hiring practices. There are many other empirical studies and anecdotes suggesting that people tend to undermine female competence in STEM fields or that females have to work harder than males to prove their capabilities: a female postdoctoral scholar has to publish at least three more papers in a prestigious journal such as Science or Nature than a male postdoctoral scholar to get the same score in the ‘competence’ ranking (Wenneras and Wold, 1997); when a woman and a man are equally successful in a male-dominated field, the woman is viewed as less likable and more hostile than the man (Heilman et al., 2004); and in 2015, two female postdoctoral scholars in evolutionary genetics submitted their
manuscript to a journal that is part of the Public Library of Science (PLOS) family, only to receive a rejection from their single reviewer, who claimed “[i]t would probably also be beneficial to find one or two male biologists to work with … in order to serve as a possible check against interpretations that may sometimes be drifting too far away from empirical evidence into ideologically biased assumptions” (Retraction Watch, 2015). Evidently, the biases against women are chronic and systematic, and they harm females at every stage in their career, from hiring, peer-review, publishing to promotion.

Another oft-repeated statement, which can be misleading without further qualification or explanation, is that underrepresentation of women is not an issue or a problem but a natural consequence of women exercising their choice. The grounds for this statement are three-fold: women are *happily* choosing to *not* enter STEM fields because (1) women choose to prioritize their families over their careers, (2) women inherently lack STEM skills compared to men, and/or (3) women prefer non-scientific disciplines to STEM (Ceci and Williams, 2011). One scholar recently even claimed, “the underrepresentation … of women in STEM … in the US … reflects the great progress that has been made empowering women to follow their passions and academic interests and should be celebrated as a great sign of female success, rather than a ‘national crisis that will be deeply detrimental to America’s global competitiveness’” (Perry, 2018).

I would like to clarify here that the statements above indeed may be true for some women: some women may choose to not pursue an education or a career in STEM fields for any one of the three reasons provided above, and these women may be content with their choices. But the statements are not true for many other women, who are being pushed out of STEM fields.
The statements oversimplify the underlying problem. They also tend to push the blame onto women, without having considered whether these women’s ‘choices’ are indeed voluntary or, in reality, forced. As for the first statement that women’s choosing families over their careers gives rise to the underrepresentation of women in STEM fields, what about the various societal and cultural factors that make it impossible for women to ‘have it all’? The hostile work environments that make it incredibly difficult for women to maintain a sustainable work-life balance, compelling them to choose their families over their careers? Another interesting counterargument is that while females are reluctant to pursue STEM careers, they are just as likely as males to pursue careers in medicine or law, careers which are also time-consuming and which pull women away from their families (Cheryan, 2016).

The second statement that women lack inherent STEM skills compared to men is very controversial, stirring up debates and fervent discussions whenever it is brought up, whether by former Harvard University President Larry Summers over ten years ago or by the Google memo last year. We are likely many years away from being able to determine the exact differences in genetic and neurologic makeups of men and women, and how these differences affect their STEM skills. In the meantime, there are several valid counterarguments to the claim that women have inferior STEM skills compared to men. One, girls perform just as well as boys in STEM classes, if not better. The evidence is anecdotal as well as grounded in hard data. STEM professors at many elite universities claim that they frequently see female students at the top of their classes and that they do not see a discernible difference between females’ and males’ academic performances (Urry, 2005; Pollack, 2013). These claims are supported by my interviews of several MIT professors that teach calculus and mathematics, which are STEM fields with some of the lowest female representations. Empirical studies also show that 15-year
old girls and boys score equally well on standardized math and science exams (National Science Board, 2016); and girls perform better and have higher GPAs than boys in high school. This is not because girls are taking easier classes than boys. As a matter of fact, girls report having earned more math and science credits than boys and also have a higher GPA from these classes (Corbett et al., 2008). A meta-analysis of around 4,000 studies also revealed a negligible difference between males’ and females’ mathematics performance (Grant, 2017).

The third statement was that women prefer non-STEM fields over STEM fields and therefore choose to pursue non-STEM fields; as a result, women are underrepresented in STEM (Lubinski and Benbow, 2006). Proponents of this claim would say that girls are “better rounded and more eager to work with people, plants, and animals than with things” (Pollack, 2015, p. 215). They are, however, not mindful of the fact that these women’s preferences may have been socially shaped. A broad range of sociocultural factors, including parents, teachers, schools, role mentors and experiences, can shape women’s interests. For example, children become aware of gender stereotypes as early as second grade. A 2011 study showed that elementary school children – both boys and girls – associated math with the male gender more strongly. If girls primarily identify their opposite sex (but not their own) with math, such identification “may exert a developmental influence on [the girls]’ interest and effort, which could subsequently affect achievement” (Cvencek et al., 2011). Many women are also being pushed out of STEM fields due to outright bias or the unfriendly male-oriented culture that invades STEM fields. Many women are exhausted from constantly feeling isolated and tackling roadblocks throughout their STEM education and career. These sociocultural factors affect women’s STEM skills and capabilities and shape women’s preferences, likely against STEM fields.
As demonstrated above, women are good at STEM and they can do it, but they are choosing not to. Why? Throughout the course of a woman’s life, there may be many moments when her potential, aptitude or interest in STEM fields is not nourished or fostered as much as a man’s. There may also be less subtle moments when a woman is overtly discouraged from further pursuing the STEM pathway. Whenever this happens, it deserves our attention.

An in-depth review of the literature revealed that a myriad of factors are responsible for discouraging women from pursuing STEM fields. These may be socioeconomic or cultural influences, or they may be specific events in women’s educational or occupational timeline such as first-year college and university STEM classes. This thesis will use the following two themes to weave through and present the existing body of research on why women are underrepresented in STEM fields in the US: (1) STEM fields are riddled with gender stereotypes, which make many women uncomfortable and feel like they do not belong; and (2) a gender confidence gap exists in STEM fields and discourages women from entering or further pursuing STEM. An examination of gender composition of STEM fields across different countries validates these two themes as well. Finally, this thesis will end with a discussion of several potential strategies for increasing the representation of women in STEM.
II. Stereotypes about STEM and Gender

The first overarching factor explaining why many women never join the STEM pipeline or are in haste to leave is that STEM fields are very ‘masculine.’ STEM fields are riddled with masculine stereotypes and cultural cues as to what a STEM professional should look and act like. These gender stereotypes affect women in many ways. Girls from a young age learn through various channels to associate STEM fields with the male gender. In contrast to boys, who are exposed to STEM early on and encouraged to pursue it, girls do not receive such exposure or affirmations. Instead, girls receive social cues that they do not belong in STEM or that they will be never good as boys at STEM.

Masculine stereotypes deter women away from STEM fields and contribute to women’s underrepresentation in several ways. Because the society does not nurture or foster women’s interest in STEM as much as men’s, many women with high STEM potential never think to join the STEM trajectory. Even when women do decide to pursue STEM, they may feel uncomfortable or like they do not belong in their surroundings. These women therefore tend to lack the motivation to persist in the field and evidently leave the STEM pathway.

This chapter will examine in detail the various masculine stereotypes and cultural cues that are pervasive in our society as well as their effect on women’s representation in STEM fields. The subsequent chapter will delve into a further consequence of these masculine stereotypes, that these stereotypes can affect women’s perception of their STEM abilities and undermine their confidence.
a. Stereotypes of STEM Fields and Their Professionals

Although stereotypes may not provide the most accurate representation of STEM fields, they can nevertheless greatly influence one’s perception of STEM fields, especially if one does not have much experience with STEM fields or does not personally know a professional working in STEM. Computer science and engineering classes are not required in high school. These classes are usually not even available at most schools in the US. Therefore, the majority of American public high school students graduate without having taken any of these classes (Department of Education, 2009). For these students then, the stereotypes they are exposed to may be the dominant, if not the sole, source of information and knowledge about computer science and engineering (Stephenson et al., 2005). For example, a 2014 survey of 1600 students conducted by Google suggests that young women, who are unfamiliar with the field of computer science, struggle with imagining the possible applications of the field beyond what they see in the media (Google, 2014).

In 1957, two renowned female cultural anthropologists, Margaret Mead and Rhoda Métraux, asked high school students to write a brief essay on their impressions of a scientist and found that the commonly shared impression was a man who wears a white lab coat and glasses and works in a laboratory (Mead and Metraux, 1957). Even after six decades, the pervasive stereotype of a scientist remains very similar, and studies show that both adults and students of both genders embrace this stereotype (Schibeci, 1986; Barman, 1999).

Mahzarin Banaji, a social ethics professor at Harvard; Anthony Greenwald, a psychology professor at the University of Washington; and Brian Nosek, a psychology professor at the University of Virginia, are renowned for having created a virtual tool called the implicit association test (IAT), which measures unconscious associations between two concepts in
people’s minds. The gender-science IAT, in particular, attempts to elucidate whether participants implicitly associate the fields of science and liberal arts with one gender more strongly than another. Since 1998 when this test was created, more than a half million people have taken the test. Of these people, more than 70% were more likely to associate the male gender with science and female gender with liberal arts than the reverse. These unconscious associations held true even for those test takers who explicitly denied these gender stereotypes (Nosek et al., 2002a).

Gender stereotypes wield significant power particularly for STEM fields with relatively severe gender imbalance such as computer science, engineering and mathematics (Nosek et al., 2002b). When people think of computer scientists and engineers, they envision a White, socially awkward, “geeky” male who spends much of his time glued to his computer (Mercier et al., 2006). Physical traits such as glasses or pale skin are also often associated with the stereotype (Cheryan, 2016). A significant majority of surveyed high school and college students described computer scientists with at least one of these stereotypes: technology-oriented, singularly focused on technology, lacks interpersonal skills, masculine, intelligent, wearing glasses or having pale skin (Cheryan S., 2016). Interviews of college students also reveal their impressions of a computer scientist to be “the myopic, narrowly focused, young male who sits at his computer all day” and of college computer science department to be “the department with the really smart students” (Fisher et al., 1997).

An additional stereotype regarding the nature of the work entailed in computer science also deters women away from the field. A career in computer science tends to be viewed as solitary and having less societal impact. Many people equate computer science to programming and are unaware of the broader social implications and applications computing can have. One
survey of college students revealed that students of both genders view STEM careers as detached from communal goals and less likely to help or care for others compared to careers in medicine or law (Diekman et al., 2010).

Such perceptions of STEM careers can dissuade women from pursuing these careers, for studies suggest that women are more likely than men to choose a career that is interactional and helps people (Lippa, 1998). It is no coincidence that there is a fairer gender balance in STEM fields that, on the surface, seem to be associated with helping others such as medicine or psychological sciences than STEM fields such as computer science or math (Diekman et al., 2010). Even among undergraduate students majoring in computer science, female students describe their appeal to their major as potentially “what they can do in the world” with computers and being able to use computers “as a tool to use within a broader context of education, medicine, communication, art and music” (Fisher et al., 1997). This contrasts starkly with the male computer science majors who describe their fascination with computers as an “alluring object” and the “ultimate toy” (Fisher et al., 1997).

b. Stereotypes of Women in STEM Fields

There also exists a stereotype of women who are competent and skilled at STEM, and that stereotypical woman is neither ‘cool’ nor considered attractive by the opposite sex. The stereotypical image therefore clashes with women’s desire to be ‘feminine’ and romantically desirable (Pollack, 2013). Many adolescent girls, who are particularly image-conscious, stay away from STEM fields in fear of being labeled unfeminine.

The stereotype is prevalent in the society. The media preys on it: in Mean Girls (2004), a popular teen comedy movie that centered around the ‘cool’ high school girls and their social
cliques, the female protagonist played by Lindsay Lohan pretends to be bad at math so that she can get closer to and flirt with one of the school’s most popular boys. Some women feel embarrassed to admit to others that they study or work in STEM. A female undergraduate at Yale University claims she does not like her sister introducing her as an astrophysics major to boys: “I kick her under the table. I hate when people in a bar or at a party find out I’m majoring in physics. The minute they find out, I can see the guys turn away” (Pollack, 2013). The American Mathematical Society also reports that girls avoid participating in math clubs and competitions because doing math for fun can result in “social ostracism” (Pollack, 2013). Experimental studies have also shown female college students to intentionally underperform on STEM tests in order to be considered desirable by the opposite sex (Park et al., 2015).

c. Sources of STEM-Related Stereotypes

The Media: How are these various STEM-related stereotypes created and propagated across the society? People become exposed to STEM-related stereotypes through various channels from their environment, including the popular culture, families, friends, schools and neighbors. As hinted above, the media is also thought to have greatly contributed to the rise of these stereotypes. For high school students, television and films are surveyed to be their “primary source of information” for their impressions of a scientist (Steinke et al., 2007). Indeed, popular TV shows and films such as Weird Science, Revenge of the Nerds, War Games, Real Genius, The Big Bang Theory, and Silicon Valley often feature brainy White male scientists and engineers as their protagonists. These characters often have a difficult time interacting with others and beautiful women in particular but are able to overcome various challenges using their computers.
People who watch these shows and films are very much receptive to and aware of these character portrayals. In a recent survey of over 1600 seventh to twelfth grade students and their parents, the participants were provided a list of 6 traits – White, Black or African-American, Hispanic/Latino, Asian, Women and wearing glasses – and asked how frequently they see a computer scientist in movies or films exhibit each trait. At least half of the students and parents most often saw a White male wearing glasses playing the role of a computer scientist. The next predominant trait was an Asian male. A mere 15% of students and 8% of parents reported most often seeing a woman playing the role of a computer scientist (Google, 2015).

