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# The Gender of Mathematics: Math Is Not Born Male

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# **THE GENDER OF MATHEMATICS: MATH IS NOT BORN MALE**

**A thesis submitted to  
Regis University  
Honors Program  
in partial fulfillment of the requirements  
for Graduation with Honors**

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## **I. Introduction**

In 2004, the American Mathematical Society initiated the question “has the Women-in-Mathematics Problem been solved?” (Jackson 776). They recognized that in the 1990s, conversations about the underrepresentation of women in mathematics, especially at the highest levels, were very common and popular to discuss. But at the start of the 21<sup>st</sup> century there seemed to be a change in the amount of public expressions of discontent. Had the issue of women in mathematics, which was once so urgent in the mathematical community, “disappeared from the radar screen?” (776). Further research proved to the AMS that though things are undeniably better than they used to be in the 90s, the problems women face in mathematics now are “not a dead issue,” but rather an “unpopular issue” (782).

Just a year later, Lawrence Summers, who was at the time the president of Harvard University, spoke at the National Bureau of Economic Research (NBER) Conference on Diversifying the Science and Engineering Workforce. Summers’ goal at the conference was to discuss the issue of women’s representation in tenured positions in science and engineering at top universities and research institutions. One of his three “hypotheses as to why we observe what we observe” was what he calls “different availability of aptitude at the high end,” that women do not have the same innate ability as men in these fields. The idea revealed how Summers shaped his speech around the

*greater male variability hypothesis*, which was originally proposed by Havelock Ellis in 1894 and states that the “variability in intellectual abilities is intrinsically greater among males” (Kane 10). Although the audience was forewarned that his speech wouldn’t be an “institutional talk,” but an “unofficial” attempt at “provocation,” the majority of listeners were very displeased. Both male and female speakers following Summers at the conference remarked that he had been “too dismissive of social explanations for underrepresentation” and “judged the work of so many of the scholars at this conference to be of no value in his ultimate conclusions” (NBER).

Rumor was that Summers’ remarks were a clever strategy to bring in funding and transform Harvard’s faculty, which was known for being only “13% women across all disciplines,” into a female-friendly and diverse group (Ceci 41). It could quite possibly be that his goal at the conference was to try to increase the “critical mass” of Harvard’s female faculty to create more of an atmosphere for students where being a woman would be “ordinary and normal” (Jackson 780). But the mathematical community, including the MAA, AMS, and AAUW, don’t believe in these underlying reasons. They believe that Summers is just plain incorrect; there are some differences in male and female innate abilities, but no one has yet uncovered any conclusive evidence that biological disparities might render women less capable of achieving distinction in these fields. Whatever the reason may be, Summers re-energized the national debate of why so few women enter technical fields, or STEM (Science, Technology, Engineering, and Mathematics) as they are more commonly known as today, in an era when women are increasingly prominent in other historically male fields such as medicine, law, and business (AAUW ix).

Research conducted after the Summers event focused on answering whether the lack of women in technical fields is due to ability and biological gender differences in performance within these fields or non-ability and environmental influences inhibiting female performance and aiding male performance. For the purposes of my thesis, I will be focusing this question and debate within the mathematical community. Most current evidence suggests that when taken in totality, non-biological factors are the major causes of the underrepresentation of women in math intensive careers. These include gender differences in cultural expectations, conflicts between career and family life, occupational preference, and more, which “limit women’s entry into these professions far more often than they do men’s” (Ceci *xii*). Biological factors, such as hormones, brain organization, and cognitive processes (spatial skills, mental rotation, and speed of processing), are only secondary factors in the explanation for women’s current underrepresentation.

This is seen cross-culturally. Countries around the world that focus more on creating a culture that fosters women in mathematics see a greater amount of female participation. Eastern European and Asian countries frequently produce girls with profound ability in mathematical problem solving, whereas “most other countries, including the USA, do not” (Andreescu 1258). Thus, this scarcity is due, to changeable factors that vary with “time, country, and ethnic group” (1257). If gender differences in means and variances are primarily a consequence of innate, biologically determined differences between the sexes, we would expect these differences to be similar across all countries “regardless of their culture” and “remain fairly constant across time” (Kane 10). However, we do not see similar differences among countries and changes over time in

mathematics variance and mean gender performance. These findings suggest that boys and girls may be born similar in “innate intellectual potential,” but end up displaying differences due to a variety of sociocultural factors present in their environment (10). This is more formally known as the *gender-stratified hypothesis*.

The main reason biological factors fail to provide significant evidence as the reason behind this problem is because the research found in favor of ability are often inconsistent and cross-cultural analysis supports the gender-stratified hypothesis. Greater male variability and gender gaps in mathematics, when present, are “large artifacts” in a “complex variety of sociocultural factors” rather than intrinsic differences (11). Still, there is no single or simple answer for why there are substantially fewer women in mathematical professions, or even STEM professions. A wide variety of factors that influence emergence into a mathematical career have been identified and include “cognitive sex differences, education, biological influences, stereotyping, discrimination, and societal sex roles” (Gernsbacher). Hence, my thesis will describe why ability factors are still an important component of the nature versus nurture debate in the context of women in mathematics, but will be dismissed so that focus remains on the larger, more influencing environmental issues at hand.

It will be important to note, in the biological section, how visuospatial skills are essential to successful mathematics performance. The ability to “mentally navigate and model movement of objects in three dimensions” is helpful in solving math problems that rely on creating mental images (Gernsbacher). Young boys excel in these mental rotation

exercises and are able to hold three-dimensional objects in memory while at the same time transforming the objects. This may explain why boys prefer to play with objects such as Legos, building blocks, and erector sets, whereas young girls are more oriented towards people in their childhood and prefer dolls and dress up (Ceci 31). But this also encourages gender bias in play styles and toy selection, which nurtures and improves male superiority in spatial ability at a very young age, giving boys an edge in solving these types of math problems. This example and many others show the result of a “complex interplay between nature and nurture,” and also the circularity between biology and the environment (Kane 11). Young boys may have an advantage in visuospatial skills when compared to young girls, but is this because of their natural interest and thus time spent with these types of toys, or is it because of their developed interest encouraged by society to play with the toys. These nature vs. nurture questions of “Which came first?” are difficult to answer and somewhat comparable to the famous Chicken or the Egg question.

Biological evidence suggesting that girls come into the world with an “orientation towards people” and boys come into the world with an “orientation towards objects,” show that nurturing different orientations for boys and girls could lead them down “differing paths of interests” (Ceci 31). The cultural section of my thesis will argue that not only do women have other responsibilities and obligations, such as to the family, which conspire to limit them in mathematics, but that the nature of mathematics itself and the mathematical community do not overlap with female interests as well as they do male interests. Society has influenced women to prefer more nurturing and people oriented

professions, such as nursing and teaching, rather than quantitative careers like mathematics, physics, and engineering. Some scholars argue that because of this reason it does not make sense to encourage and direct females to take part in jobs that they essentially don't have a preference for and will eventually be unhappy with. However, I will be making the case, after having my own personal experiences in the mathematical community, that females should be encouraged to develop mathematical talent, even if it is unnatural for our society to do so in present day. Mathematical fields would advance significantly if they were to embrace solutions to become a more desirable female profession because "there is not simply one mathematical reality" (Henrion 264). It is important to have many different people participating in mathematics much like anything else in the world because individuals see things in different ways and bring unique perspectives.

### **Summers Dilemma**

Lawrence Summers' remarks caused a national stir because many took his statements as direct insults to the intelligence of women in the science and engineering workforce. He publicly argued that one of the main reasons we see a gender gap in science and engineering fields is because males and females are cognitively different in these areas. This public statement got people's attention more so than similar research studies previously published and debates erupted over whether "intrinsic differences

between the sexes” were responsible for the underrepresentation of women in mathematical and scientific disciplines (Gernsbacher).

Summers’ remarks upset so many people because it implied that there was no way to fix the women in math and science problem, that any attempt to “close the gap was futile” and we should just accept the natural order of things because women are “naturally deficient” (Gernsbacher). Not only were people furious he put so much emphasis on biology and less on socialization, but that he also thought people, that is mostly women, “choose” to have careers of one kind or another in business that are less demanding of “passionate thought” all the time, alluding that other timely responsibilities, such as duties to the family, do not require passionate thought and devotion. Even if Summers’ remarks were extreme, his speech was successful. His main point was to “provoke thought” on the question of the underrepresentation of women in these careers and the “marshaling of evidence” to contradict what he had said in his three hypothesis speech (Summers).

