TOWARD A FEMINIST MATHEMATICS PEDAGOGY

by

MEGAN ROSE KENNEDY

A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Arts

Graduate Program in Women's & Gender Studies

written under the direction of

Dr. Mary Hawkesworth

and approved by

____

____

____

New Brunswick, New Jersey

May, 2013

ABSTRACT OF THE THESIS

Toward a Feminist Mathematics Pedagogy

By MEGAN KENNEDY

Thesis Director:
Dr. Mary Hawkesworth

Popular research on mathematics performance differences often lead researchers to produce student-focused, social, and biological based theories that attempt to address these differences. This paper analyzes the contributions of classroom atmospheres to the "gender problem" in mathematics and proposes potential approaches to addressing this matter in mathematics education. The study begins with a discussion of crucial related issues, such as the extent and impact of the mathematics-science overlap and the roots of mathematical inquiry. This is followed by the introduction of a new, flexible, inclusive mathematics, which integrates these critical issues with the paper's guiding questions and calls upon the pedagogical theories of Paulo Freire, feminist standpoint theory, and poststructuralist approaches. Next, specific ideas and methods for the implementation of the proposed pedagogy are provided, as well as a discussion of potential counterarguments and resistance to its implementation in classrooms. Finally, the paper concludes with the implications of this shift, which include, but are not limited to, the possibility of breaking down entrenched gender stereotypes and boundaries.

Table of Contents

Chapter 1

Introduction

The goal of this thesis is to create a feminist pedagogy designed specifically for mathematics classrooms. Students entering mathematics classrooms bring their own unique viewpoints and experiences with the subject, yet most common pedagogical practices today fail to take the great variety of identities in the classroom into account. This project will aim to create a feminist pedagogy that not only recognizes these identities, but also acknowledges their pedagogical importance to creating an atmosphere that is conducive to learning mathematics. In doing so, important questions will be addressed, such as: What does a feminist pedagogy of mathematics look like, why is a feminist pedagogy of mathematics necessary, and what are the possible implications of such a pedagogy? These three questions will be the main questions that this project aims to answer.

In the rest of this chapter, I will explore the current state of mathematics education in the United States, considering its international ranking as well as the number of math degrees awarded, to whom they are awarded, and how those numbers compare to the overall number of post-secondary degrees that are awarded. I will also consider what has been done in the past and what is being done now to improve those numbers. Finally, I will turn to a review of research conducted to probe the relation between gender and mathematics.

The second chapter of this thesis questions the discipline of mathematics itself in producing gendered practitioners. I consider the overlap between science and mathematics, which is an important distinction to make, as well as outlining and questioning so-called mathematical ways of thinking, and what happens when mathematics is questioned at a foundational level.

In the third chapter, I create a feminist pedagogy of mathematics after reviewing various feminist pedagogical texts relevant to this project. After mapping the contours of a feminist pedagogy of mathematics, I discuss its implications for math education.

The final chapter reviews the central arguments of the previous chapters and discusses the future impact my feminist pedagogy in mathematics, and identifies areas for future research.

The Status of Mathematics

Much of the research in mathematics education today responds to the release of statistics concerning student performance on standardized tests, with data being compiled that focuses on elementary school students to post-secondary students. According to the most recent report published by Aud et al. (2012) for the National Center for Education Statistics (NCES), the average scores on the National Assessment of Educational Progress (NAEP) mathematics test for students in the 4th- and 8th grades have noticeably increased between 1990 and 2011. While most might see this as a sign of positive changes in mathematics education, other issues raise troubling questions. There is a startling trend in this data that becomes visible when the distribution percentages are examined. In 1990, fifty percent of students in the 4th grade tested below basic levels, while forty-eight percent of 8th grade students tested below basic levels (Aud et al., 2012, p.65). This data indicates that fewer students were testing below basic levels in 8th grade than students in the 4th grade, which implies slight improvement. In the year 2000, thirty-five percent of 4th grade students and thirty-seven percent of 8th grade students were testing at below basic proficiency levels in the NAEP mathematics achievement levels (Aud et al., 2012). Somewhere between 4th and 8th grade, an additional two percent of the students failed to test at basic levels. To put it in more simple terms, they fell behind. Compared to the numbers for 1990, this is a four percent swing. By 2011, fewer students than ever were testing below basic proficiency levels, yet the number of students who fell from proficient or basic levels to below basic levels between 4th and 8th grade was at its peak. Only eighteen percent of 4th graders tested below basic levels while twenty seven percent of 8th grade students did so (Aud et al., 2012). The only group that increased between 4th and 8th grade was the number of students who tested at advanced levels, and that was by a marginal amount (Aud et al., 2012). Comparative statistics for students in 12th grade were unavailable.