**Toys:** The perception that science is for boys can become implanted in children’s minds from very early on, as early as when children first start to play with toys. The social norm dictates that boys play with building blocks, robots and video games while girls are to play with Barbies and stuffed animals. The toy industry is also partly to blame for how gendered toys have become. For many decades, the industry has marketed different categories of toys for different gender, contributing to the divisive notion that there are certain things reserved for boys but not girls and vice versa (Weale, 2016). One research institution, after examining leading searching engines and toy retailers’ websites including Google, Yahoo, Bing and Amazon, recently found that toys with STEM characteristics were 3 times as likely to be targeted at boys than girls (Institution of Engineering and Technology, 2016).

Gendered toys can effectively give boys a head start in STEM compared to girls. Because boys are exposed to science and engineering-related tools, devices and machines earlier than girls, boys’ interest in and curiosity about STEM fields can arise and develop faster. Studies also indicate that by playing with these toys, boys also pick up a foundation of skills required for STEM fields such as spatial and logical reasoning skills (Gold et al., 2018).
In one study, the authors gave a spatial reasoning test to 345 undergraduates at University of Colorado Boulder and found that the students, who had played with action-oriented video games or construction games (such as Legos and blocks) in childhood, scored significantly higher on the test than the students who had not (Gold et al., 2018). A gender gap in spatial skills was also found with males outperforming females, but when the authors controlled for childhood play patterns, the gender gap disappeared. In other words, males and females, who played with video games and construction toys in similar manners when they were young, performed similarly well on the spatial reasoning test. There exists much literature debating whether there exists a gender difference in spatial reasoning and if so, whether the underlying explanation for the gender difference is biological or sociocultural. However, studies such as Gold et al. (2018) indicate that gender differences found in spatial reasoning may be due to differences in childhood toys and play that the society imposes on boys versus girls.

In another study, children who played with puzzles between 26 and 46 months of age were later found to have greater spatial skills at 54 months of age than those who did not, controlling for differences in parents' education, income, etc. (Levine et al., 2012). Although puzzles are not as gendered a toy as video games or building blocks – demonstrated by the fact that there were no differences in the frequency of puzzle play across gender, – the study found that boys played with more complex and difficult puzzles than girls and therefore outperformed girls in spatial reasoning skills.

Not only is spatial reasoning essential for everyday activities, spatial competence during childhood has also been linked to greater success in STEM disciplines in kindergarten and primary school (Kris, 2017). One study found a link between spatial skills and mathematical skills in three-year-olds (Verdine et al., 2014b). Another longitudinal study found spatial skills
at age three to predict math performance into kindergarten (Farmer et al., 2013). Gendered toys such as building blocks and video games can therefore give boys an advantage in spatial skills compared to girls, which in turn translate to a head start in STEM at the start of formal elementary education, a critical juncture in the STEM pipeline.

A rich amount of literature has also demonstrated the importance of spatial reasoning skills in success in STEM fields later on in one’s life. Because spatial reasoning skills are relevant to and necessary for various STEM fields such as mathematics, chemistry, biology, physics and geology, deficient spatial reasoning skills are thought to serve as a “gatekeeper” to STEM careers (Uttal and Cohen, 2012). Spatial skills have also been found to predict who will pursue STEM careers. Figure II.1 below demonstrates a correlation between higher spatial competence and STEM occupations. The figure provides on the x-axis, average standardized spatial scores of individuals from when they were in grades 9-12 and on the y-axis, their occupations revealed by a 11-year-follow-up.

Figure II.1: Spatial scores in high school students and their occupations at 11-year-follow-up (Verdine et al., 2014a)
Are children aware of how gendered their toys are and the gender stereotypes that these toys reinforce? Research shows that children begin to form gender stereotypes very early on and that these stereotypes can play a significant role in shaping children’s interests. Many 18-month old children recognize their own gender as well as other people’s, and the children who do so are more likely to play with toys associated with their gender such as trucks versus dolls (Zosuls et al., 2009). Around age 3, children begin to develop basic gender stereotypes, associating certain roles, toys and abstract associations (such as hardness as male; softness as female) with each gender. As they grow older, these stereotypes broaden to include associations such as sports, occupations and adult roles (Martin and Ruble, 2010).

In order to protect girls from these negative gender stereotypes regarding STEM, it is important to reach girls when they are young and before they become aware of such stereotypes. Toys can also be used to expand the notion of who belongs in STEM and inspire more young girls to pursue STEM. Recently, there has been many other developments to combat gender stereotypes in the context of toys or to use marketing of toys to change girls’ perceptions about STEM fields. Major retailers in the toys industry such as Target, Amazon and Toys R Us have gotten rid of gender labels or gender specific designations for their merchandises (Addady, 2015). An increasing number of STEM toys are being marketed for girls as well as boys (Fenn, 2015), and STEM toy companies such as GoldieBlox and Roominate that mainly target girls have also seen great success. GoldieBlox, for example, was founded in 2012 by a female Stanford University engineering graduate with the intention of “disrupting the pink aisle” and encouraging more young girls to become engineers (Sterling, 2016). Each GoldieBlox kit comes with a construction set and a storybook starring Goldie, a young girl inventor who undergoes various adventures and solves problems by coming up with creative solutions and building
machines. GoldieBlox has been very successful, winning various awards and recognitions, including being the first start up to have an advertisement air on Super Bowl.

**Personal Computers**: Marketing of personal computers, akin to the marketing of toys, has also helped entrench the gender science stereotype. As Figure II.2 below demonstrates, the share of women in fields such as medicine, law and physical sciences has been on a constant rise since the 70s. However, in computer science, the percentage of women has peaked at around 37% in 1984, only to continue decreasing. Currently, women constitute less than 20% of computer science. What could be responsible for reversing the increasing trend in women’s representation in computer science?

![% Of Women Majors, By Field](image)

*Figure II.2: Percentages of women majors by field from 1970 to 2010 (Henn, 2014 from NPR.org)*

Many believe that marketing of personal computers may help explain the decline in women’s representation in computer science. It was in the 1980s that American families, in
significant numbers, began to purchase personal computers for use in homes. These first computers included TRS-80 Micro Computer System, Commodore 64 and the Apple II series. However, these computers were marketed targeting men and boys. Advertisements also contained mostly men and boys using the computers. A good example is an old Apple II advertisement from 1985 that features a boy named Brian Scott who learns to use an Apple computer for his science studies. As Brian works on an Apple computer in a classroom, in the meantime pulling a prank on a female classmate by playing with her computer, a male announcer’s voice narrates, “This morning, Brian Scott made a career decision. He decided to be an astronaut. ... [W]hatever Brian wants to be, an Apple personal computer can help him be it” (YouTube, 1985).

Perhaps swayed by these marketing tactics, American families in the 80s and 90s were more likely to put their newly purchased personal computers in their sons’ rooms rather than their daughters’ (Smith, 2014). Interviews of computer science majors at Carnegie Mellon University (CMU) also confirm these tendencies. A great majority of the male students had their own computer or had the family computer placed in their room when growing up. In contrast, only 1 out of 7 females had her own computer (Fisher et al., 1997). The female students also tended to describe their experiences with the computers as not active but rather passive such as “watching their dad work at the computer, or having their older brother show them how he programs the machine” (Fisher et al., 1997). Studies also indicate that men were more likely than women to exercise control over the decision whether or not to purchase a computer for their home (Levin et al., 1993).

Personal computers from this time, not being very sophisticated, were frequently used for playing games. By mostly targeting boys, the game industry also contributed to the stereotype
that games, and by extension, computers are for boys (Henn, 2014). One of the first handheld consoles, Game Boy, which was released in 1989 and garnered huge success internationally, noticeably contains the word ‘boy,’ the gender the game industry was targeting (Andrews, 2017). Also, female characters did not appear in these earlier games, and when they did, they were represented in a sexist way (Kendall, 2017).

These circumstances all likely contributed to the decline in women’s representation in computer science beginning around 1984. By 1985, a report on the everyday usage of home computers revealed that men were much more likely than women to use a computer on a weekly basis and to use it for more hours (Riccobono, 1986). Beginning around 1990, the share of women in computer science dipped below 30%, as demonstrated in Figure II.2 above, and currently, less than 20% of computer science majors at the bachelor level are women (National Science Board, 2018).

Because boys are exposed to computers earlier than girls and have been honing their computer skills for years, a gender gap in previous experience with computers is often found by the time students enroll in computer science classes at the secondary or post-secondary level (Shashaani, 1994; Fisher et al., 1997). Male students tend to be comfortable with the course material — sometimes enough to place out and move up to advanced classes — while many female students are learning the material for the first time. Concerned that they are unable to catch up with the male students, many female students can feel anxious and discouraged from pursuing even more advanced classes.

The gap in experience with computers manifests itself in various statistics and facts. High school computer science classes contain more boys than girls, with the difference greater for more advanced classes (Fisher et al., 1997). In 2014, which is the most recent year with
gender data available on Advanced Placement (AP) exam takers, 81% of computer science A AP exam takers were males and only 19%, females (College Board, 2014); in Mississippi, Montana and Wyoming, not a single female high school student took the AP Computer Science exam that year (ComputerScience.org, 2018). Finally, interviews with first-year undergraduates studying computer science at CMU revealed that 40% of the male students had passed the AP exam, therefore placing out of the university’s introductory level class while no first-year female placed out (Fisher et al., 1997).

Several colleges and universities have recognized how intimidating and discouraging the gap in previous experience with computers can be on those that fall on the less experienced end. In response, schools such as Harvey Mudd and Carnegie Mellon have created introductory computer science classes that are specifically designed for students without any programming experience, an approach which has increased the number of female students studying the subject (Margolis and Fisher, 2002).

Considering that many high schools do not offer computer science, increasing girls’ exposure to computer science through extracurricular activities may help girls start on a more equal footing with boys once they reach the post-secondary level. There has been a huge proliferation in the number of non-profit organizations whose goal is to encourage young girls to try computer science and equip them with computing skills. These organizations include Girls Who Code, Code First: Girls, Black Girls Code and Ladies Learning Code, to list a few. According to the organization Girls Who Code, one of the biggest leaks in the computer science pipeline for girls is between the ages of 13-17 (Girls Who Code, 2018). The organization therefore targets various after-school clubs and summer courses at girls between these ages. Since its establishment in 2012, Girls Who Code has grown quickly and has taught almost 90,000 girls in all 50 states.
According to the organization's annual report for 2017, the organization's alumnae have gone onto major in computer science or a related field at a rate that is 15 times greater than the national average (Girls Who Code, 2018).

**Parents and Teachers:** Parents and teachers can also greatly influence students' interests and identities throughout students' lives. It is indeed natural for students to seek out their parents' and teachers' advice or rely on them for any challenges that may surface in the road. However, an increasing body of research shows that parents and teachers unconsciously adopt gender stereotypes affiliated with STEM fields. Parents and teachers also express different expectations of success in STEM subjects to boys versus girls.

According to a recent survey of over 1600 parents and 1000 teachers of 7th to 12th grade students, parents and teachers were more likely to believe that boys would be more interested in learning computer science than girls. Parents and teachers were also more likely to believe that boys would be more successful in learning computer science than girls (Google, 2015). Another survey of 770 parents of children between ages 11 and 16 revealed that parents of boys were more likely than parents of girls to believe that a career in STEM would be appropriate for their children. When asked which of the career opportunities would be a good career choice for their children, 18% of boys' parents chose STEM, in contrast to 9% of girls' parents. The gender disparity was more severe for engineering: 11% of boys' parents chose engineering compared to only 1% of girls' parents (Davidson, 2014). Girls' parents believed that their daughters would enjoy fields such as education, childcare, art, healthcare and hair and beauty more than they would enjoy (Austin-Morgan, 2015).

In Lavy and Sand (2015), sixth graders were given math exams, and the exams were graded by two sets of teachers: one set of teachers who were these students' classroom teachers...
and therefore knew the students well and another set of external graders who did not know anything about these children including their genders. Results showed that compared to the external graders, the classroom teachers tended to give higher scores to boys and lower scores to girls, suggesting that classroom teachers were exhibiting a gender bias in assigning grades (Lavy and Sand, 2015). Such discrepancy between classroom teachers and external graders was not found for other subjects. Lavy and Sand then tracked these students till their final year of high school and found that boys went on to enroll in more advanced STEM classes than girls.

Studies also show that some teachers unconsciously communicate different cues – verbally and nonverbally -- to boys and girls regarding their STEM abilities (Powell et al., 2013). To male students, teachers tend to convey subtle ‘affirmations’ of the students’ STEM skills, implying that the students belong in this environment and are doing well. On the other hand, teachers tend to convey subtle ‘aggressions’ to female students, implying that the students do not belong in this environment or that they are performing poorly (Sparks, 2015; Smith, 2017).