His first hypothesis, the *high-powered job hypothesis*, suggests that the “most prestigious activities in our society,” such as a career in mathematics, “expect of people who are going to rise to leadership positions in their forties near total commitments to their work.” They expect a “large number of hours in the office,” “flexibility of schedules to respond to contingency,” “a continuity of effort through the life cycle,” and they expect that the “mind is always working on the problems that are in the job, even when the job is not taking place.” Summers states that it is a “fact about our society” that these

high-powered jobs require a particular level of commitment, that a much higher fraction of “married men have been historically prepared to make than of married women.” He explains this is not a judgment of “how it should be,” but rather what the career expectation is. More men choose to accept the commitment of having their job at the forefront of their minds than do women and for obvious reasons such as commitments to the family.

Summers second, most controversial hypothesis is *different availability of aptitude at the high end*, the core of his biological argument. It explains how men by nature have talent for the highest levels of STEM career fields. Summers reasoned that there are many human attributes that are “not plausibly, culturally determined.” Such attributes include “height, weight, propensity for criminality, overall IQ, mathematical ability, [and] scientific ability.” Summers, sure of his case for the biological, says these examples have “relatively clear evidence” that there is a difference in the standard deviation and variability of a male and female population, only the difference in means is debatable. Summers would prefer to believe in something else besides this hypothesis, but says that it is an “unfortunate truth” that there is a different availability of aptitude at the high end. For Summers, it would be easier to address a “serious social problem,” but it is wrong-headed to just dismiss the biology.

The third hypothesis is concerned with patterns of discrimination and socialization. Summers explains, there is strong evidence of “taste differences between little girls and little boys that are not easy to attribute to socialization.” He claims that

little girls are socialized towards nursing and little boys are socialized towards building bridges only to a certain point because the last decade of empirical psychology has confirmed that “people naturally attribute things to socialization that are in fact not attributable to socialization.” Summers believes that the socialization case is pretty much “over,” but doesn’t provide any evidence other than his opinion that the “human mind has a tendency to grab to the socialization hypothesis when you can see it, and it often turns out not to be true.” He argues that the case for discrimination as a “dominant explanation” of the patterns observed is also over. Based on my own independent research, I also agree. Surely there is some discrimination that goes on to contribute to the gender gap in mathematics, but current research is pretty conclusive that this is a minimal factor creating a lack of women in mathematics and similar fields. Recent studies indicate that even if discrimination does happen today, it is usually implicit (AAUW 74).

Summers ranked the order of these three hypotheses in order of importance, so it would seem that Summers placed biological related factors ahead of environmental related factors, and placed commitment and expectations (in a high-powered job) even higher, separated from biological and environmental factors. Though Summers doesn’t see it, his highest priority reason for the lack of women in science and engineering is actually at its core an environmental issue. The expectations and level of commitment of a high-powered job are not only set by the requirements of the discipline itself, but by the norms defined by a culture. For example, earning your bachelor’s degree and then obtaining a full-time job is common in America just as having at least a master’s degree

and working over forty hours a week most likely defines the bulk of “high-powered” professionals. The common expectation to work nine to five doesn’t really come from the job itself, but from the way American’s have traditionally structured their daily routines. The fact that Summers asks “is our society right to expect that level of effort from people who hold the most prominent jobs” shows how commitments and expectations are undeniably tied to the environment of our professional culture.

The big question Summers feels must be addressed is who “wants” to do high-powered intense work, as if it is only a matter of having interest in the work and agreeing to the commitments and expectations of the job. But the reality is that there is a huge difference between wants and needs. Many women may want to do high-powered intense work forty-plus hours a week, but they need to take care of their responsibilities to the family such as caring for their children and taking care of a household. Many times, the needs that males and females put first are culturally defined such as the mother being the primary care provider and the father the breadwinner. Both men and women make employment choices based on interests, but they also base decisions on how society perceives their choices and how it will affect them within their situation. A father may opt to work and not be a stay-at-home dad because it’s not a job that gives him the credit or satisfaction he seeks and a mother may turn down a job with a rigid nine to five schedule because no one would be home with the children after school.

Therefore, Summers’ question, “Who wants to do high-powered intense work?” would really be a lot stronger if it consisted of three parts:

### **Ability Related Questions**

*Skills*            1. Am I qualified to do high-powered intense work?

### **Non-ability Related Questions**

*Interest*            2. Do I want to do high-powered intense work?

*Situation*            3. Can I do high-powered intense work and still address my needs?

Men are more likely than women to be able to answer yes to the last two questions and make the decision that they can have a job that they think about 40 hours a week. Experts became furious with Summers because he thinks that answering question number one depends on your gender, that “in the special case of science and engineering, there are issues of intrinsic aptitude, and particularly of the variability of aptitude, and those considerations are reinforced by what are in fact lesser factors involving socialization and continuing discrimination.” The skills you need to be successful in a high-powered job are not in any way prohibited or enhanced by your gender alone, and gender most certainly does not determine your skill level.

A possible reason for the lack of women in mathematics and other STEM fields could be a general “clash between people’s legitimate family desires and employers’

current desire for high power and high intensity” as Summers suggests, but intrinsic aptitude is not a major reason for this gender gap. Thus, I will now address how biological differences between genders provide less convincing evidence than environmental factors for the reason behind the lack of women in mathematical professions, especially at the highest levels of mathematics, and that gender does not significantly affect or inhibit the skill of an employee in a mathematical career. I want to mention that even though I have read many books and articles on this topic, I still struggle with this nature vs. nurture debate and trying to figure out how to rationalize a logical reason for the problem. It is unquestionably a highly difficult problem that persists in our world, with no easy answers.

## **II. Mathematical Ability**

When thinking about female math ability, one question that arises is “Do women do mathematics differently from men?” and if so, is the way they do mathematics more or less beneficial to the mathematical community? (Jackson 783). In order to answer such a question, it must be determined what the mathematical community is like, what defines mathematical ability, and find out if women and men possess different traits and skills that make them equally or unequally qualified to do mathematics. Even though males and females work on the same kinds of mathematical problems they tend to have different working styles, strategies, and approaches to the problems and this may lead males and females to have different mathematical strengths and abilities, some that could be more suitable for a high-powered career in mathematics.

### **Traits that Affect Female Approach to Mathematics**

One of the ways women tend to differ from their male counterparts in behavior and character is that they tend to not engage in the “aggressive, highly competitive sparring” that sometimes enters mathematical conversations among men in the workplace or at a university (783). Because women approach competition and criticism differently from men, they are more likely to “shy away” from competitive or aggressive

confrontations over mathematics (783). In a professional environment, competitive debates could show an employee's passion for their work, their pursuit of knowledge, and display their on hand skills. However, competitiveness could also distract the collaborative workplace and frustrate colleagues, limiting the progress and success of work. Though gender traits like this may be hard to distinguish whether they prohibit or favor women in math, other strategies and approaches females tend to use in mathematics are undesirable, such as their use of manipulatives that contribute to their lack of mathematical intuitiveness when compared to men.

Recent research has shown that girls' understanding of mathematics in the primary grades may be limited by their overreliance on manipulatives, which could affect how they practice mathematics in their futures. The study showed that the majority of grade school girls had a tendency to fall back on model representations suggesting that girls "often adopt concrete strategies and use them exclusively" (Ambrose 18). However, grade school boys tended to adopt abstract strategies by not using the manipulatives and invent their own solutions using "mental mathematics" (17). The boys did not have difficulty with extension problems showing that they understood the mathematical idea being taught in their classroom whereas the girls struggled to show they understood as well as the boys when they were asked to answer extension problems. A potential explanation for why these primary school girls may have chosen to operate on "automatic pilot" and use concrete strategies and standard algorithms could be that they had been practicing a technique that they had perfected months ago, one that "always worked to find an answer that she could easily explain" (18). Another reason could be that the girls

thought that the teacher “expected” them to do so, that concrete strategies using manipulatives taught in the classroom was what the teacher wanted to see replicated in the exercise (19).