In sum, many parents and teachers are vulnerable to influences of various gender STEM stereotype such as that boys are better than girls at STEM or that STEM is for boys not girls. These beliefs or biases can fail to provide an environment where girls feel encouraged to broaden their interests or career search beyond the traditionally feminine fields. As a result, female students may believe that they are not good at STEM and become discouraged to pursue it further.

d. Negative Effects of Masculine Stereotypes in STEM Fields

As a result of these channels proliferating and disseminating the narrative that STEM = male and men are better than women at STEM, these stereotypes have become firmly rooted
within the society. A countless number of studies and surveys show that both genders of all age groups and races embrace it (Schibeci, 1986; Barman, 1999; Finson, 2003; Nosek et al., 2009). As discussed above, these stereotypes can conflict with women’s desire to be feminine and romantically desirable and therefore deter them from pursuing further studies or careers in STEM. Gender STEM stereotypes also make women feel like they do not belong in STEM environments. Here, a ‘sense of belonging’ refers to a feeling or intuition that one would fit in the environment with its members, components and culture (Master et al., 2016). A sense of belonging is thought to be a fundamental human need, and in the context of academic environments, it has been shown to help students feel at ease and increase their motivation to learn, resulting in superior performance (Master, et al., 2016; Feldman et al., 2018). Because women grow up all their lives, exposed to masculine cues of STEM fields and conditioned to think that STEM fields are for males, women are less likely to feel a sense of fit or belonging in STEM environments. As a result, women express less interest in STEM fields and are less likely to pursue or persevere in STEM (Cheryan et al., 2009).

Experimental studies have demonstrated a sense of belonging to be a significant predictor women’s interest in and pursuit of STEM fields (Master et al., 2016). For example, stereotypically masculine objects commonly found in computer science classrooms such as Star Trek posters, video games boxes, junk food and technical magazines are sufficient to act as triggers and lower female students’ interest in computer science. Even simple interventions such as filling classrooms with objects less stereotypical of computer science – such as nature posters, art, healthy snacks and general interest books – have shown to foster female students’ interest in computer science to similar levels as male students’ (Cheryan et al., 2009).
Gender STEM stereotypes also impair women’s performance in STEM fields through a phenomenon called ‘stereotype threat.’ Stereotype threat refers to the phenomenon “when individuals know others expect people of their social category (e.g., women, African-Americans) to do relatively poorly on a task, [and] this knowledge creates anxiety and actually leads to poorer performances” (Correll, 2001). Stereotype threat arises because people are afraid that their performances will confirm the negative stereotypes about their social category’s competence or intellect.

Since Claude Steele and Joshua Aronson coined the term in the 90s, over 300 studies have corroborated the phenomenon with women and African-Americans, particularly in surroundings where they are minorities (Hill et al., 2010). Many women are well aware of the society’s general view that men are better than women at STEM and can therefore fear of being judged by that standard. A case in point is Spencer et al. (1999) where female undergraduates performed significantly inferior to their male peers on a math exam when the students were told before the exam that the exam had, in the past, revealed a gender gap with males outperforming females (Spencer et al., 1999). As Figure II.3 below demonstrates, a significant difference in performance existed for the stereotype threat group. However, in the ‘no stereotype threat’ group of students who received no such information about the gender gap, female students performed just as well as males. The female and male students had been picked to have similarly strong math backgrounds.
Stereotype threat is thought to surface especially in stressful environments; many scholars claim that the phenomenon partly explains why female students obtain superior grades in STEM classes at school compared to their male peers but sometimes score lower on more high-stakes and high-stress exams such as SAT Math and AP exams. Even the more competent and talented female students have been shown vulnerable to the phenomenon. (Hill et al., 2010).
III. The Gender Confidence Gap in STEM

The gender confidence gap refers to the tendency of women to lack confidence and underestimate their competence or worth compared to men. The phenomenon emerged repeatedly throughout my research of underrepresentation of women in STEM. Women at all stages throughout their lives – from young girls in primary school to working professionals – were expressing doubts in their STEM abilities or intelligence and choosing to believe that they did not have the skills to continue on the STEM trajectory. The most troubling aspect was that women were in reality just as capable and proficient as men, if not more; actual performance measures often showed that these women’s self-doubts were unfounded. Such gender confidence gap contributes to and aggravates underrepresentation of women in STEM fields at every point throughout a woman’s educational and vocational timeline. However, before this thesis dives into demonstrating the existence and the effects of such a confidence gap in STEM fields, it is worthwhile to note the ubiquity of confidence gap in fields other than STEM and its resulting consequences.

The gender confidence gap can be found in business, politics or every field and for various human traits and attributes. For example, women are less likely than men to speak up and share their opinions. (Detert et al., 2010; Degges-White, 2017). Women do not feel as comfortable self-promoting themselves (Chira, 2017). Women are less likely to believe that they deserve to be promoted (Kay and Shipman, 2014). Women underestimate their worth and are less likely to negotiate for their wages than men (Babcock et al., 2003). Women tend to give credit to luck for their achievements while men tend to give credit for their achievements to their abilities. But when things go badly, women will blame themselves, while men will blame it on bad luck (Bradshaw, 2011; Center for Creative Leadership, 2018). Relatedly, women are more
likely to apologize than men (Schumann and Ross, 2010). Women also tend to preface their opinions or suggestions with qualifiers such as “I’m not sure what you think, but,” “I’m no expert, but,” “Sorry, but” or “What if we tried” (Wilding, 2016). On the whole, these examples show that many women tend to hold a poor view of themselves and that they don’t believe their ideas are worth sharing. In fact, women are apologetic about sharing them. Many women also fear being wrong and appearing all-knowing or arrogant.

Even powerful women seem to suffer from some degree of insecurity and lack of self-confidence. Sheryl Sandberg, chief operating officer of Facebook and author of the famous book *Lean In*, which discusses the dearth of women in various leadership positions, claims, “There are still days I wake up feeling like a fraud, not sure I should be where I am” (Hannon, 2014). Clara Shih, one of the few women CEOs in Silicon Valley and one of Fortune’s Most Powerful Women Entrepreneurs of 2011, claims she felt like an ‘imposter’ as an undergraduate student at Stanford University, although she finished with the highest GPA among the computer science majors (Kay and Shipman, 2014). These feelings of self-doubt are echoed in interviews with dozens of other successful and accomplished women (Kay and Shipman, 2014).

The gender confidence gap is significant and worthy of our attention because it, in turn, contributes to other types of gender gaps. One, the gender confidence gap exacerbates the underrepresentation of women in fields where women are a minority, such as STEM fields. When placed in environments consisting mostly of men, women are likely to feel isolated and therefore even less confident and “like a fraud” (Goudreau, 2011; Frenkel, 2012).

Second, the gender confidence gap also contributes to the diminishing representation of women as they move up the career ladder. Some psychology scholars claim that confidence can be just as important as competence when it comes to propelling one’s career. Confident people
exhibit other nonverbal and verbal cues such as “expansive body language, a lower vocal tone, and a tendency to speak early and often in a calm, relaxed manner” (Kay and Shipman, 2014). Confident people are more likely to be liked and admired by others regardless of their actual competence. As a result, incompetent but confident people are often promoted over their competent but less confident peers (Furness, 2012). In addition, according to an internal report by Hewlett Packard, while male employees applied for promotions even if they believed they met 60% of the criteria listed, female employees applied only if they believed they met 100% of the criteria (Kay and Shipman, 2014). Because women lack confidence in their abilities and speak up less compared to men, women receive less opportunities and lack visibility at the workplace.

Finally, the gender confidence gap is partially responsible for the wage difference across gender. The commonly quoted statistic on the gender pay gap in the US is that women earn 77 cents per male dollar (DeNavas-Walt et al., 2013). One explanation for the pay gap is that women tend to accept the amount of salary offered by their employers and negotiate less frequently than men do. When women choose to negotiate, they ask for an amount that is 30% less than what men would ask for, according to one study (Babcock et al., 2003; Kay and Shipman, 2014). Another study revealed that a significant percentage of women cite lack of confidence for why they do not attempt negotiation (Enwemeka, 2017). These differences across gender can accrue to almost 2 million dollars in lost earnings throughout their careers (Sankar, 2017). In order to fully close the gender gap, the gender confidence gap needs to be addressed and bridged.
a. What Gives Rise to the Gender Confidence Gap?

Many explanations, ranging from biological traits to various sociocultural factors, have been proposed as the underlying cause of the gender confidence gap. Some scholars claim that testosterone may be the culprit: men have more testosterone than women, and testosterone can give rise to increased confidence and more risk-taking behaviors (Huston, 2017). Studies such as Bleidorn et al. (2016), which purport to have found a gender confidence gap in as many as 48 nations worldwide, suggest that lack of self-confidence is a common trait for all women worldwide and therefore nature rather than nurture may be at play (Bleidorn et al., 2016).

On the other hand, the same study also found differences in the magnitudes of the gender confidence gap across different nations. Such a finding then indicates that social and cultural norms unique to each nation may also be responsible for the gender confidence gap. For example, a double standard exists in many societies such that women, who are indeed confident and who speak up their minds, are deemed unattractive or bossy. Such norms can then discourage a woman from embracing confidence, in fear that she may be called a “nasty woman.” Women’s relative lack of confidence also makes sense historically, given that for thousands of years, women’s roles in the society were defined and constrained by men.

The various gender stereotypes and pervasive cultural cues that exist in STEM fields, which were discussed in the previous chapter, are also thought to give rise to the gender confidence gap regarding STEM skills.

b. Demonstration of the Gender Confidence Gap in STEM

Several studies have shown the gender confidence gap regarding STEM abilities to exist as early elementary school. According to Herbert and Stipek (2005), third-grade girls’ self-
assessments of their mathematical abilities are lower than boys’ although their actual math performances do not differ (Herbert and Stipek, 2005). Girls at all grade levels in primary school, more so than boys, tend to experience math anxiety, “an extremely debilitating fear of mathematics,” and even the most talented girls are vulnerable to it (Franklin, 1990). These findings are not surprising, considering that children have shown to become aware of negative gender stereotypes as early as second grade and that these stereotypes in turn affect females’ perceptions of their abilities.

One particular point in time that many scholars have focused on is 10th grade or high school sophomore. This is because it is an important milestone for STEM education and career paths, for students are given the choice to enroll in advanced math and science classes if they would like. Therefore, 10th grade can be a clear crossroad in that students have to start making decisions that can affect their career trajectories. Data show that enrolling in upper-level math and science classes during high school increases students’ odds of pursuing a postsecondary STEM major (Riegle-Crumb et al., 2012). This, in turn, increases the odds of commencing a STEM career. Because most STEM careers require STEM degrees and most STEM degrees demand students to go through defined curricula, it becomes increasingly difficult to aspire to a STEM career after starting college, if a student has not taken upper-level STEM classes during high school.

10th grade carries additional significance, for the high school years beginning with 10th grade and the early college years are well-known as large leaks for the STEM pipeline. Many scholars have documented a substantial outflow of students (including female students) from STEM fields during these years (Girls Who Code, 2018).
One study examined 16,200 high school sophomores’ responses to how much they agreed with statements such as “I’m certain I can understand the most difficult material presented in math texts,” “I’m confident I can understand the most complex material presented by my math teacher,” and “I’m certain I can master the skills being taught in my math class” (Perez-Felkner et al., 2017).

The results revealed a significant difference between male 10th graders’ and female 10th graders’ perception of their mathematical abilities. Overall, males exhibited a significantly higher perception of their math competency compared to females. Interestingly, even among the most mathematically capable students, i.e. male and female students who scored in the 90th percentile, females held less confidence than males. In fact, females in the 90th percentile bucket exhibited only as much confidence as males who scored in the 70th percentile (Perez-Felkner et al., 2017).

The gender confidence gap in STEM fields at the postsecondary level has been recently corroborated by an online Q&A platform called Piazza. Used by over 700,000 students from 1,000 schools per year, the platform is increasingly becoming a popular choice for college and graduate school STEM classes across the country. The platform allows students to post questions and answer each other’s questions using their names or anonymously. The platform also allows teaching assistants and professors to endorse, comment on, or correct these answers. The option to post anonymously was put in place to encourage participation from the less confident students, who would be reluctant to raise hands and speak up in class even though they have important questions or insights to share. According to Poola Sankar, the CEO of Piazza, “shy students, particularly women, really appreciate … the ability to ask and answer anonymously” (Wasserman, 2015).
A review of user activity of almost 1 million college and graduate school students confirmed that female STEM students indeed lack confidence compared to male STEM students. This confidence gap was demonstrated by two differences in user behavior across gender: within STEM classes, women tended to answer fewer questions than men, and women were more likely to post anonymously (Marketwired, 2015; Sankar et al., 2016). Specifically, women STEM students answered 18% fewer questions than men, and women STEM students posted anonymously 39% of the time while men posted anonymously only 22% of the time (a 11% difference). These differences in user behavior were greater for computer science classes than other STEM classes, perhaps implying a larger confidence gap in computer science: women CS students answered 37% fewer questions than men, and women CS students posted anonymously 35% of the time while men posted anonymously only 22% of the time (a 13% difference). These gender differences in user behavior were more prominent for STEM classes compared to other departments such as humanities, business and social sciences, prompting Piazza to conclude that the gap seemed to be a “purely STEM phenomenon” (Sankar et al., 2016).

c. Negative Effects of the Gender Confidence Gap in STEM

How then does the gender confidence gap manifest? How does it contribute to or aggravate the gender imbalance observed in STEM fields? One can expect self-confidence to have many cascading consequences on one’s goals, motivation and career plans: a confident person is more likely to be motivated and engaged and to set higher goals for oneself; a confident person is also likely to persevere and carry on in the face of adversity or a failure; and one usually needs to feel confident in the skills necessary for a certain career path to want to pursue that path. By closely tracking high school students throughout their high school and
postsecondary years, several studies have also detailed how confidence affects the various
decisions students make in the STEM trajectory, from pursuing STEM-related opportunities,
enrolling in advanced optional STEM classes to choosing a STEM major. The gender
confidence gap therefore disadvantages women at every critical gateway to the STEM path.