Not only are girls characteristically less competitive and confrontational than boys, they also tend to be particularly more “sensitive to the directions of the teacher and try to comply with expectations whenever they can” (19). Because girls are often more interested in “explicit communication,” they may be attracted to strategies that can be “explained clearly and are familiar to other students in the room” (19). The girls listened to what was taught and used teacher-sanctioned strategies. Though, it seemed like a rational choice for the girls to make, “unfortunately these choices seemed to limit their understanding” of the material (19). While the girls choose conventionality, the boys furthered their learning beyond the girls by increasing their mathematical intuitiveness, a very important skill to have when doing math. Thus, adjusting techniques seems to “increase the power of mental mathematics” because the child has to “actively think through the problem rather than go on automatic pilot” (19).

The concrete vs. abstract strategies example represents the fact that even at a young age, boys are naturally more inclined to “work in their heads” (20). This could explain why men historically score better than females on the ACT, SAT, and GRE and why females historically earn better grades in college mathematics courses that are much more explicit than standardized tests and require following the expectations of the teacher. Even in their adulthood, men in mathematics attempt “conceptual shortcuts and

unconventional techniques” while females tend to use “school-taught, often less efficient techniques” (19). Could this be the reason women lack in the field of mathematics?

It seems that the general female behavior of being compliant with expectations limits females from success in math, beginning at an early age. Though this behavior appears to occur naturally in females more so than males, it is not certain that any behavior and characteristic traits are biological in origin because of the uncertainty in whether “differences in behavior result purely from socialization or purely from biological causes” (Gallagher 319). The first information that a family receives is the sex of their newborn and this single piece of information “sets in motion a lifetime of culturally based expectations and sanctions” (318). All children are socialized from birth into their “sex classification” with “different sets of behaviors either rewarded or discouraged by parents, teachers, and peers, depending on the gender group to which the child has been assigned” (319). Thus, it is completely impossible to separate any behavior and characteristic traits due to biology from traits that may be due to socialization.

Because traits that affect female ability in mathematics can’t help the case for biology in the reason for the lack of women in mathematics, the next step is to discover if there are particular mathematical skills or abilities needed to be successful in mathematics that are not trait-based, or abilities that are learned and not given at birth. As was explained previously, mathematical intuitiveness is a greatly desired skill to have in a mathematical career because it allows for adaptability to different problem sets that the

mathematician may face and more successful outcomes than relying on standard, by the book techniques. Though the previous study proved that men have this skill more often than women, how important is this skill to an individual's success in the career field as a whole? There must be other skills such as mental rotation and spatial ability that are important for mathematicians to have. What learned skills are necessary for a successful math-oriented career and are these skills that men possess more often than women?

### **What makes for a “Good” Mathematician?**

Math is very versatile. To be in a math-oriented vocation could mean you are an actuary, cryptanalyst, economist, electrical engineer, professor, statistician, or computer scientist, of which are all very different positions. Math-oriented jobs are not defined to one area and practically carry over into the majority of other career fields out there: business, computers, science, engineering, etc. For example, there is a large difference in skill set if you do mathematical research or if your work requires more applied mathematical problem solving. Both theory and applied mathematics require exceptional math ability, “outstanding mathematical intuition and creativity,” and interest in devoting “considerable time and effort toward acquiring extensive knowledge in the field” (Andreescu 1257). However, while research requires “stamina” to work on problems over extended periods of time without knowing whether or not a solution even exists, real world problem solving does not (1257). In industry, applied mathematics involves using

what works. Sometimes what can be done quickly in a business is not necessarily the most effective mathematical solution to a practical problem.

For the purposes of this thesis, I will define anyone who works in any one of these many math-intensive professions to be a “mathematician” no matter if they do theory based or applied mathematics. You can’t really rule out or quantify all the skills that would be necessary to make a so called “good” mathematician because “there is no single intellectual capacity that can be called ‘scientific ability,’ the skills important for work in the fields of STEM (Gernsbacher) and one can’t assume that achieving a PhD in mathematics is a good measure of extremely high math potential (Ceci 19). Nobody knows specifically what it takes to be a successful engineer, physicist, or operations research analyst, but we do know that within all these given fields there is considerable reliance on mathematical, spatial, and reasoning ability. Since we don’t even know which occupation high-end math students will be seeking, what needs to be determined is which precursor abilities, or abilities “under one’s belt before heading down the road to success,” these students need to be a “good” mathematician (80). These are the combined skills that would be needed of any mathematical profession. Experts Ann Gallagher and James Kaufman of *Gender Differences in Mathematics: An Integrative Psychological Approach* highlight the top cognitive skills that underlie mathematical ability as follows:

1. **Verbal abilities** are needed to interpret and understand the problem context.
2. **Visuospatial skills** are often needed to represent mathematical concepts and the relationships among concepts and to manipulate visual representations of the problem space.
3. **Quantitative competence** (numeracy [basic operations, calculations, estimation], reasoning, applying logic, judging accuracy of solution) is needed to reach a solution.
4. **Speed of processing** is important in timed tests (e.g., national and international normed tests) and in problems where the time demands may cause loss of information from working memory.
5. **Self-efficacy/motivation** and executive processes that monitor progress toward the solution.

(Gallagher 64)

## #1 Verbal Skills

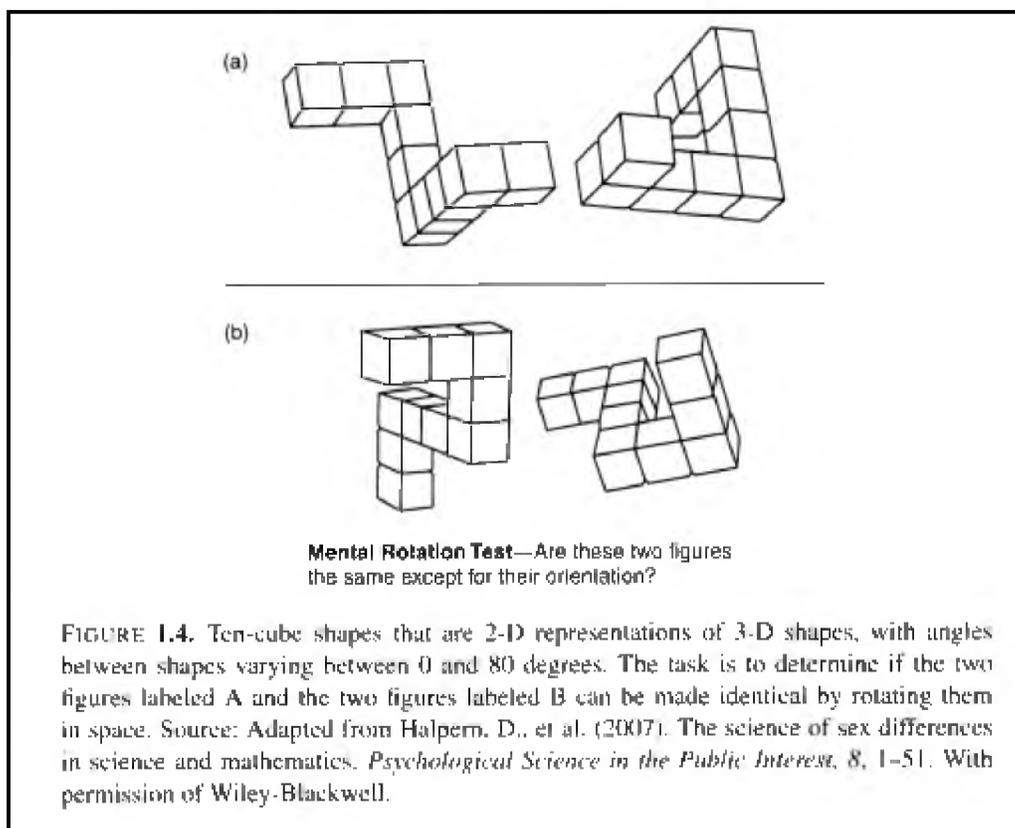
Verbal skills, cognitive process number one, have been repeatedly proven by research to be a strong quality that females possess. Many educators and psychologists claim that “men excel on skills subserved by the right side of their cortex, such as quantitative and spatial skills” and that women excel on “skills subserved by their left cerebral cortex, such as verbal measures” (Ceci 83). Thus, women tend to perform better on most assessments of verbal abilities “by the end of grade school and beyond” while

males are, “on average, at a rather profound disadvantage in the performance of this basic skill” (Gernsbacher). Verbal skills are essential for a mathematician to have in the work environment so that he or she may effectively explain issues and revelations to colleagues. A good employee with strong communication skills will be able to converse with others to gain new knowledge in the workplace. Overall, a successful mathematician needs strong verbal skills to display to superiors their understanding of the mathematical concepts related to the work to further his or her success in the career path. Thus, verbal skills are extremely important to a “good” mathematician, but because verbal skills do not give male mathematicians an advantage, this skill is not contributing to a lack of women in mathematics.