**Pursuit of STEM-related opportunities and challenges:** Confidence in one’s STEM
skills or competence has been shown to significantly impact whether she would pursue various
STEM-related opportunities. By underestimating their STEM capabilities, many women choose
to miss their windows of opportunity and steer away from STEM even though they are just as
competent as their male colleagues or competitors.

Ehrlinger and Dunning surveyed undergraduate students of both genders at Cornell
University regarding their perceptions of their scientific abilities (Ehrlinger and Dunning, 2003).
The students then took a test comprised of 10 scientific reasoning questions and were asked to
estimate their performance on the test by providing both their raw score and percentile ranks.
Finally, without being told the results of the test, the students were invited to a science
competition and were asked whether they would be interested in participating in it.

Although both genders performed very similarly on the test (women and men
respectively answered 7.5 and 7.9 questions correctly out of 10), arguably demonstrating similar
levels of scientific competence, the surveys showed that female students were less assured than
male students about both their scientific reasoning ability as well as expected test performance.
On a scale ranging from 1 to 9, women self-evaluated their scientific reasoning ability to be 6.5,
while men estimated 7.6. Women also estimated their test performance to be around average
while men estimated themselves to be above average.
The lack of self-confidence also affected women’s willingness to try out for the scientific competition. While 71% of the male students expressed interest in signing up for the competition, less than half of the female students expressed interest. Logistic regression analyses revealed that signing up for the competition was linked to the students’ perception of their performance on the test rather than their actual performance (Ehrlinger and Dunning, 2003). The gender confidence gap thus prevented women from recognizing and seizing various STEM-related opportunities.

Enrolling in advanced STEM classes in high school: Confidence in one’s mathematical ability has also been shown to be a significant predictor of whether a student will take advanced science classes in high school (Nix et al., 2015). More than 17,000 10th graders were surveyed regarding their perception of ability to overcome challenges in math. Results revealed a gender difference with male students rating themselves as significantly more confident.

The students were tracked for several years, and data were collected regarding the most advanced science courses they enrolled during high school. The courses were categorized into three groups: (1) Chemistry I or Physics I or less, (2) both Chemistry I and Physics I, and (3) Chemistry II and Physics II. With all else being equal, female students were 24% less likely to take Chemistry II and Physics II – the most advanced science classes offered at the secondary level – than male students. And students’ perception of their math ability in 10th grade was found to be a significant predictor of completion of these classes.

Majoring in STEM at the college or university level: A female student’s degree of confidence in her mathematical skills also affects whether she would choose to major in STEM. In fact, students’ self-assessments were found to be a stronger predictor of STEM major choice than their objective abilities (Nix et al., 2015).
In Correll (2001), around 10,000 high school sophomores from over 1,000 schools were given a math test and surveyed regarding their assessment of their own math skills (Correll, 2001). The students were tracked for several years afterwards, to see whether they had enrolled in calculus by their senior year of high school and which major they chose two years post-high school. Calculus enrollment was checked because calculus is not a required class during high school and thus reflects student’s interest in pursuing a STEM path, for calculus is a required class for most STEM majors at the college or university level. Therefore, students’ decision to enroll in calculus during high school “represents a choice that students make and one that has occupational consequences” in the STEM fields (Correll, 2001). Data from this study also showed that female students who took calculus in high school were 3.22 times more likely to choose a quantitative major than females who did not. A quantitative major was defined in the study to include all engineering majors, chemistry, physics, other physical sciences, computer programming, statistics and mathematics (Correll, 2001).

Although both genders obtained similar scores on the math test as high school sophomores, male students expressed more confidence in their math skills than female students. The greater confidence, in turn, affected the students’ likelihood of enrolling in calculus as well as choosing a quantitative major. Controlling for students’ mathematical abilities, male students were 1.23 times more likely than females to take calculus by their senior year of high school and 3.86 times more likely to choose a quantitative major by year two post-high school. A higher self-assessment of one’s mathematical abilities can then increase the odds of choosing a STEM major or enrolling in classes that guide the student towards the path for a career in STEM.

**Persisting in STEM:** Many scholars have suggested that a student’s perception of her abilities can affect her persistence or perseverance in the face of a difficult or challenging
situation (Nix et al., 2015). Females’ lower confidence contributes to a greater female attrition rate at the college or university level, as females abandon STEM majors when they come across a challenging and difficult class as part of their required STEM coursework.

Introductory calculus or Calculus I class at the college or university level is a good example. The class is a requirement for most STEM majors and thus a gateway to STEM careers. Yet, it has long had a notorious reputation for being one of the most difficult classes for many students. Unsurprisingly, it has been shown to be the cause behind many students’ departure from STEM majors (Ellis et al., 2016).

Although there are some STEM majors that do not include Calculus II in their requirements, most STEM majors do. Therefore, students’ intentions to continue onto Calculus II after Calculus I can be thought as intentions to persist in the STEM path. College or university students who were enrolled in Calculus I were surveyed at the beginning as well as the end of the semester regarding their intention to continue onto Calculus II. Of the 4,868 students that had originally planned to continue onto Calculus II at the beginning of their Calculus I class, 4,065 students remained as ‘Persisters,’ planning to uphold these intentions even after completing Calculus I. The other 803 students, or ‘Switchers,’ no longer wished to continue onto Calculus II. These Switchers’ reversal of intentions can be thought as intentions to effectively leave the STEM path (Ellis et al., 2016).

Data revealed that female students were 1.5 times more likely to leave the STEM path (and not continue onto Calculus II) after taking Calculus I, compared to male students of similar student preparedness, career goals and mode of calculus instruction. Male and female Switchers were also given a list of reasons for not continuing onto Calculus II and asked to select all that they concurred with. While only 14% of male students cited a lack of understanding of Calculus
I as their reason behind ‘switching,’ 35% of female students – more than twice the percentage of males – cited to it. Other potential reasons on the list garnered a similar percentage of male and female Switchers (Ellis et al., 2016). Thus women’s confidence in their math skills serves as an important factor behind their decision to continue with more advanced calculus classes, and therefore the STEM trajectory.

d. Ways to Bridge the Gender Confidence Gap in STEM Fields

Hopefully, it has been demonstrated by now that the gender confidence gap needs to be addressed and reduced in order to increase the representation of women in STEM fields as much as possible. The gender confidence gap is perhaps one of the more frustrating causes of gender imbalance in STEM fields. The gender confidence gap suggests that women are competent at STEM but that women are choosing to disregard what their performance measures indicate about their actual abilities. Instead, these women are choosing to believe that they are incapable and unskilled at STEM. What can then be done to build women’s self-confidence and self-esteem?

The mindset theory, first set forth by Carol Dweck and Ellen Leggett in their seminal research publication in 1988, can be helpful here (Dweck and Leggett, 1988). Now widely accepted by scholars, the theory proposes that people implicitly hold either of the two mindsets – fixed mindset or growth mindset – regarding the extent and malleability of their intelligence. People with the fixed mindset believe that intelligence is fixed, and that people are born with different levels of abilities. Consequently, when a fixed-minded student encounters a challenge such as a difficult assignment or a poor grade on an examination, she puts in less effort to overcome the hurdle and is more likely to show resignation quickly. On the other hand, people with the growth mindset believe that although genetic traits may initially predispose people to
different levels of abilities, intelligence and competence can also be enhanced and cultivated over time. Therefore, a growth-minded student is not discouraged by challenges and is less likely to consider a poor performance on an examination as a reflection of her competence; she is likely to consider them as opportunities to learn from and improve (Feldman et al., 2018).

Encouraging girls to adopt the growth mindset can help with their insecurities and self-doubts by leading them to believe that they can further develop or improve their STEM skills. Gender stereotypes in essence insinuate that women are inferior to men at STEM and that women cannot do STEM, thereby discouraging women from pursuing STEM fields. The growth mindset can then empower women by helping them believe that STEM skills or abilities are not fixed but malleable with effort and practice. The growth mindset therefore can counter the adverse effects of various gender stereotypes and inspire women to persevere in STEM. This is substantiated by one study that tracked hundreds of female students throughout their calculus courses. In the study, females that were identified to have hold the growth mindset were more likely to report that they too belonged in math and that they were planning on enrolling in other math courses, even though they were aware of the negative gender stereotypes surrounding math. In contrast, female students that had the fixed mindset showed greater vulnerability to gender stereotypes, a lower sense of belonging as well as lower interest in taking additional math classes (Good et al., 2007; Dweck, 2008).

Is it then possible for a female to change her mind and adopt different beliefs regarding her intelligence, for example, from a fixed to a growth mindset? Can the society, schools or parents employ measures to help with such transformation? Several scholars claim that it is indeed possible and have suggested a few different methods. Blackwell et al. in 2007 demonstrated a successful example where 7th grade students were asked to participate in 8
weekly sessions, each 25 minutes long, during which the students were taught that intelligence is not fixed but malleable and that students can actively control the learning process (Blackwell et al., 2007). This message was communicated through discussions, activities and scientific readings that contained “vivid analogies (e.g., to muscles becoming stronger) and examples (e.g., of relatively ignorant babies becoming smarter as they learned).” After the end of the 8 sessions, these students were more likely to adopt the growth mindset than fixed and exhibited an increase in their motivation in classes. Their mathematics teachers, who were unaware of whether their students were placed in the experimental or control group, also noted changes in the behaviors of students who were in the experimental group. The experimental group also showed an improvement in their math grades during the course of the study as demonstrated in Figure III.1 below. Seventh grade can be a difficult time as adolescents begin junior high school and therefore need to adjust to a new environment. Many students have shown to stumble academically during this period and suffer a decline in grades such as that exemplified by the control group in Figure III.1. On the other hand, the experimental group of students, who came to embrace the growth mindset of intelligence, began to perform academically better once the intervention or the 8 weekly sessions started.
Figure III.1: Effect of growth mindset on 7th graders’ math performance (Blackwell et al., 2007)

Aronson et al. (2002) were also successful at shaping students’ mindsets to believe that intelligence is malleable and a trait that can be actively developed (Aronson et al., 2002). The authors asked African American undergraduate students at Stanford University to participate in a pen pal relationship with underprivileged middle school students, in an attempt to mentor and encourage these middle school students to overcome various challenges. The undergraduate students were in particular encouraged to emphasize in their letters, the following theme of the malleability of human intelligence: “If these student view intelligence as a fixed quantity, they may feel that they are incapable of learning if they encounter difficulty with their school work. If, however, students can be convinced that intelligence expands with hard work, they may be more likely to remain in school and put effort into learning.” The undergraduate students were however unaware that these middle school students were fictional and that the true purpose of writing the letter was to convince the undergraduate students themselves of the growth mindset. Such exercises were shown to be sufficient for the undergraduate students to adopt the growth mindset. In addition, the experimental group of students reported greater joy regarding their
academic experiences and valued academics more, compared to the control group. Finally, the experimental group obtained higher grades than the control group (Aronson et al., 2002).

As the abovementioned studies demonstrate, the mere act of informing female students of the malleable nature of human intelligence may help reduce the gender confidence gap. The conveyed message may incorporate analogies such as the human brain is “like a muscle” (Dweck, 2008), that as the brain forms new connections, humans become more intelligent and competent; and that humans are in active control of this process. Such communication may persuade female students, who underestimate their STEM abilities, that they can further improve upon their skills to eventually attain the requisite competence or mastery for majoring in STEM or having a STEM career.

Some other approaches that can help empower women and build their self-confidence in STEM fields include: (1) offering more frequent feedbacks to women regarding their STEM abilities, in an attempt to provide them a more accurate and objective assessment of their STEM abilities and bring their perceptions into line; (2) communicating to females how widespread and pervasive the gender confidence gap is, in an attempt to make them realize that their insecurities are not just about themselves; and (3) encouraging women to work with other female colleagues or in small groups that consist mostly of women.
IV. Insights from Cross-National Findings

Several cross-national studies indicate that many other nations have higher representation of women in STEM fields compared to the US. These nations not only have a robust representation of women medicine and biological sciences but also in math, engineering and computer science, STEM fields that the US has a severe gender imbalance in.

For example, a 2008 report published by the American Mathematical Society reviewed the participants’ data from the most prestigious international math competitions and found that the US tends to produce a smaller number of female competitors compared to several other nations. Many of the female students on the US team were also immigrants or children of immigrants and not born in the US (Andreescu et al., 2008). Several Eastern European and Asian countries have sent more females than the US to the International Mathematical Olympiad (IMO), an annual math competition for high school students that has been ongoing since 1959. The US first joined the participation in 1974 and for over two decades, failed to send any female students as its team member. Melanie Wood was the first female to make it on the US team in 1998, and since then only 5 out of 66 students (a mere 8%) on the US team have been females. In contrast, Bulgaria has sent 30 girls to the IMO since the founding of the competition. Russia’s team between 1988 and 1998 also had a relatively higher representation of girls (20%). And countries such as South Korea, which have joined the competition later than the US, have managed to send more female students than the US.

Are there lessons to be learned from these nations that are able to attract more females into STEM fields and retain them throughout the pipeline? Do these nations engage in certain social or educational policies that the US can adopt or emulate? Or what is it about these nations’ culture and philosophy that result in a greater representation of women in STEM fields?
a. Developing nations have higher representations of women in STEM

Interestingly and perhaps counterintuitively, women of developing nations fare better in STEM fields than women of developed nations. A rich amount of statistics and facts demonstrate the meaningful presence and representation women hold in STEM fields in developing nations. Countries such as Kazakhstan, Thailand, Algeria and Albania have some of the highest percentages of women graduating from colleges with STEM degrees (Andreescu et al., 2008; United Nations Educational, Scientific and Cultural Organization, 2017). Mexico and South Africa have the highest percentages of women with computer science degrees at the post-secondary level (Khazan, 2014). According to a study in Nature that performed a global analysis of recently published scientific papers, South American and Eastern European countries had the greatest gender parity in terms of female authorship (Lariviè re et al., 2013).

In 2010, Jordanian women composed around 30% of all registered engineers in the Jordan Engineers Association and 40% of undergraduate students majoring in engineering at Jordan’s two largest universities, the University of Jordan and Jordan University of Science and Technology (Abu Lail et al., 2012). In Malaysia, the gender ratio among engineering students at higher education institutes is almost 50:50. And according to a survey of engineering students at the Universiti Teknologi Petronas, a renowned private university in Perak, Malaysia, 90% of Malaysian female students claim engineering to be a suitable career for women (Abu Lail et al., 2012). In China, women are an integral part of the country’s tech industry. 80% of Chinese tech companies have women in the C-level suite, and 61% of these companies also have women among their board of directors. In contrast, 54% of US tech companies have women at the C-level jobs, and only 34% of US companies have women as their board members. 53% of UK’s tech companies have women at the C-level jobs, and 39% of companies have women as their
board members (Lacy, 2017). The president and COO of Didi Chuxing, a company widely
known for its recent competition and victory against Uber in China, is also a woman.

Several theories exist as to why these developing nations enjoy a greater representation of
women in STEM fields compared to developed nations. One is that developing nations have
some of the fastest growing economies, which translates to more jobs and opportunities for
everyone. In contrast to developed nations with more mature industries and economies, where
people with nontraditional experiences such as women tend to be overlooked and passed over,
developing nations and their emerging tech markets enable these people to contribute and play an
important role (Lacy, 2017).

Another theory is that STEM education and employment are thought to be particularly
valuable in the labor market of developing countries. For example, female students in Jordan
cite economic reasons – that engineers earn relatively high incomes – as one of the top reasons
they chose to enroll in engineering degrees at the bachelor’s level (Abu Lail et al., 2012). As
mentioned above, Mexico has one of the highest percentages of representation of women in
computer science at the post-secondary level. These women are thought to pursue computer
science because of the field’s relative abundance of high-income jobs (Khazan, 2014). Similar
reasons underlie how Romania came to have the greatest percentage of women pursuing an
education or a career in information technology (IT) among European nations (Fiscutean, 2016).

STEM education is also considered as a good investment with high monetary returns in
developed nations as well. America’s shared passion for STEM education is partially based on
the belief that STEM jobs are high paying (Lohr, 2017). And one of the often-proffered reasons
for encouraging more women into STEM fields is that doing so will help close the gender wage
gap (Resnick, 2016). American college students in developed nations are constantly reminded
by the media that graduating with STEM degrees will yield the highest starting salaries. For example, in 2016, the average starting salary for a college graduate with an engineering degree was $64,891 and computer science degree, $61,321. These figures are significantly higher than the average salaries education or humanities majoring students make right out of school: $34,891 and $46,065 respectively (Close, 2016).

However, the fact that STEM occupations tend to be high-paying plays a bigger influence on students’ career decisions in developing nations than in developed nations. Students in developing nations have less economic security and therefore place a greater utility on the value of STEM occupations. These students believe that these jobs will reward them and their families with higher income as well as higher social standing. Students and their parents in developing nations therefore pursue completion of higher STEM education, in hopes that they would one day reap substantial financial returns.

The final theory as to why developing nations enjoy a greater representation of women in STEM fields compared to developed nations is historically very interesting as well. Many of these developing nations with high representation of women in STEM fields have a communist past. Communist regimes expected everyone to work and contribute to the society. In the famous words of Mao Zedong, Chinese women “held up half the sky” and were to work just as hard as men (Lacy, 2017). Romania was also under a communist rule between 1947 and 1989, during which no distinction existed between men and women in the labor market. Women were told that the “country needed them” and that they were “catalysts of the nation’s economic growth” (Fiscutean, 2016). As Romania underwent a rapid industrialization during this period, the regime pushed its citizens to pursue STEM education so that it could reproduce the Western World’s computers and cars in its own factories. As a result, the Romanian media from this
period often featured females in the roles of scientists, engineers and even crane operators and welders (Fiscutean, 2016).

The tradition and culture of women being treated as capable of working in STEM fields has thought to continue and endure up to this date. “Raised by their breadwinner mothers through harsh times, many [Romanian] girls now in their 20s and 30s have chosen a career path in technology, which pays the bills,” and now, a third of Romania’s IT work force are females (Fiscutean, 2016). Similar stories are told in Kazakhstan and Thailand. Chinese women have founded as many as half of new internet companies and enjoy a greater representation at the top of these companies (Lacy, 2017). The few countries in which women outperform men regarding STEM publication authorship are mostly formerly-communist nations such as Macedonia, Sri Lanka, Latvia, Ukraine and Bosnia and Herzegovina (Larivière et al., 2013).

b. Developed nations have lower representations of women in STEM

Developed nations tend to be more gender progressive than developing nations, with more social structures and legal policies placed to help women fight for equal rights and pursue their dreams. The developed nations score higher on the Global Gender Gap Index, an index published annually by the World Economic Forum that evaluates each nation’s degree of gender equality using measures such as earnings, access to employment, access to basic as well as advanced education, political empowerment and health outcomes such as life expectancy. And yet, several studies show that developed nations – including the United States – have less women representation in STEM fields compared to the developing countries discussed above (Andreescu et al., 2008; United Nations Educational, Scientific and Cultural Organization, 2017).

Scandinavian countries are a good starting point for discussion. Scandinavian countries are often hailed by the media to be the world’s best at gender progressiveness, welfare policies
and education. They consistently place at the very top of various cross-national rankings such as the Global Gender Gap, the Global Peace Index and the Environmental Performance Index (World Economic Forum, 2015). As one journalist aptly put it:

The country examined by the Economist this summer to explore the benefits of paid paternity leave? Sweden. The country touted by long journalistic profiles and best-selling books alike for its education system? Finland. The country profiled by the BBC for its creative approach to bettering the lives of the homeless? Denmark. The first country profiled by Slate in its examination of how good life is elsewhere for working parents? Norway (Tamkin, 2014).

And yet, Finland still has one of the world’s greatest gender imbalances for college STEM degrees: only 20% of Finnish college graduates in STEM degrees are women. Finland is also closely followed by other Scandinavian countries such as Norway and Sweden, which have less than 25% representation of women in STEM fields at the bachelor’s level (Stoet and Geary, 2018).

What might explain this rather counterintuitive or paradoxical finding that the nations that pride themselves in progressiveness and gender equality actually witness greater gender disparity? Curiously, ‘women-friendly’ policies sometimes have unintended consequences and work against women in developed nations including these Scandinavian countries. Women across all nations tend to bear the heavier burden when it comes to caring for children and doing housework. For example, in the US, more than twice as many women as men do household chores on an average day, and women also spend twice as much time caring for and helping their family members (Bureau of Labor Statistics, 2016). Therefore, family-friendly policies such as allowing employees work part-time can significantly help women balance their work with family responsibilities. Maternity leave policies protect the mothers’ jobs until they return to work, help mothers recover after childbirth and allow them time to bond with their new children. Due to
these policies, women no longer have to give up their jobs to care for their families, as may have been the norm years ago, but can stay in the work force as long as they would like.

Scandinavian countries are indeed generous when it comes to maternity leave policies. Sweden has one of the longest paid maternity leaves in the world, allowing parents to take up to 480 days (more than 68 weeks) of paid leave (Akerstrom, 2018). Norwegian parents are entitled to either 49 weeks of leave while being paid 100% of their salary or 59 weeks of leave while being paid 80% of their salary (Nav, 2018). In Denmark, parents may take up to 52 weeks of paid leave after a child is born (Oresunddirekt, n.d.). Although these nations’ policies usually allow mothers and fathers to share the entitled days, data show that mothers tend to use up the significant majority of the entitled leave (Sweden, 2018). The US, in stark comparison, does not mandate any length of paid leave. The Family and Medical Leave Act that was passed in 1993 requires employers to provide up to 12 weeks of unpaid and job-protected leave for mothers when a child is born or adopted (United States Department of Labor, n.d.).

In Scandinavian countries, because maternity leaves are so long and therefore burdensome and costly to employers, they can deter employers from hiring women in the first place. Employers may choose to hire males over females out of concern that one day if their female employee goes on maternity leave, the employer would have to not only make arrangements to fill in for the work that is not being done, but also pay out a salary for the length of her leave, which can be as long as a year or even longer.

One study that surveyed various women academics in Scandinavian countries also partially attributes the underrepresentation of women in professorships to these policies: Sweden, Norway and Denmark are below average among European nations in terms of percentage of women professorships. Sweden ranks 13th, Norway, 15th and Denmark, 21st among the 27
European Union nations (Seierstad and Healy, 2012). Several of the surveyed academics agreed that men tend to be preferred over young women at the hiring stage as a consequence of the maternity leave policies. Although not from a Scandinavian country, a survey of 500 managers in the UK also revealed similar concerns of employers over maternity leaves. A quarter of these managers admitted that they would rather employ a male over a female, citing financial costs arising out of maternity leaves as their source of concern. 40% of managers also admitted that they are generally wary of hiring women of childbearing age (Press Association, 2014).

Other women-friendly policies tell a similar cautionary tale as well. In 1999, Spain passed a law that allowed parents to work part-time without fear of being laid off until their child turns seven years old. Although both mothers and fathers were allowed to do so, the vast majority of those who claimed the benefits ended up being mothers. Data from the next fifteen years suggest that as a result of the passed law, women of childbearing age were 45% more likely to be dismissed. Employers were also 6% less likely to hire women and 37% less likely to promote them. Finally, female employees were more likely to be switched to short-term contracts, which are not required to provide the benefit (Kranz and Rodriguez-Planas, 2013).

This is not to suggest that these laws and welfare policies are futile; they have indeed protected many women’s jobs and helped them juggle their family responsibilities along with work duties. However, for some women, it seems as if there can be too much of a good thing. Too large or generous an amount of women-friendly policies can actually be harmful; they can create obstacles in a woman’s career path, the exact obstacles that the policies were put in place to eliminate. Welfare policies therefore need to be implemented with caution, in adequate amounts and with assurances that they are serving their original intentions.
Freedom of choice and self-expression is another hypothesis raised to explain why developed nations have less women in STEM fields compared to developing nations. According to one study, countries that “give girls and women more educational and empowerment opportunities and that generally promote girls’ and women’s engagement in STEM fields” tended to have lower percentages of women graduating with STEM degrees at the post-secondary level (Stoet and Geary, 2018). Figure IV.1 below demonstrates this phenomenon, which the authors call the ‘gender equality paradox.’ The scatterplot shows prosperous and developed countries such as Finland, Norway, the Netherlands, Sweden, Switzerland, France, Spain and the US in the upper-left quadrant, scoring high on the Global Gender Gap Index but low regarding percentages of women among STEM graduates.