## #2 Spatial Skills

The second cognitive skill, visuospatial skills, has been frequently researched and talked about again and again in many of the books published after the Summers dilemma. Visuospatial skills are the ability to “mentally navigate and model movement of objects in three dimensions” (Gernsbacher). This includes having an advantage in things such as solving mazes, creating mental images, and of course, solving any geometry related math problem. Some claim that visuospatial skills are some of the most important skills for people with extraordinary math talent to possess. Others say though it is important, there are still many other skills that are of comparable importance to succeed in math such as logic and reasoning. Visuospatial skills have many manifestations. These include mental

rotation or spatial transformation, “holding a three-dimensional object in memory while simultaneously transforming it” (Gernsbacher). For example, a mental rotation problem on a test would involve two-dimensional and three-dimensional perspective drawings shown at different orientations. The test-taker must determine if the two objects are indeed the same object (see Figure 1.4).



(Ceci 25)

Unfortunately, some of the methods for assessing mental rotation and other spatial abilities are sometimes inconsistent because “minor adjustments” to the test administration procedures, such as changing the time allotted or the number of problems

involved, can significantly affect results (24). Hence, it is hard to obtain accurate results of sex differences that experts encompass as spatial ability. Nevertheless, on spatial problems similar to the ones shown above, the sex difference is large, “often falling in the  $d \sim 0.7-0.8$  range” (84). To solve such a problem, a man will likely form the “image of one object and rotate it mentally to see if it aligns with the other object,” while a woman will likely “engage in a feature-by-feature comparison of the objects” (85). Because men tend to utilize spatial transformation techniques more often than women, it is said that they possess more spatial ability; “males score higher than females on both spatial cognition tests (particularly mental rotation tests) and math fact retrieval tests,” which is more commonly known as speed of processing (Gallagher 116).

The differences in spatial skills are another example of how men and women do math differently, not how men do math better than women. Depending on the problem, spatial transformation strategies may be more useful than others. Spatial skills help with finding an acceptable problem representation. This can involve visualizing a graph on a coordinate plane, intersecting planes in three-dimensional space, or being able to compare the scale of two objects in your head to solve a problem. Only once a problem is represented can you proceed to finding a solution. One would think this would allow you to more accurately solve the problem, but interestingly the most recent studies conducted have not been able to find a correlation between spatial scores and math performance (79). Spatial ability predicts more accurate problem representation, not accuracy of mathematical performance. Spatial cognition is an “index of an examinee’s ability to create a problem representation that can be used to develop and guide a solution to a

problem” (116). Thus, a more recent conception between mathematics and spatial function suggests that “spatial cognition is not directly related to mathematical functioning; rather, spatial abilities mediate mathematical abilities” (104).

Even if spatial skills are separate from mathematical processes, they still actively affect the overall ability to produce valid mathematical solutions, the end goal for any “good” mathematician. Spatial skills are a great tool for students to utilize because success in finding an appropriate problem representation will lead you to a proper solution faster so you can move on to the next problem, which will allow you to become more familiar with different types of mathematics or different ways to approach a problem. Thus, spatial ability advantages students taking standardized tests like the SAT-M; “spatial ability and math fact retrieval ability are predictors of math test performance” (116). Spatial ability can go a long way, especially if you are trying to get a near perfect score on the SAT to get into MIT or compete with others for a spot at another topnotch technical university. Whether you get to go to MIT or your local community college clearly affects your career path and entrance into high-end mathematical occupations. And if you are able to get into that college and land that high paying job, spatial skills will continue to help you become an efficient employee by allowing you to conceptualize the problems encountered in the real world.

Girls and boys start school being essentially equal in math, but girls score less and less at the right tail in math tests as they grow older. There is “a great deal of data” showing the underrepresentation of girls scoring at the outer right tail of the spatial ability

and math distributions, “those whose aptitudes rank in the top 1% and higher” (Ceci 29). Since research proves male superiority in spatial ability and also in math performance, does this mean spatial skills are one of the reasons why women don’t make “good” mathematicians and there is a lack of women in the workforce? Out of all the skills observed spatial skills do seem to be the most convincing skills that separate men and women math, but as mentioned before there is no concrete evidence because of the lack of correlation between spatial scores and math performance. If more research comes forward suggesting that spatial ability is the reason women lack success in mathematics, the biological case would still fail to be a reasonable explanation for this skill difference simply because spatial ability can improve with practice and is not innate. According to widely respected researchers Stephen Ceci and Wendy Williams of *The Mathematics of Sex: How Biology and Society Conspire to Limit Talented Women and Girls*, a life time of “different experiences could bring about substantial change in spatial behavior and/or the brain regions that support it, which are not necessarily genetic in origin:

*If boys spent their childhoods building with Legos and erector sets and girls spent their childhoods playing with dolls, it would not be surprising to find that this resulted in brain changes that in turn led to later spatial and social skill differences, but their existence would not prove their origin was innate.”*

(85)

The authors of *Why So Few* from the American Association of University Women, Dr. Catherine Hill, Christian Corbett, and Andresse St. Rose, also agree that

spatial skills are not innate, but “developed” because spatial skills are learned. Spatial skill can be improved with training - that is the reason for an education system in the first place (AAUW 56). They convey the importance of women increasing their spatial abilities, as it will give them increased confidence in their math skills because they will be able to more easily interpret mathematical diagrams and drawings to formulate a solution.

John Van de Walle, who has been recognized by the MAA for his writings on elementary mathematical education and developmental teaching, actively promotes reform mathematics, that mathematics is learned and that anyone can be taught to do math well. He says there are no excuses like “I was never any good at math.” He uses the basic tenet of constructivism to prove that anyone can construct their own mathematical knowledge; “the tools children use to construct knowledge are the ideas they already have. To use ideas to construct new ideas means that children must be mentally engaged in the act of learning” (Van de Walle). Thus, mathematical ideas, such as the use of spatial ability, form a representation can be “taught via problem solving” (Van de Walle). Conclusively, there is still more research to be done on gender differences in spatial skills, but any new confirmations that prove gender affects spatial ability will only provide information to understanding gender differences in math achievement, not innate ability, because anyone can learn these skills with enough practice.

### #3 Quantitative Skills

There has been much talk about the variation of quantitative aptitude between genders, the numeracy, reasoning, and logic competence to reach a mathematical solution. Two of the most common ways our society measures quantitative skills before entering a career is through grades and test scores and there is without a doubt variation in math performance in these assessments when one compares men to women. Females overall get higher grades in math classes and males score higher on high-level math tests like the SAT-M, ACT-M, and GRE-M. Though women make up fifty percent of college math majors (Ceci 5), they only account for 24% of the STEM workforce according to the United States Department of Commerce. Do different assessments affect one's perception of quantitative ability, creating a disconnect between men and women? Which assessments really matter and display true quantitative ability?

Males have outperformed females on the SAT-M for 30 years (Gallagher 101). US-born women are also vastly underrepresented among top Putnam scorers, a mathematical competition for undergraduate students in the United States and Canada (Andreescu 1250). The reason why this occurs is disputed. Most researchers today believe this is due to the fact that males often display "more variability of performance on standardized tests than do females" (Gallagher 101). Female test scores are more centered in the distribution, while male test scores range from extreme lows to extreme highs. Because boys are variable test takers, there are more males than females left at the high end of the distribution. Some people take this to mean that more boys are mathematically

gifted. They disregard classroom grades and see that test scores show “females of any age are more clustered toward the center of the distribution of skills and males are spread out toward the ends” (Gernsbacher). So they believe that because men “outnumber” women at the very high and very low ends of the distribution, men have overall higher quantitative abilities (Gernsbacher).