Figure IV.1: Percentages of female STEM graduates and GGGI across countries (Stoet and Geary, 2018)
In an attempt to explain the phenomenon, the authors examined PISA assessments of almost 475,000 adolescents from 67 different nations. Specifically, they examined these students’ scores in three different areas—reading comprehension, math and science literacy—and calculated each student’s relative strength. For example, a student’s relative math strength was calculated by subtracting her average score of three subjects from her math score. The analysis revealed boys’ relative strengths to be in math and science and girls’ relative strength to be in reading. Most interestingly, this sex difference was more pronounced for the more gender-equal countries.

c. Gender stereotypes contribute to developed nations’ gender imbalance

The authors propose that their findings regarding the students’ relative strengths help explain why developed and gender-equal nations have less women representation in STEM fields: women tend to be stronger at reading compared to math or science, and women of developed nations are less likely to be compelled by economic concerns when selecting careers. Instead, they feel empowered to pursue their interests and design their academic and career paths based on their personal strengths. Based on these findings, one scholar, Mark Perry, even claimed that the underrepresentation of women in STEM in the US “should be celebrated as a great sign of female success … [and] may actually be the result of the great advances in female empowerment, progress, and advancement that have taken place in recent decades” (Perry, 2018):

If— and emphasis on the ‘if’ here— women’s relative strength indeed lies in non-STEM fields such as reading, education and humanities, the underrepresentation of women in STEM fields in the US may not be as a significant problem as it may be perceived. The
underrepresentation would actually be proof of the “luxury of not pursuing STEM degrees and careers” (Perry, 2018). In other words, the underrepresentation would serve as a confirmation that women in the US are freely choosing to pursue what they are best at. This would suggest that the ideal gender ratio in STEM fields does not have to be 50:50. This is similar to the rather refreshing idea that the severe gender wage gap found in the Netherlands may not be such a bad thing after all. The huge wage gap partially arises out of many Dutch women happily choosing to work less and earn less. Currently, around 77% of Dutch women are estimated to work less than 36 hours a week, compared to only 27% of men (Moss, 2015).

However, it seems premature to end the discussion here and to celebrate the low representation of American women in STEM fields as a sign of female success, as some might suggest. The conditional clause, that women’s relative strength lies in non-STEM fields such as reading, education and humanities, needs to be examined. This brings back the debate as to whether women inherently favor humanities and social sciences while men inherently favor math and science. To clarify, the conditional clause may indeed be true for some women; some women are born with a natural affinity for and strength in reading. But it would seem too quick to generalize it for all women. One should not conclude that women are comparatively better at reading than math, science or engineering without probing whether the society and the culture is conditioning women to like reading.

In the previous chapters, this thesis discussed the prevalence of negative STEM gender stereotypes and the numerous studies that detail the stereotypes’ effects upon women. Boys tend to be exposed to STEM early on with toys, video games and computers, and throughout their lives, receive explicit as well as implicit encouragement to pursue STEM fields. In contrast, girls are less likely to be provided such exposures, and girls tend to receive social cues to associate
math and science with males. Then it seems rational to deduce that for many women, who identify reading rather than math and science as their personal strengths or preferences, these identifications are not truly self-willed but shaped by society to some degree.

This thesis therefore proposes that one of the reasons why developed nations such as the United States tend to have greater gender imbalance in STEM fields than developing nations, is due to the pervasiveness of negative gender stereotypes and defined roles for each gender. Several supporting arguments can be made: first, there is some evidence to suggest that in countries where gender STEM stereotypes are not as prevalent, we do see increased representation of women in STEM fields. Many women in these countries do not automatically associate STEM careers as within the male domain, and they believe that STEM careers are also suitable women. For example, Othman and Latih argue that Malaysians do not tend to view computer science as a masculine field (Othman and Latih, 2006). Their surveys of undergraduate students reveal that Malaysian female students are just as likely as, if not more likely than, male students to agree that computer science and IT are suitable for women; that computer skills are important; and that they plan to work in the computer/IT industry after graduation. Malaysia has one of the higher representations of women in computer science and IT programs at the bachelor’s and master’s levels (Othman and Latih, 2006). A survey conducted by Microsoft on 11,500 girls from various European countries revealed that Russian adolescent girls view STEM more positively than other European girls. Russia also has less gender imbalance in STEM fields compared to many European nations (Bullock, 2017; Trotman, 2017).

The extreme version of this argument is that in communist societies, there are no gender stereotypes about STEM fields and also no defined gender roles. This thesis has already
demonstrated above that countries with communist histories tend to have greater representation of women in STEM fields. In communist states, no distinctions are made between men and women in the workforce, and science and engineering are not associated as masculine fields. Women are expected, as much as men, to work and contribute to the society as scientists and engineers. To be clear, this thesis in no way advocates for communism. However, it is interesting that these nations enable us to imagine an alternate universe where some of the factors, which deter women from STEM fields in developed nations, do not exist. These nations tell us that it is indeed possible for a society to do without negative gender stereotypes and deeply defined gender roles. The social and cultural obstacles to the STEM pathway, obstacles which stir up math anxiety among young American girls and which socially condition them to pursue fields or occupations deemed more appropriate for women, do not exist in certain nations.

Second, even in developed nations where there tends to be a greater gender gap in STEM fields, the gap diminishes for the most socioeconomically advantaged class. And one hypothesis that may explain this phenomenon is that parents of higher socioeconomic classes tend to have less rigid views of gender roles and therefore are less likely to pass on gender stereotypes to to their children (Mcmaster, 2017b). Therefore, some of the factors that deter women from STEM fields fail to deter children of the higher socioeconomic classes. Studies from the United Kingdom and the Netherlands reveal that while young women from less advantaged families are less likely to study STEM subjects, young women from advantaged backgrounds are just as likely as men to study STEM (Mcmaster, 2017a; van de Werfhorst, 2017).

Finally, cross-national studies show that adolescents of developed nations have a greater gender confidence gap in math, compared to adolescents of developing nations. And one of the sources of the gender confidence gap is thought to be the various gender STEM stereotypes
constantly reminding women that math is for men and that women are not good at math. Figure IV.2 below shows the OECD’s data on the percentages of girls and boys who reported “feeling helpless when doing a mathematics problem.” Again, in developed nations, we see a gender confidence gap with a greater percentage of girls feeling less confident than boys. These nations include, moving from left to right of the scatterplot, France, Italy, Norway, Switzerland, United Kingdom and United States. According to this study, girls from developed nations tended to express more anxiety about math even though they performed just as well as boys on the PISA test. In contrast, countries with a greater percentage of boys feeling math anxiety than girls all tend to be developing nations such as Thailand, Jordan, Malaysia, Bulgaria, Albania and Kazakhstan.

Figure IV.2: Percentages of students with math anxiety by gender (OECD, 2018)
V. Methods That Have Been Proposed to Close the Gender Gap in STEM Fields

a. A departure from traditional teaching methods

Several studies indicate that male and female students differ regarding how they learn and make sense of STEM concepts. This seems natural given that the male and female genders grow up with different STEM-related exposures and experiences. As an example, one survey given to high school students to evaluate their familiarity with physics-related concepts and activities showed that boys reported greater familiarity with activities such as using a drilling machine, fixing something with dowel and screw, assembling a plug, etc. In contrast, girls reported greater familiarity with physics concepts in the context of household-oriented activities (Labudde et al., 2000).

The traditional teaching method, which continues to be employed in the majority of colleges and universities in the United States, does not take into account gender differences in learning or cognitive processes. The traditional method also consists of students taking a rather passive role in the learning process, whether it’s sitting in lectures, taking notes or reading textbooks.

A reform in the traditional pedagogy seems particularly needed considering that many students report dissatisfaction with how their STEM classes are thought. In their oft-cited study, Seymour and Hewitt interviewed around 460 undergraduate students and ranked the most common reasons for students choosing to abandon STEM majors. The third most cited reason was poor teaching by STEM faculty, following loss of interest in STEM disciplines and interest gained in a non-STEM major. More than 90% of students who abandoned STEM majors and 75% of students who chose STEM majors reported that they were concerned about how poorly
their STEM classes were taught. In particular, students commented on the lack of interaction between instructors and students, ‘coldness’ of the classroom and dullness of presentations (Seymour and Hewitt, 1997; Watkins and Mazur, 2013).

These problems with teaching methods are even more aggravated for first-year college and university STEM classes. Many studies have documented the substantial attrition of college students from STEM fields during the first year of college. Students cite their experiences in their freshmen science courses as very influential in their decision to switch out of their major (Strenta et al., 1994). Introductory STEM classes are often huge and competitive with a severe grading curve. Their pedagogical styles are rather traditional, centered towards lectures and problem sets. They are often very fast-paced and demand significant time and attention, whether in classes, laboratories or on assignments. They are also frequently taught by graduate students, postdoctoral scholars or teaching assistants rather than professors, and these instructors are predominantly males. All of these factors can contribute to female students’ loss of interest and poor performance.

Calculus I is, in particular, a good example of a first-year college STEM class that aggravates the gender gap. For example, Ellis et al. have shown based on data from 2266 undergraduate students from 129 different universities, that female students are 1.5 times more likely to stop pursuing a STEM major after taking Calculus I. Calculus I is a fundamental course that is required for most STEM majors or the “gateway to all areas of science and engineering” to borrow National Science Foundation’s words (Steen, 1988). Yet, Calculus I has behaved more like a bottleneck, discouraging many students from pursuing further STEM education or careers (Steen, 1988; Ellis et al., 2016). Ellis et al. estimate that if our society does not lose these women who drop off the STEM path after Calculus I, the number of women entering the
STEM workforce can increase by as much as 75%. Then, women would compose about 37% of the STEM workforce, as opposed to the current 25% (Ellis et al., 2016).

A movement away from the traditional teaching method is therefore necessary to not only encourage more students, of both genders, to study STEM but also to reduce the gender gap in STEM performance. Several alternatives to traditional teaching methods will be presented below. The term ‘active learning’ is often used to encompass many of these approaches, for they engage students more actively in the learning process, usually requiring them to think more about the concepts they are learning and perform various learning activities. These methods have been shown to benefit both male and female students, but especially the latter.

Unlike traditional teaching methods, which rely on transmission of knowledge through lectures and textbooks, student-centered or active learning encourages students to engage with the class through participation and to engage with the scientific concepts at issue. The dynamic learning process therefore helps the newly gained knowledge last longer and be more transferable to other contexts.

Student-centered or active learning therefore usually entail collaborative learning with other peers in small group settings. Here, collaborative learning refers to interactive activities that encourage collaboration and communication among the students working toward a common goal. Collaborative learning includes activities such as discussions, peer tutoring and cooperative problem-solving activities. The collaboration towards a common goal is important for our purposes, for female students tend to be negatively affected by competitive environments (Springer et al., 1999). Several studies show that the male and female gender react differently to competitive environments. One study found that while women performed just as well as men on a STEM-related activity in a non-competitive group setting, when competition was introduced
into the experiment so that the highest performers in each group would receive a monetary award, women performed much worse than men (Gneezy et al., 2003). Women are also turned off by competition and tend to shy away from environments in which they would be forced to compete (Niederle and Vesterlund, 2010). There is also some evidence to suggest that men tend to prefer competitive and individualized learning more than women (Cakiroglu, 1999).

Pair-programming is a form of collaborative learning in the context of computer science where two programmers work together at one keyboard, with one (driver) operating the keyboard and writing the code while the other (navigator) reviews the codes for errors and alternative approaches. Many studies have documented the various benefits of pair programming such as better performances, greater mastery of programming and increased confidence in one’s skills. Interestingly, pair programming has shown to benefit female and minority students in particular. For example, paired women programmers were more likely than solo women programmers to complete the course as well as declare a computer science related major. Paired women programmers also reported greater confidence in their work and programming abilities (Werner et al., 2004; McDowell et al., 2006).

Collaborative learning works more efficiently in small group settings and are particularly difficult to implement in introductory STEM classes due to their large student body and a high student to teacher ratio. The students’ interests are also often too diverse. For example, a typical introductory Calculus I class will contain students majoring in STEM disciplines all different from one another such as biology, computer science, engineering, geoscience and astronomy. It is therefore difficult to design a curriculum that can tailor to everyone’s interests (Steen, 1988). In classes with too large a number of students such as
introductory STEM classes, instructors can encourage small group activities during classes or implement them in recitations.

Student-centered learning also entails more frequent opportunities for assessment and feedback, which can take the form of short low-stakes quizzes, homework checks or asking questions to students at regular intervals during class (Pearson, 2016). The recurrent assessment opportunities enable students to evaluate the degree of their understanding and correct any misunderstandings. The repeated retrieval of newly learned information also forces the students to actively process STEM concepts and has been shown to lead to long-term retention and transfer of STEM knowledge (Karpicke and Blunt, 2011; Pearson, 2016). Frequent feedbacks can especially help girls because girls tend to feel less confident about their STEM skills or performances compared to boys. The feedbacks can provide female students encouragement as well as assurances that the students are in control of the course material (Pollina, 1995).

Phenomenon-based learning is a pedagogical initiative that has received much attention recently after Finland made it part of its National Curriculum Framework. Since 2016, all Finnish students between 7 and 16 years of age have been required to go through a certain period of phenomenon-based learning, with the duration of the period to be decided by the schools. Helsinki, for example, has set the duration of the period at 2 years (Strauss, 2015).