Though I can see where this line of thinking could make sense when comparing males and females in the high end of the distribution, I know that accurately measuring quantitative ability is a complicated task in and of itself. Some think that grades in math courses are more reflective of strong quantitative skills whereas others claim that standardized tests are more reflective. In school you have a chance to be taught the material, giving you access to the tools you need to apply reasoning and logic and calculate a solution to a problem. Because there should be no surprises on what you will be tested on in a math course, people say that grades do not reflect purely intuitive mathematical thinking and sharpness, unlike standardized tests where you have no idea which type of math problems will be thrown at you and you are limited on time. However, math grades are equally as important as standardized test scores because they document your continual dedication to learning mathematics and participating in the community of mathematical scholars. Good grades show that you are hard-working, understanding the material, and are not just a good test taker.

An employer of “good” mathematicians should value both assessments of quantitative ability. Good scorers and A+ students will be similarly efficient and accurate

workers. Sure, the good scorer may be quicker on their feet, but the A+ students will have the drive and motivation to do his or her job well and will be less likely to ever procrastinate or take the easy way out on the job. Both would become “good” mathematicians. Overall, I believe both grades and standardized scores are judged relatively equally in our society. For example, universities, which give students the opportunity to become “good” mathematicians, will be lenient and let in an applicant that has a bad high school G.P.A. and a 36 on the ACT just as much as they will accept the applicant who has a 4.0 and only a 20 on the ACT. Quantitative skills are really proven through grades, scores, or both in our society. Thus, the perception and assessment of quantitative skill is defined by our culture. Quantitative skill is learned and achieved through grades and scores in a societal system. It is not an innate skill and is not the reason for the disproportions between genders in mathematical careers and interestingly enough, “when all data on quantitative ability are assessed together, however, the difference in average quantitative ability between boys and girls is actually quite small” (Gernsbacher).

#### #4 Speed and Memory Skills

There are many studies that agree that females also have an advantage in memory of faces and in episodic memory, “memory for events personally experienced and are recalled along with information about each event’s time and place” while men are noted to be better than women at speed of processing, the ability to use information from

working memory (Gernsbacher). Like spatial skills, speed and memory skills are benefits when doing mathematics, especially when earning a grade or taking a standardized test. These skills are still very valuable later in life, in a math career where accomplishing projects, problems, and tasks in a timely matter is important and easier when one is able to use their working memory when they come across a problem they have not seen in a while. Speed and memory skills can be developed and enhanced with practice and exposure as I talked about with spatial ability. Speed of processing is not innate and gender does not affect the attainment of the skill. However, interest and drive greatly affect the development of spatial ability, speed of processing, and other learned abilities that help one to do well in math.

#### #5 Interests and Drive

Interest and drive, though not really skills, distinguish those who want to do math from those that do not; they do not distinguish those who have natural talent for mathematics. All men are not born with a desire to pursue math and neither are women. Interest to do mathematics is developed like the other skills that we have considered that make for a “good” mathematician. I have found through analyzing the various skills required to do “good” mathematics that gender does not affect skill though I still need to consider whether gender affects non-ability related questions like one’s interest and situation to do math. For each skill we considered would make for a “good” mathematician, we have failed to find that women definitively lack the abilities at birth;

rather, the abilities to do mathematics are mostly learned and nurtured, which invalidates the case for biology. Things like interest, as I discussed in the Summers dilemma, are non-ability related questions. Some argue that boys find it intrinsically more interesting to do mathematics than women, but I will show later that this is due to female perceptions of their ability being affected by society's perceptions. In all, I have found biology and culture are complexly integrated. Biology cannot be separated from culture. Hence, biology fails as the major cause of the lack of women in mathematics because none of the cognitive skills associated with math abilities as defined above are conclusively biological

### **Gender Ability Similarities**

By nature, men and women are more alike than different in their acquirement of mathematical skills and thus have similar mathematical ability. In fact, the *Gender Similarities Hypothesis* seconds this notion of gender similarities in mathematical ability because men and women share cognitive skills such as “mathematical problem solving,  $d = 0.8$ ” where the  $d$  statistic measures the distance between male and female means in standard deviation units (Hyde). The research, which was based on testing of more than 3 million people and 100 studies, found emerging patterns in gender differences in math performance, such as the age of test takers and the cognitive level of the test. “Girls outperformed boys on computation in elementary school and middle school ( $d = -20$ )...there was no gender difference in high school...[and] no gender difference in

deeper understanding of mathematical concepts at any age” (Hyde). Even for complex problem solving there was no gender difference in elementary and middle school and only a slight difference favoring boys in high school with  $d = 0.29$ . During college, “women major in mathematics in nearly equal numbers to men” (Ceci 17). According to the U.S. Department of Education's National Center for Education Statistics, women have earned 43% of bachelor's degrees in mathematics from 2008 to 2011. Thus, many findings are consistent in demonstrating that “substantial numbers of women” do have the ability to engage in mathematics successfully at the advanced levels and that there must be a particular attribute about the nature of the work environment that limits women from continued advancement of their abilities and achievements in a career.

Another study consistent with the gender similarities hypothesis concluded that “gender similarities characterize math performance;” for grades 2 to 11, the general population no longer shows a gender difference in math skills (Hyde). With this research they also found slightly greater male variability in scores, although the “causes remain unexplained.” Curious, the experts tested to see whether greater variability translates into gender differences in the upper right tail of the distribution, or superior abilities in mathematics. If gender differences exist in the upper right tail this could be an explanation as to why there are so few women in the field of mathematics, that “cognitive complexity” and “depth of knowledge” are crucial for advanced work. To do this, the researchers used data from state wide testing. They tested mathematical knowledge in three levels: 1. Recall, 2. Skill and Concept, 3. Strategic Thinking, and 4. Extended Thinking. Unfortunately, it was “impossible” to determine whether there was gender

performance difference at Levels 3 and 4 simply because “for most states and most grade levels, none of the items were at levels 3 or 4.” Whether the gender gap remains in complex problem-solving is inconclusive because “state assessments designed to meet NCLB (No Child Left Behind) requirements fail to test complex problem-solving of the kind needed for success in STEM careers.”

But as I have said before, it would be practically impossible to test the kind of complex problem solving required for success in STEM or mathematics alone because the field is so broad and applicable. As mathematics continues to grow in depth and breath, it becomes “increasingly difficult to capture it in a simple definition” (Henrion 263). Currently, research verifying gender differences exist in the upper right tail distribution have been inconclusive or simply don’t exist, probably because such a hypothesis would be hard to test given the of adaptability of math to many areas. Because of such reasons, we may never know if there are truly gender differences in the upper right tail distribution; “we know far less than we should about the assessment of mathematical ability and the measures we currently use require recalibration” (Lewis). Until such conclusions are drawn we must ask ourselves: Why is there still a gap in the workforce if men and women have similar mathematical abilities? A decade of literature suggests there is a gap in our society because obtaining success in mathematics is affected by our environment more so than other fields are. The gap is not differences in ability, but in differences of achievement.

Culture, ability, and achievement are highly relational and dependent on one another. Though natural abilities between men and women in math are presumed to be largely similar, learned abilities obviously increase with achievements, opportunities, and experiences. Achievements in math differ between genders when cultural pressures conspire to limit the continual development of mathematical abilities for females. Thus, the dearth of women in mathematics is not a matter of ability. It is a matter of how biology and culture are assimilated; achievements depend on potential given to us at birth and abilities enhanced by our experiences in society. Because the problem is grounded in how our abilities are derived from our experiences and achievements, the argument for the case for biology can be superseded by the case for the environment even though they are integrated. As the case for biology is left to rest in this chapter, I progress the debate in the next by determining the reasons why our environments have created large differences in professional mathematical achievement for men and women when only minor differences in precursor abilities exist. Is there a prevalent assumption in our society that “being a woman and being a mathematician are incompatible”? (Henrion 67).

### **III. Mathematical Achievement**

One of the strongest examples explaining how an environment can create significant gender differences in mathematical achievement is a cross-cultural analysis or study of the differences in math performance between genders across nations. As I mentioned in the introduction, cross-cultural analysis supports the *gender-stratified hypothesis* that boys and girls may be born similar in innate intellectual potential, but end up displaying differences due to a variety of sociocultural factors present in their environment. These factors are *changeable* such as time, country, and ethnic group. Countries like Eastern Europe and Asia see a higher percentage of women succeeding in math because their culture supports and fosters female participation in mathematics.

#### **Cross-Cultural Analysis**

In 2008, the American Mathematical Society (AMS) published *Cross-Cultural Analysis of Students with Exceptional Talent in Mathematical Problem Solving*, which proved that because there is no evidence of “similar differences” in mean gender performance across countries and across time, there is no way the differences can be innate (Andreescu 1258). The co-author of the article, Titu Andreescu, the former director of the MAA American Mathematics Competitions states “innate math aptitude is

probably fairly evenly distributed throughout the world, regardless of race or gender.”

The huge differences observed in “achievement levels” are most likely due to socio-cultural attributes specific to each country. In other words, differences in achievement are not in favor of genetically driven explanations because of “international variability in sex differences” (Ceci 163). The article presented for the first time a comprehensive compilation of data that included cross cultural comparisons regarding young people identified during the past twenty years as possessing “profound aptitude for mathematics based upon their performance in extremely difficult examinations in mathematical problem solving” (Andreescu 1249). The article identified the right tail of the distribution and found that there are many girls who possess extremely high aptitude for mathematics, but the “frequency with which they identified” is due to a variety of environmental factors (1249). They believe there are certain unknown conditions that girls must be raised in to have profound mathematical ability later in life. Only 12% - 24% of the girls in this study were raised under these conditions while “under others, they were 30 fold or more underrepresented” (1249).

American culture is shown to be lacking the conditions necessary to raise successful women in math. In the U.S. there is a social stigma associated with math. When U.S.-born whites and minorities gifted in mathematics were asked why they did not participate in math activities (math clubs and teams, AMC exams, and MATHCOUNTS) they typically responded “only Asians and nerds do math (extracurricularly)” (1256). Doing math for fun (outside of school) is uncool in the United States and doing so can lead to “social ostracism” (1256). Boys most likely feel

comfortable doing math for fun because they are “less socially astute or less concerned” about social status than most girls are (1256). Gifted girls, therefore, would be more likely than boys to “camouflage” their mathematical talent and spend time on nonmathematical pursuits in order to fit in better with peers (1256). This is backed by the fact that in the U.S. gender differences in math only begin to accumulate at the onset of adolescence, when social activities become a larger part of one’s life and they start to feel “pressure to conform to peer and societal expectations” (1257). There are “compelling explanations” on cross-cultural analysis out there focusing on differing national expectations and experiences between the ages of 9 and 13 more so than explanations involving genes (Ceci 165).

The United States needs to greatly improve the public’s perception of mathematics. I cannot even count the number of times I have told someone I am a math major and they have given me a weird look, raised their eyebrows, or told me they hate math in response. They usually ask “So you are going to teach, right?” Because being a teacher is socially acceptable and common career path for an American woman, they ask themselves why else I would be spending my time doing mathematics. In addition, it is only on rare occasions that I get a positive response from my peers when I say I’m a math major. To improve the public view would require new media, TV shows, movies, and role models to make civilians aware that women and girls in math are not necessarily nerds and that doing math is important and interesting. If the public’s perception still remains negative, American women will continue to not go into or stay in math careers because our country’s culture fails to provide support them. The AMS also found in their

study that profoundly gifted children “usually invest more of their effort in the fields that provide more positive feedback,” a fine explanation to why the U.S. would produce more female math teachers than females working for companies in the area of STEM (Andreescu 1257). Socio-cultural factors inherently influence the “fields in which profoundly gifted children are identified” (1257). What, then, are the factors that influence positive feedback for women in math in other countries besides the U.S.? It seems that countries like Asia and Eastern Europe may have an idea. They have repeatedly included at least 10 girls on their high school teams for the International Mathematical Olympiad while the U.S. only sends 3 girls, and even they were “often immigrants or children of immigrants from countries where learning mathematics is important” (MAA).

In other countries like the Netherlands and Lithuania, sex differences are larger at the left tail of the distribution meaning there are more gender differences in math between those who are not very good at it. In Sweden, differences occur at the higher scoring end or right tail, indicating male superiority at advanced levels. In the U.S. and Hungary, girls tend to “do as well as or better than boys at the left tail, but worse at the right tail” (Ceci 164). In Russia and Austria, sex differences are definite in the middle of the distribution. With so much diversity between countries there is no way sex differences can be due to biology, where consistency across countries should be seen. Because girls and boys “differ much more in some countries than in others” and at different points of the distribution, sex differences depend on “where you look” (167). The gender gaps in

some countries are very different than others because they have different cultures. If only American culture could show they value the power of doing math!

Sadly, experts have not been persuaded by the specific environmental explanations put forward about what it particularly is about each of these countries that “tilt” their sex differences in the distribution. Reasoning could go as far as a country’s use of math symbols and notations or even just the habits of the mind within a culture. Historical and cross-cultural analyses suggest what we consider “universal” in our experience with numbers may actually be “specific to societies that are economically developing and culturally open” (Hersh 49). Hence, the United States mathematical culture may not be as open as one would think, especially for women. For example, many indigenous languages such as those in Papua, New Guinea, only have words for “one,” “two,” and “many.” They do not have arithmetic or number words, but communicate “almost as much by singing, whistling, and humming as by using constants and vowels” (49). Even shared language and tools to do mathematics differ greatly among cultures. A women’s experience in America may be so different than a women’s in Asia that it could be like comparing how one does math in an indigenous culture with no number words or counting to how one does math in contemporary Western mathematical communities, with logic, abstraction, intuition, analogy, and visualization. It’s the culture that sets the state of the women’s and men’s experience with numbers.

Although the factors that influence women to feel positive about doing math in some countries and not others are unknown because most explanations seem

“suspiciously post hoc” such factors can definitely still be inferred (Ceci 164). Some countries “identify and nurture” females with exceeding math ability at a higher frequency than other countries (Andreescu 1257). The U.S. definitely needs to improve their ability to do this not only because careers in math are challenging, well-paying, abundant, fascinating, and beneficial to our society, but because doing so is “vital” to the future of the U.S. economy (1258). America needs to reduce their loss of mathematical talent because STEM jobs are the jobs of the future. In order to identify where the U.S. mathematical community needs to improve in its fostering of female mathematicians, I must understand what its culture entails and where it fails or succeeds at making women pleased in the field.

### **The Mathematical Community and Culture:**

#### **Seemingly Instinctual, Solitary, Single Males**

A career in mathematics is affected by the culture of its community. The mathematical community has had a long and rich history. Many mathematicians agree with Paul Halmos, the Hungarian-born American mathematician, who said mathematics is “Security. Certainty. Truth. Beauty. Insight. Structure. Architecture” (Hersh 46). The aesthetic components of discovery, proof, shapes, and patterns brings a source of joy to the field. The community sees the extraordinary beauty and elegance of the geometry and logic of arguments that lead axioms to proofs. But if one is going to see such beauty and unite with the members of their culture their “personal intellectual preferences – or what

psychologists call learning styles” must be consistent with the prevalent “modes of thought, of the culture, and of one’s chosen field” (47).

Basic mathematical activities require the “acquisition of abstract modes of thought” (48). Persons in the community must be able to think in terms of abstractions, that is the “idealization or stripping away of irrelevant details” and the “extraction or pulling out the essential features of a problem” (48). Thinking in this way, mathematicians “release a powerful emotional appeal” as they find patterns in nature and represent them mathematically (48). Some mathematicians call this the “Aha” experience or being in the zone. Andre Weil, a French mathematician who founded the term, describes the state as a “lucid exaltation in which one thought succeeds another as if miraculously and which the unconscious seems to play a role” (51). This experience, which is more formally known as intuition, is a habit of the mind generally associated with the mathematical community, making people think that the culture is full of intuitive, almost prodigy like thinkers. Intuition is a “perception that is plausible or convincing in absence of proof” and is very helpful in mathematical discovery because it is much less rigorous than “deductive methods needed for justification” (50).