Phenomenon-based learning starts with observation of a real-world phenomenon and then guides students through the course material that would help them understand the phenomenon. For example, students will be presented with a phenomenon such as: "When a figure skater on ice is spinning in one spot with her arms out, why does she spin so much faster as she brings her arms in?" Students will then use this phenomenon to learn the concepts and theories of conservation of angular momentum (Larson, 2017). Phenomenon-based learning therefore
enables students to think and act as a real scientist or engineer would (Twig Education, 2017). It also helps students form connections between abstract scientific concepts and the real world. Phenomenon-based learning has been shown to be better than traditional teaching methods at promoting students' critical thinking and long-term retention of knowledge and skills. By making learning STEM concepts more interesting and approachable, phenomenon-based learning has also shown to increase student satisfaction in their learning process (Yew and Goh, 2016).

Phenomenon-based learning can also contribute to reducing the gender gap in STEM, for it incorporates teaching strategies that have been demonstrated to benefit girls: integration of everyday experiences into STEM curricula and application of STEM subjects to a broader worldview (Lorenzo et al., 2006). By incorporating everyday experiences into STEM curricula, phenomenon-based learning makes the content more relevant for female students, and as a result, female students express increased interest in the subject and perform better. As one scholar put it, "girls do not think that they understand a concept until they can put it into a broader context. In particular, they try to understand the relations of the system of physics to the world as a whole" (Stadler et al., 2000).

Peer Instruction is a teaching method that incorporates many of the student-centered or active learning strategies. Implemented at Harvard University by Professor Eric Mazur in his introductory calculus-based physics class, Peer Instruction modified the traditional lecture style into short lectures lasting 10 to 15 minutes alternated by conceptual questions. When students were presented with these questions, they were encouraged to solve them together in small groups and address any difficulties they had in understanding the material. From the
abovementioned list then, Peer Instruction checks off collaborative learning with other peers in small group settings as well as frequent assessment and feedback opportunities.

Not only did Peer Instruction enhance understanding of the class material for students of both genders, it also reduced the gender gap that existed before Peer Instruction was implemented. Peer Instruction is also thought to increase students’ likelihood of declaring a STEM major. Mazur and his colleagues claim that Peer Instruction also allows students “to get to know each other and share ideas, perhaps reducing the “coldness” and increasing the “openness” of the introductory science classroom” (Watkins and Mazur, 2013), therefore addressing the concerns from the abovementioned Seymour and Hewitt’s study. Peer Instruction or similar forms of Peer Instruction have been implemented at other schools and have yielded similar positive results (Lasry et al., 2008; Adegoke, 2012).

b. Challenging existing gender stereotypes and rebranding STEM

One of the more urgent and potentially high-impact steps we can take to increase the representation of women in STEM fields is to challenge the existing stereotypes regarding STEM fields. Although there exists much literature demonstrating the pervasiveness of gender STEM stereotypes and their effects, there is not much literature discussing how these stereotypes can be changed or eliminated, perhaps speaking to the difficulty of the task. Unlike explicit bias or discrimination, stereotypes and cultural cues tend to be more implicit and subtle. They are also pervasive and deeply ingrained in our culture and yet they tend to be hidden. As a result, it can be difficult to pinpoint these stereotypes or target them at their exact source.

Perceptions of scientists and engineers as a geeky white male in a lab coat or poring over his computer need to be broadened. By increasing the visibility of non-stereotypical scientists and engineers in the society, STEM can appear more inclusive and appeal to students of all
genders, ethnicities and backgrounds. Efforts should be made to shatter predefined gender roles and implicit associations that are deeply embedded in people’s minds – that STEM are for males or that males are better than females at STEM. Doing so will likely increase women’s interest in STEM fields and enhance their self-confidence. Even simple acts such as changing the physical environment of STEM will help women feel like they too belong in STEM. According to one study, replacing stereotypical objects (such as Star Trek posters, video game boxes, junk food and technical magazines) in computer science classrooms with less stereotypical objects (such as nature posters, art, healthy snacks and general interest magazines) resulted in high school girls three times more likely to be interested in a computer science class (Cheryan et al., 2009).

STEM also needs to be rebranded to make it more familiar and approachable to young girls and boys so that it does not appear to be just about abstract principles and equations. For example, students report being far more likely to associate STEM occupations with employers like NASA but less so with more accessible consumer companies such as Instagram or Coca-Cola (PRNewswire, 2017). Finally, emphasizing the social relevance and broad applications of STEM fields will help attract more women into these fields. This strategy will particularly appeal to women, for studies suggest that women are more likely than men to want a career that is interactional, communal and has societal relevance (Lippa, 1998).

It will be important to target young girls before they become aware of and are influenced by gender stereotypes. As mentioned previously, children, around the age of 2, show increased tendencies to play with toys associated with their gender (for example, boys with trucks and girls with dolls) and at age 3, begin to develop very basic gender stereotypes (Martin and Ruble, 2009). Studies have also found that students, as early as first and second grade, associate STEM subjects such as math and engineering with the male gender more strongly (Cvencek et al.,
By the time students enter third grade, girls have been shown to assess their STEM skills lower than boys despite no gender difference in performance (Herbert and Stipek, 2005; Ganley and Lubienski, 2016).

Just as boys are exposed to STEM toys and gadgets early on, young girls should be encouraged such exposures. Toys can be helpful at increasing the appeal of STEM to young girls. One study conducted with 105 children from ages 5 to 7 revealed that playing with a robotics kit designed for young children can significantly increase girls’ interest in engineering (Sullivan, 2016). Before the children started playing with the robotics kit, boys were more likely than girls to agree with the statement that they would “enjoy being an engineer.” However, after the children had played with the robotics kit for almost two months, the gender difference disappeared, and girls were just as likely as boys to agree that they would “enjoy being an engineer.”

Girls should be engaged in STEM subjects as early as possible because studies also show that although girls show interest in STEM at a younger age, their interest quickly diminishes with age. Figure V.1 below provides a visualization of girls’ losing interest in STEM fields at a faster rate than boys. While fourth grade boys and girls report having similar degrees of interest in science, girls’ interest in STEM dwindles quickly as they get older. By the time they reach 12th grade, 59% of female students and 70% of male students report having interest in science. Upon entering college, only 17% of women claim intentions to pursue a STEM degree, compared to 32% of men (Ellis et al., 2016).
Efforts of multiple stakeholders will also be needed to successfully challenge the existing stereotypes and to rebrand STEM. STEM occupations need to be rebranded so that students not only recognize the wide range of opportunities available in STEM but also the broad societal impact a career in STEM can exert. **Partnerships between schools and local STEM employers** can be helpful here. For one, the employers can provide students real-life examples of scientists and engineers, thereby expanding the conventional stereotypical image of a geeky male coding all night long. The employers can also help students envision the potential applications of the STEM subjects they learn in school. As many as 30% of teenagers report not knowing of potential job opportunities in engineering, and 20% have no idea about engineering’s impact on the world. However, after Intel told these teenagers about the various applications of
engineering – for example, engineering enables us to drive, text, social network and deliver clean water to the poor communities in Africa – half of them claimed that they would more likely consider engineering as a career (Intel, 2011).

The media can also partake in the effort to challenge gender stereotypes. Popular shows, films and books that contain positive images of female scientists and engineers have indeed been shown to increase young girls’ interest in STEM fields. *Hidden Figures*, a biographical film which was released in 2016, depicted three black female mathematicians who worked at the National Aeronautics and Space Administration (NASA) in the 1960s. The three women’s work deserve credit for John Glenn becoming the first American astronaut to successfully orbit the Earth. After receiving much critical acclaim and earning more than $230 million worldwide, the film has inspired many young girls to pursue STEM fields and also a State Department exchange program whose purpose is to promote women in STEM fields (Hatch, 2017; White, 2017).

‘The Scully Effect’ also demonstrates the great extent to which the media can shape and influence people’s interests and career aspirations. Dr. Dana Scully was one of the leading characters on *The X-Files*, a popular science-fiction drama in the 90s. She was featured as an intelligent and confident FBI agent and a medical doctor, and she was also one of the first STEM female professionals to be depicted on screen. A recent survey of over 2,000 females who had watched the show confirmed that Scully has indeed inspired many females to pursue education or careers in STEM. A great percentage of women reported adopting a more positive attitude towards STEM fields as a result of watching Scully, including believing in the importance of STEM and encouraging their daughters or granddaughters to pursue STEM fields. Women who had watched relatively more episodes of the show were more likely than other women to have considered working or to have actually worked in a STEM field. Close to two-thirds of women
who currently work in STEM fields reported that Scully had served as a role model for them (21st Century Fox et al., 2018).

Students these days are comfortable with social media and a frequent user of platforms such as Instagram and Twitter. Therefore, using the very platforms the students are familiar with to counter the gender stereotypes may help the message resonate more with them. Two recent social media campaigns - #ILookLikeAnEngineer and #distractinglysexy – are good examples of the social media being used as a vehicle for women to connect with one another as well as to challenge the existing stereotypes and gender norms in STEM fields.

The “I Look Like an Engineer” movement arose after Isis Wenger, a software engineer, posed in a picture for a recruiting campaign for her employer OneLogin. Upon seeing her picture, many people posted sexist comments, doubting her engineering skills or expressing disbelief that she was an engineer, claiming she was “too pretty” to be one. In response, tens of thousands of women began to post their photos with the hashtag #ILookLikeAnEngineer, in an attempt to broaden the preconceived notion of what a female scientist or engineer is supposed to look like. Just within the first month of the movement, the hashtag drew 86,000 posts from around 50 countries (Tan, 2015). Figure V.2 below includes a tweet posted by the MIT of its female engineering researchers and professors using the hashtag.

The #distractinglysexy movement began in 2015 in response to renowned Nobel Prize winner Tim Hunt’s toast at a conference for female journalists and scientists, “Let me tell you about my trouble with girls. Three things happen when they are in the lab: you fall in love with them, they fall in love with you, and when you criticize them they cry.” Since his speech, the hashtag #distractinglysexy went viral, with many female scientists posting pictures of themselves in their STEM environments. One example is provided in Figure V.2 below.
Are **single-sex schools** a solution to challenge the gender stereotypes or counteract their negative effects? In the last decade or so, the US has seen a great renewed interest in single-sex schools. In 2004, there were 34 single-sex public schools, but that number increased by 25-fold to around 850 schools just in 10 years (Anderson, 2015). Several co-educational middle and high schools have also expressed interest in creating single-sex classrooms for just math and science classes (Yap, 2016).

Single-sex schools or environments are often proposed as a way to protect girls against gender stereotypes. The idea is that because girls are surrounded only by girls, girls are less affected by gender stereotypes regarding STEM fields. In the absence of boys, girls feel less pressure to be seen as ‘feminine’ and are therefore more likely to express interest and enroll in STEM classes that are regarded as ‘masculine.’ The all-girls environment is also thought to improve both teacher-student and peer-group interactions (Park *et al*., 2013). In co-ed settings,
boys tend to receive more attention than girls, speak up more and raise their hands more quickly than girls (Erisman, 2014). Naturally, girls in co-ed environments tend to receive less attention from teachers and speak up less. In contrast, in single-sex environments, girls feel more confident about taking risks and speaking up in front of their peers. They also feel more confident in their own STEM abilities (Park et al., 2013).

Several studies have shown that girls who attend single-sex schools are more likely to study science than girls in their co-ed counterparts (Institute of Physics, 2012). One study in Australia showed that female high school students in single-sex environments were as much as 85% more likely to enroll in advanced STEM classes such as intermediate math, advanced math and physics (Forgasz and Leder, 2017). According to the UK Department for Education and Skills, single-sex school students may hold less gender stereotypical views regarding STEM. For example, boys in single-sex schools were more likely than boys in co-ed schools to prefer biology over physics; girls in single-sex schools were more likely than girls in co-ed schools to report liking physics (Stables, 1990; UK Department for Education and Skills, 2007).

However, there exists much controversy regarding the positive impact of single-sex schools. Several cross-national studies and meta-analyses have found no strong support for single-sex education. There are also many factors that confound the correlation between single-sex schools and girls’ improved educational outcome. In many countries including the US, single-sex schools have tended to be private schools that accept tuition. Therefore, single-sex schools may seem to result in better outcomes, but these results are likely due to self-selection bias. The better outcomes achieved by single-sex schools have shown to decrease when various controlling factors are introduced such as students’ prior achievement or socioeconomic advantages (OECD, 2009; Park et al., 2013).
Given these findings, it seems premature to suggest single-sex schools as a possible solution to protecting young girls from negative gender stereotypes. Single-sex schools also cannot avoid the criticism that the act of separation by gender itself actually reinforces gender stereotypes. Finally, single-sex schools may not prepare female students for the various gender stereotypes they will face after graduation and upon joining the STEM work force.
VI. Further Recommendations on Closing the Gender Gap in STEM

As the previous chapters have demonstrated, women’s underrepresentation in STEM fields is a complex phenomenon with many different contributing factors. These factors may also come into play at different stages in life for different women. Some women never find STEM appealing enough to dip their toes into it. For some women who choose to enter, only to later leave the STEM pipeline, the decision to leave may be the result of a long-term build-up of frustrations and discouragements. For others, the decision may be triggered by a single event. These decisions are also highly personal and individualized that there is simply no silver bullet solution to increase women’s representation in STEM fields. What is likely needed is multiple different interventions, involving the efforts of numerous stakeholders, aimed at women at various stages in their lives through various channels. This thesis suggests four such recommendations that can be implemented to encourage more women to take interest in STEM and pursue STEM education or careers. These recommendations are my personal conclusions based on two years of extensive literature research as well as discussions and deliberations with others on this topic.

a. Extracurricular STEM program for socioeconomically disadvantaged girls

The extracurricular program would be provided free of charge and prioritize targeting socioeconomically disadvantaged neighborhoods. Targeting girls from lower socioeconomic classes is imperative to ameliorate the underrepresentation of women in STEM fields because these girls tend to express less interest in studying STEM as well as pursuing STEM careers compared to their peers of both genders. Standardized test scores in STEM subjects also reveal
girls from lower socioeconomic class to score lower than girls from higher socioeconomic class. The program can be designed as an after-school program that meets for a few hours per week or a longer, more immersive camp-like experience during the summer.