Intuitiveness is thought to be tied with the *myth of homogeneity*, which says “Either you are mathematically inclined or you’re not” and makes it sound as if there is some kind of mathematical magic you must be born with that can’t be learned otherwise (54). Such thinking is simply untrue. Though intuition seems like a mode of thought that one is unable to do at will, creativity researcher Mihaly Csikszentmihalyi describes this state of deep immersion as “*flow*, a condition when challenge and skill are well matched”

(52). Mathematicians who have as much developed skill as the complexity of the problem at hand are more likely to figure out solutions. There is no magic in the process, only experience and practice.

In our culture, boys are far more often noted as being mathematically inclined and having this flow that is so valued in mathematical communities. This means that girls more often face a mathematical challenge where their skills are not equally matched with the problem and are not able to enter a state of flow. But, Csikszentmihalyi also stresses that to be in this state one must concentrate so deeply on a task that “they stop being aware of themselves as separate from the actions they are performing” (52). To have flow or intuition, one must let go of all the other thought processes of the mind and be encompassed in mathematical thought. British mathematician Michael Atiyah describes this experience and how mathematics must always be with you if you are to actively work in the community:

*“When I get up in the morning and shave, I am thinking about mathematics. When I have my breakfast, I am still thinking about my problems. When I am driving in my car, I am still thinking about my problems...acute concentration is very difficult for a long period of time and not always very successful. Sometimes you will get past your problem with careful thought. But the really interesting ideas occur at times when you have a flash of inspiration.”* (53)

Atiyah’s insight into mathematical success through intuition begs the questions of whether or not a career in mathematics is too intrusive in daily life. Though some women

may be able to enter into an intuitive state of mind, Atiyah's accounts show great evidence as to why women would be less intuitive when compared to men. Women in our society are usually responsible for waking up their children, feeding them breakfast, making their lunches, and dropping them off at school before work. The time before and after work is usually not a time when they can be immersed in thinking about their work when they have multiple other responsibilities flowing through their minds. "Even when husbands and wives both work full-time, women continue to assume most of the child care duties and shoulder most of the responsibility for tending to sick and elderly family members" (Gernsbacher). Many women are the "rock" in their families, they make sure their children and spouses don't require anything from them before they even begin to worry about themselves. Letting their minds go slack from all the culturally established responsibilities they are entitled to in order to be successful as mathematicians is unreasonable and impractical for anyone who has other interests besides math or for anyone who wants to have a life outside of the mathematical community, even if some of the best inspirations do come outside the eight hour work day.

The intrusive nature of math brings up the question of family life for a mathematician. A major issue that keeps the number of female mathematicians down is their desire to have children, which forces them to interrupt their continuation in the mathematical community. Women "opt out of careers to have children (or segue to part time employment) [and] this is a choice men are almost never required to make" (Ceci 203). A century ago, "the few women who aspired to [mathematical] academia expected to remain unmarried" and childless (Hersh 243). This limitation is not accepted by the

majority of women who pursue applied or research focused careers in math today. Having children is guaranteed to disrupt a mother's professional activities and study no matter the profession, but the main concern is how much the *child penalty* differs for women and men in mathematical careers. Men show a "slight tendency to benefit professionally when they become fathers" while for women, having children is associated with lower income (Gernsbacher). So the cultural norm for fathers to earn the family income is as harmful as is helpful. Until fathers assume an equal role in childcare and experience similar career limitations that come with it, mathematical communities need to provide "mother-friendly options" and get rid of the "strong disincentives" in place for talented women who want or have children, for example the loss of tenure for women in university research positions (Ceci 198). The community needs to change their overall perspective of mathematicians becoming mothers and convey "a very clear message that having children is not in conflict with a career in mathematics" (Hersh 251). Employers could show a change in attitude by offering day care options, extended maternity leave, and part-time status during certain periods of their careers to allow "people to have children and yet remain professionally active" (251).

The dedication and intensity of a mathematical life contribute to the notation of women being disinclined to math mostly because family responsibilities and interruptions affect women more so than men. Luckily, concentrated and narrow focus in math, or intuition, is not the only modal of thought that succeeds in the mathematical community, contrary to myth. Mathematicians differ in their approaches to discovery. They use visual, intuitive, unconscious, motor, auditory, and mixed "mechanisms of thought" (50).

And the culture should accept the diversity of style. Some rely on more geometric and visual processes while others may rely on symbolic and verbal, and others use a combination of the two. It is important that a mathematical community recognizes that mathematical intuition is developed and limited by society, and that the application of the talent is quite complex. A community should “recognize and appreciate the great diversity of thinking modes that contribute to the experience of mathematicians” (54). Such a culture should be open to “groups and individuals with varied talents and practices” and “varied cognitive styles” especially when culture seems to be prohibiting them (58).

Besides seemingly a culture of instinctual thinkers, the community of mathematics also appears to be a community of solitary thinkers from the perspective of an outsider. In reality there is lots of collaboration that goes on when one is doing mathematics. Mathematics today is “essentially an oral culture; to keep abreast of it one must attend conferences and workshops, or better yet, be associated with leading research” (178). Collaborative discussion using online forums is another more recent tool mathematicians have been taking advantage of. The amount of collaboration and social activity that goes on varies greatly among the many areas mathematicians can pursue, but “one can think of the whole mathematics community as the union of all these smaller subcommunities” (178). Each interacting mathematical community is unique in its own way. For example, one may choose to go into teaching math and be involved in a community of educators and students or one may instead find that they work better in a more independent community of researchers. As a whole, mathematics is a more solitary

field when compared to other professions given the type of independent work involved. The lack of social involvement in the discipline is a major reason why women may not be as satisfied with a career in math. Men may be able to come to terms with the “emotional complexity of living in an abstract world” by “cherishing their colleagues’ foibles” whereas women may be thwarted in how to deal with such abstractions when they feel so separate and unique among their male counterparts (68). Thus, in this traditionally male field, men may gain more, intellectually and socially, out of their conversations with peers because of that initial base of commonality they have of being male and understanding each other’s character and the way each other think and behave (see the beginning of Chapter II). A female mathematician most of the time faces a lack of female perspective, leadership, and role models and has a more difficult time finding those who understand her in the same manner and way she partakes in the community. Consequentially, the social aspect of the community does not appeal to her as it does to her male peers and she is faced with “greater difficulty establishing the connections and support systems” that are essential to her success (242).

Therefore, the definition of a community means to “include and to exclude” (179). Even the most successful women in mathematics continue to feel like outsiders. The separateness between men and women in the social sphere of math has led to tension, stereotypes, bias, and generalizations about intelligence in the past making entry into the mathematical community a “challenging and at times discouraging process” (180). The role of gender, or who are the insiders and outsiders, has been essential to the creation of the mathematical community; “Gender – femininity and masculinity – is not peripheral to

the social history of science and mathematics, it is fundamental” (Jones 7). The historians of *Femininity, Mathematics, and Science* have pointed to the “long-standing connection between masculinity and rationality on the one hand” and “femininity and the emotions on the other” (Jones 174). Though, these dualities have led to the exclusion of women from mathematics (and the sciences), the long exclusion has not lead to the realization of evidence in the inferior intellect of the female rationality or in male emotional capacity. Anyone who wants to make the argument that women are restricted in thinking rationally must also argue that men are restricted emotionally. I doubt any man would agree that women are better able to love, to empathize, or to be happy or sad. Just as with mathematics, women might have the opportunity to exercise such emotions more frequently than men because there are not as many constrictions on their role in society as there are for men. The example “men don’t cry” is an excellent example of such illogical judgments.

In ideal situations, entry into mathematics would be based exclusively on mathematical merit, but environmental factors have influenced access into the career field. If only the community could remain in its abstract world, away from the standards, biases, and values of the larger society. It is better understood in today’s culture that just because women fit in differently in this community does not mean they are worse at math or unable to be as successful in a professional career. It is vitally important that women, especially American women, remain determined to make their place in a characteristically male math culture. Professional practice is not “immune from long held society-wide assumptions about women’s contributions to outstanding intellectual work”

(Hersh 84). That is to say the mathematical community “never did exist in a vacuum” (180). Women will have to continue to fight for a comfortable place in this non-ideal community and the only way the culture of math will change is if women realize the environmentally established factors that conspire against them, those that affect their personal preferences, values, ambitions, career aspirations, choices, self-expectancy of success, and more.

### **Stripping of the Environment:**

#### **Revealing the Truth about Women’s Capabilities in Math**

In the introductory chapter it was established that there are three questions anyone must ask themselves before going into a career in mathematics or other high-power job field: “Am I qualified to do high-powered intense work?,” “Do I want to do high-powered intense work?,” and “Can I do high-powered intense work and still address my needs?” A woman who excels at math should be able to answer the first question of skill with confidence in her talents; “I am qualified to do high-powered intense work because I have had the opportunity to be trained and have been successful in my training.” The second question of interest still presents a problem when considering bringing women to the workforce because simply more men are eager and interested in math because the environment of the mathematical community and culture is better suited for them than a woman. If women are not interested in math, should society coax them into a field that they will be dissatisfied with in the long run?

Our environment is so superior to us that it can even determine our likes and dislikes. Most of us dream about pursuing a career where we hold interest. A 2004 study by Stanford University sociologist Shelly Correll verified that when “cultural beliefs about male superiority exist” girls “assess their abilities in that area lower, judge themselves by a higher standard, and express less of a desire to pursue a career in that area than boys do” (AAUW 44). When society decreases the interest of the mathematical field for women, it lowers their confidence and dilutes the perception of their true skills, which is particularly harmful. Many factors influence an individual’s career choice, but at a minimum, individuals “must believe they have the ability to succeed in a given career to develop preferences for the career” (44). People like the things at which they perform well. Just like when you are playing a game, losing is no fun. If girls do not believe they possess the ability to do well in the profession, they will choose to do something else to devote their time to and develop interests in another area besides math because individuals form career aspirations in part by “drawing on perceptions of their own competence at career-relevant tasks” (49).

Girls lower self-assessment of their math ability “even in the face of good grades and test scores, contribute to fewer girls expressing preference for and aspiring to STEM careers” (49). Society limits women in math because they make them believe the myth they are unequal in mathematical ability and are not as capable as men to achieve success in STEM careers. But if women prove their abilities in math by sticking it out in the currently less female friendly math community, they will gain larger achievements in math. This success will eliminate male superiority over time and the environment of the

mathematics community will change to be better suited for women since they have proven they are assets to the community. Once the community is female friendly, more women will have an interest in math and a preference for a career where they can see women are valued and rewarded.

Women will hold interest for math in an improved environment. It will take self-assured and revolutionary women to change the nature of math careers and establish mathematics as a discipline where women hold interest. Individual women will have to strip away and ignore the American culture that conspires against them if they want to reveal the truth about women's capabilities in mathematics. Thus, the national debate about women in math should not focus on biology and innate abilities between men and women; it should not focus on the environment and the ways society aids or inhibits genders. What should be of concern to the world is focusing on improving social confidence in math for individually talented women because I have seen through my analysis that the most significant thing that needs to be changed to fix the issue is a women's self-expectancy of success. Women need increased confidence in their math abilities for achievements in mathematical careers to advance, especially since society develops their insecurities in these skills.

Mindset matters. A woman who wants to be a mathematician should be able to, but she is going to have to think about herself in a new way if she wants those amongst her to think of her differently. As culture is slow to change, it is easier to change and improve yourself rather than the society as a whole because we can only redeem a part of

the world as it is. That is to say that progress is made by the actions of individuals. The more females who believe that they can learn “what they need to be successful in STEM (as opposed to being gifted)” the more likely they are to succeed (35). It is necessary that society completely shifts their view of mathematics ability from ‘gift’ to ‘learned skill’ ” (35). To do this, females must have a confidence in themselves because assurance in one’s self and one’s abilities can go a long way. Females must also be accepting of a challenge and embody a growth mindset, which promotes “not only higher achievement but increased persistence in STEM fields” (34). They must accept that a career in math is going to be a difficult struggle, but remember that there is going to be personal future payoff.

#### **IV. Conclusion**

Compelling evidence has been suggested to make the case for the environmental or non-ability stance in the issue of the underrepresentation of women in mathematics. I am sure that equally compelling evidence can also be recruited by the supporters of the biological or ability side of the argument, such as Summers' attempt at the NBER conference. But who should we believe in this world full of evidence? How do we know that one statistic is more significant than another in this evolving debate? There is an excessive amount of research on this topic, but even more research is still needed to address this complex issue in a full scope. I believe I have a strong idea as to why there is a lack of women in mathematical careers. I think it is because of a combination of biological and social factors, with social factors acting as the greatest influencer and that an improvement in female confidence in mathematics would go a long way to provide a solution to the issue in the future. But do I or anyone else really know that this is the case? No. At this time no one can truly know what the cause of this major problem is and the ultimate best solution because the issue is too multi-faceted.

What I now know is that we will probably never have all the information, research, and statistics necessary to address the problem fully. This does not mean that I should stop engaging in the discussion. Rather, because I have a complicated issue consisting of both knowns and unknowns, I know I must continue to engage with others

on the topic. By engaging with each other we are actively searching for the solution and answer to promote women in mathematical fields. If both sides of the argument are allowed to voice their position and present their evidence then our community will be able to come closer to a more rational solution. Together we can integrate each other's research and shift our arguments accordingly to build a well-constructed consensus over time because in reality, no one has all the pieces to this women in mathematics puzzle.

Some believe that allowing the debate to continue may be harmful to a woman's self-conceptions and motivation in mathematics, that talking about the issues damages girls by "broadcasting doubts about their math ability" (Ceci 151). But if no one ever talks about these issues, that does not mean they go away. Not talking about the issue leaves women who may be questioning their abilities in mathematics to think that they are the only ones having this experience, which would be more harmful. The mathematical community should not indirectly allow seclusion by suppressing the debate. They should be proactive by endorsing the sharing of experiences and communicating the issues. If a woman knows that there are other females out there having similar experiences, it may make the experience seem not that bad, as she will feel comforted in being able to relate to another.

It can also be very encouraging for a woman to realize that the issues with her self-doubts are at rooted with a cultural context and that she still has the ability to pursue her own interests. It is important that a talented woman realizes that the "problem" is not with her, that she is not incompetent or unintelligent, but that she maybe processes or

expresses quantitative ideas and concepts differently. Is this bad? Of course it's not. It is okay to think and do differently. Talking about this nature vs. nurture debate in mathematics helps to us realize this difference and see that one way is not necessarily the right way. Both men and women can do mathematics for the greater good of society. Though they may not always accomplish such in the same manner, progress will be made nonetheless. Thus, an open debate on this topic will only lead to progress. If any damage is done to inhibit women, it will be minimal and a small price for society to pay in order to mend the issue at large.

To continue such discussion and search for truth, I would like to suggest that though both ability and non-ability factors do matter and play a huge part in the women in mathematics issue, there is a third factor that is key and arguably more important than the others and that is confidence, which drives the decisions and choices we make. Confidence in mathematics is a very important belief for all female mathematicians to have to obtain and continue a successful career in mathematics and probably more confidence in one's abilities is needed for female mathematicians than male because of the current structure of society. Women and girls may or may not develop confidence in their mathematical abilities based on how they perceive their abilities and experiences with the discipline. If females do not think positively and accept the facts they hear about males dominating the math class, job, activity, or test then they will have lost out on an opportunity only at first glance. From my own experiences, I have seen how thinking in such a manner has affected me at times in my math career and brought down my confidence – “I am the only girl,” “Why do the boys seem to get it faster than I,” “I don't

think like that,” and “Why am *I* even doing this?” Thoughts like these can harm girls’ confidence and later decisions in mathematics. I am glad that I have pushed forward during these times of struggle and shown myself what I am truly capable of. All females interested in mathematics, no matter their age, should believe in the power of positive thinking and feel proud of their accomplishments in the field. This nature vs. nurture debate is bound to confront them during their STEM careers. If these females do not let it induce negative thinking, but instead let it increase their confidence and interest in the field, they then prove to society and the mathematical community that it’s not our chromosomes nor where we live or how we were raised that decide our futures in mathematics, but the individual who makes the choice confidently that mathematics would be a great field to pursue.

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