Girls would be encouraged to join the program early on, beginning around kindergarten. Children begin to develop gender stereotypes at very young ages, and by the time they reach first or second grade of primary school, they begin to associate STEM subjects more strongly with the male gender than the female. It will therefore be important to target young girls before they become aware of and embrace these gender stereotypes.

The program would provide education of STEM concepts and exposure to successful real-life scientists. STEM concepts would be taught in a way that encourages active learning and incorporates hands-on activities, collaborative learning with peers and phenomenon-based learning. Girls would be encouraged to spend time using various STEM tools such as computers, softwares, calculators, engineering kits and robots. The aim is to inspire more girls to take interest in STEM. The program should be fun, creative and interesting so that it does not come across to young girls as another dull obligation or homework-like exercise.

Another goal of the program would be to close the gender experience gap in STEM. Boys tend to grow up spending more time with STEM-related activities and tools (such as computers, video games, robots and building blocks) compared to girls. As a result, a sizable STEM experience gap presents by the time they enter school. In primary school, boys will often show greater familiarity with various STEM concepts and adeptness at using computers. In high school when advanced STEM electives become available, boys will often place out and enroll in more advanced STEM classes than their female peers. The experience gap has shown to increase
girls’ concern and anxiety over whether they would be able to catch up with their classmates and discourage girls from pursuing more advanced STEM classes.

Girls would also learn about famous scientists from the past as well as real-life STEM professionals from the present. The pool of scientists should include a healthy balance of female and male scientists to deter young girls from making implicit associations between STEM careers and the male gender. The pool should also include scientists of various ethnicities and backgrounds to increase the appeal of STEM careers to as diverse students as possible. By providing examples of STEM professionals that the girls share similarities with – such as a common gender or ethnic identity, – the program will be able to offer more concrete and effective role models for these girls. In addition, a broad scope of STEM professions should be represented, including non-stereotypical careers such as male nurses or female petroleum engineers. Local STEM employers can also get actively involved by connecting young girls to their STEM employees or inviting girls to visit their laboratories, factories and other workplaces.

b. Experimentation of different teaching approaches for Calculus I

Introductory calculus or Calculus I at the college or university level is a required course for most STEM majors. The class has long received criticism for how it is taught: the material is usually taught in the traditional pedagogical style, centered on lectures and problem sets. Equations and algebraic formulas and symbols often dominate the course material. The class sizes also tend to be large, for a typical Calculus I class will contain students majoring in all different STEM disciplines. A large class size translates to high student-instructor ratio, lack of interaction between students and instructors, and a curriculum that cannot be tailored to students’ needs. As a result, Calculus I tends to have a notorious reputation among students as one of the
most difficult classes. Many students fail, perform poorly in the class or decide against a major in STEM as a result of the class. Calculus I has been shown to be a major leak particularly for female students. Yet, despite decades of criticisms and discussions regarding a reform of the teaching methodology, the majority of American colleges and universities continue to teach calculus in the traditional style.

The need for a reform in how Calculus I is taught is urgent. Different teaching approaches should be devised, experimented and examined for their effectiveness. As one example, rather than first presenting new calculus concepts to students in abstract, formulaic forms, teachers can first provide real-life examples of the calculus concept. These examples can help students relate abstract mathematical concepts to their surroundings and therefore make these concepts more interesting and familiar. The relevant algebraic explanations and equations for the concepts can then be introduced to the students. The class can then end by asking students to apply the newly learned calculus concept to another real-life example. By way of illustration, the concept of derivatives can first be presented to students by showing them a video of the Olympics 200 meters race from 1996. Students become familiar with the concept as they calculate the speed or velocity of Michael Johnson, the gold medalist for that race and also one of the most renowned sprinters of all times, at every second interval. After learning the necessary equations and symbols, students may then be given a set of actual data such as the average global temperatures for the past couple decades. Students will be compelled to retrieve and make use of the new concepts as they perform various exercises such as plotting the data, calculating rates of changes, finding the fitted curve and predicting temperatures in the future.

Calculus has a broad range of interesting applications in various fields, but the traditional pedagogical style does not make good use of these applications. One teaching approach can
experiment with putting a greater emphasis on demonstrating to students how calculus relates to other STEM disciplines. Under the supervision of or with the aid of calculus professors, professors from other science and engineering departments can be brought in to teach a certain block of classes. These professors from other STEM departments can focus on the applications of the calculus concept to their fields; the professors may also share how the concept is used in their research. This approach enables students to gain exposure to a variety of STEM fields that they would not otherwise obtain.

It will be interesting to observe over time how calculus concepts will be taught under the new curriculum Finland has recently implemented. Finland has announced that phenomena-based learning will form a more integral component of its curriculum, and there will be less emphasis on teaching of individual subjects such as calculus, biology and physics. An effective synergy among various STEM teachers and departments will likely be needed to identify biological, chemical or physical phenomena that can be used to teach standard calculus concepts such as limits, derivatives and integrals.

Colleges or universities may also explore having different tracks of Calculus available such as calculus for life sciences, calculus for physicists, calculus for engineers and so on. Naturally, these courses will provide more tailored curricula for students and be able to show the students how various calculus concepts will be used in more advanced level classes in their majors.

Finally, the use of various active learning approaches discussed in the previous chapter should be fully encouraged to make Calculus I interesting to female students in particular. For example, it is important to create a collaborative rather than a competitive class environment, for female students tend to be turned off by competition and to avoid competitive environments
compared to male students. Collaborative learning activities such as discussions, peer tutoring and cooperative problem-solving should therefore be encouraged. Instructors should also scatter frequent opportunities for assessment and feedback during class time, another teaching strategy that has shown to particularly benefit females. These can take the form of short low stakes-quizzes or presenting students questions to check their conceptual understanding.

c. Use the media to promote strong female role models in STEM

The media has a huge influence on how we perceive the world. Surveys reveal that television and films serve as the most dominant influence behind students’ perception of scientists and engineers. This is not surprising, given that most American students graduate from high school without having taken courses such as computer science or engineering. And yet, the media continues to portray STEM professionals as disproportionately male. These portrayals help propagate the notion that certain jobs are for men and others for women.

The media should be mindful of the impact it can have upon young students and make it part of its corporate social responsibility (CSR) efforts to increase portrayal of successful female scientists and engineers who can potentially serve as role models to young girls. When producing a new show, movie or an advertisement that entails portrayals of STEM fields and STEM professionals, the media should be careful not to reinforce existing gender stereotypes. Popular movies and shows such as Hidden Figures, Bones and The X-Files have successfully depicted female protagonists in traditionally male-dominated STEM environments and have inspired thousands of young girls to take interest in STEM or pursue careers in STEM fields. Imagine the impact it could have if successful movies and films like these were released every year.
Promoting strong female role models in STEM fields does not have to be against the media’s financial interests. The abovementioned films and shows with female STEM protagonists are proof that media can serve its social responsibility but also create works that win critics’ acclaim and generate huge profits. Casting actors of diverse ethnicities as protagonists can also appeal to more diverse viewers and bring in larger audiences. As an example, the film *Hidden Figures* is thought to have particularly appealed to the female audience as well as the African American viewers, factors which contributed to the film being one of the most profitable films released that year.

Hosting contests or offering funds, with the aid of well-resourced organizations, to independent producers for media submissions that challenge gender stereotypes in STEM fields could also be an effective method. The media is one of the best tools we have to change people’s perceptions by depicting the society as we would like it to be. The media should therefore be actively used as an instrument to challenge gender stereotypes and make STEM more approachable to women.

d. **Educating parents and teachers of their gender biases**

Parents and teachers have shown to adopt unconscious gender biases in the context of STEM fields. For example, many parents and teachers express different expectations of success in STEM subjects to boys versus girls. Many parents and teachers will encourage boys to pursue STEM but send cues to girls that they are not good at STEM or they do not need to pursue advanced STEM classes. Parents and teachers are also more likely to perceive STEM careers as more appropriate for boys than for girls.
Parents and teachers are usually unaware that they exhibit these biases. Therefore, it is important they are educated about these biases and their impact on young girls. Parents and teachers play an instrumental role in shaping their students’ interests and career paths. Parents’ and teachers’ gender-biased behaviors can therefore decrease girls’ interest in STEM subjects and discourage girls from pursuing further education or a career in STEM fields.

All STEM teachers need to be educated about these biases, including a sample of statistics and studies that show how widespread these teachers’ biases are. One example of a study teachers should be informed of is a recent famous one that was covered by many media outlets. The study showed that sixth-grade math teachers tend to overestimate boys’ performances on math exams and give them higher grades than they deserve while underestimating girls’ performances, giving them lower grades than they deserve. Teachers should be trained to catch and correct any gender-biased behavior they may exhibit. Teachers should also be trained to hold high expectations for girls in STEM subjects as they would for boys and to challenge the girls to pursue more advanced STEM classes. Finally, teachers should be trained to offer words of encouragement and positive feedback to girls in STEM classes.

Teachers can also play an important role in educating parents about parents’ potential gender-biased behaviors. The information can be conveyed during parent-teacher conferences or workshops for parents. The information can also be disseminated to parents in newsletters or handouts.

In addition, many parents provide their daughters and sons unequal STEM-related opportunities or encouragement to pursue STEM. For example, many parents encourage their sons to play with STEM-related toys such as robots, building blocks and action-oriented video games, but not their daughters. STEM-related toys not only increase boys’ interest in STEM
fields but also effectively give boys a head start in STEM by giving rise to foundational STEM skills such as spatial and logical reasoning skills. Parents should therefore be educated on the importance of introducing their daughters early on to STEM-related toys.

Computers are another example. Parents are more likely to put the family computer in their sons’ rooms rather than their daughters’. Parents are also more likely to buy their sons their own computers than for their daughters. Parents should be educated regarding these prevalent tendencies and be encouraged to provide their daughters and sons equal access to computers, for example, by placing the family computer in a neutral location.

e. Challenges to implementing these recommendations

Significant effort and funding would be needed to plan and execute these recommendations effectively at the national level. For example, financial aid from a variety of private and public funds will be necessary to provide extracurricular STEM programs to socioeconomically disadvantaged girls nationwide without charge. Leadership from the state or federal government or a well-established non-governmental organization will also be necessary to recruit and train all the teachers needed for the extracurricular STEM program. Careful planning and execution will be needed to make these extracurricular programs interesting and captivating so that these programs do not have the contrary effect of decreasing young girls’ interest in STEM subjects.

Several barriers and challenges are also anticipated for the second recommendation of experimenting with different teaching approaches for Calculus I. Limited resources make it difficult for math departments and professors to experiment with different teaching approaches or overhaul class curricula. A methodical review and modification of curricula and teaching
styles require much time and pulls professors away from their research as well as other obligations. Many of the active learning strategies suggested above also require smaller class settings and therefore more resources, including professors and teaching assistants.

People also tend to be resistant to change. This is true for math departments and professors as well. Many professors may prefer to continue using their own curricula and teaching style, which they are very familiar with and have honed over many years of teaching, to trying new approaches. Because professors were taught calculus in the traditional pedagogical style when they were students themselves – and they still found the subject interesting and performed well, – they may not think it is necessary to introduce any changes.

To overcome these barriers, it will be important to first persuade math departments and professors of the potential benefits students gain from newer teaching approaches. The math departments and professors should be made aware of the various case studies and experiments that more risk-prone schools have tried and demonstrated success in. Strategic allocation of math departments’ current resources and funding from external sources will then be needed for the transition of departing from the traditional teaching style and implementing new approaches.

One major challenge for the last recommendation of educating STEM teachers and parents of their potential implicit gender biases arises from the fact that these biases are usually implicit, and they occur despite people’s best intentions. As a result, parents and teachers may find it difficult to identify and correct their own biased thoughts and behaviors. It would likely help parents and teachers to inform them when these biased behaviors are more likely to occur or manifest. This information can be obtained by researching a wide range of cases and studies that have detailed established such biases among parents and teachers. A single training session regarding these biases is also unlikely to be effective for many parents and teachers. Parents and
teachers will likely need to put in substantial effort over time to be truly able to reduce their implicit biases. Active involvement and institutional commitment from the schools to help the parents and teachers in this regard will also be helpful.
VII. References


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