Looking at mathematical performance at an international level is also intriguing. The NCES report examines the results of a test taken by 15-year old students that is designed to compare international test scores, called the Program for International Student Assessment (PISA). The 34 countries that the results from the United States were compared to are all members of the Organization for Economic Cooperation and Development (OECD), representing most of the world's top and emerging economies (Aud et al., 2012). The report looked at PISA scores from OECD countries and the United States from 2003 and 2009. In 2009, all OECD countries had a higher percentage of students test at advanced levels than the

United States (Aud et al., 2012, p. 68). When each group's results are compared to the 2003 results, it is clear that the United States' percentage of students testing at high levels did not improve, while OECD percentages actually decreased (Aud et al., 2012). When it came to students who tested at levels that are indicative of basic skill sets required to manage everyday life situations, the United States' percentage of students testing at this level decreased between 2003 and 2009. The percentages for OECD countries increased slightly. In 2009, the difference between the United States and the OECD countries was not "measurably different" (Aud et al., 2012, p. 68). What these data indicate is that for students performing at a basic level, the United States and the OECD countries are closer than many popular reports might lead society to believe.

When it comes to university achievement in mathematics, one might think that students avoid math like the plague after looking at the numbers of mathematics and statistics degrees awarded. In the 2009-10 academic year, nearly 1.7 million Bachelor's degrees were conferred in the United States (United States Department of Education 2011, table 290). Out of all those degrees, only sixteen thousand mathematics and statistics degrees were awarded, or less than one percent of the total number of Bachelor's degrees. The United States Department of Education (USDE) broke those total numbers down by sex, revealing that although women earned approximately fifty-two percent of all Bachelor's degrees, they only earned forty-three percent of the mathematics and statistics Bachelor's degrees (USDE 2011). Compared to other fields, the forty-three percent number is low, considering that women earned between fifty to eighty-five percent of the degrees awarded in the five most popular fields: business, management, marketing, and personal culinary services; social sciences and history; health professions; education; and psychology (Aud et al., 2012). At the Master's level, a similar situation can be seen. Women earned approximately forty percent of Master's degrees awarded in mathematics and statistics, and sixty percent of all the Master's degrees earned in 2009-10 (Aud et al., 2012). The most marked drop-off occurs between the percentage of degrees earned by women at the Master's and Doctoral level. Women earned roughly fifty-two percent of all Doctoral degrees, yet they earned only thirty percent of the Doctoral degrees awarded in mathematics and statistics (USDE 2011). Unfortunately the data were not broken down by sex and race, so it is impossible to tell how many of these degrees went to those who would be classified as female and as a minority.

How do these numbers reflect the status of women in the various fields related to Science, Technology, Engineering, and Mathematics (STEM)? The American Association of University Women (AAUW) addressed that question in Hill, Corbett and St. Rose's (2010) report concerning the progress women are making in the STEM fields. Hill, et al. (2010) acknowledge that women are in fact making progress in STEM fields, with progress defined as having an increasing number of women in the classrooms and workplaces of these fields. Gains have been made, however the smallest gains are in fields such as engineering, computer science, and physics, all of which can rely quite heavily on mathematics (Hill, et al., 2010). What hinders the progress of girls and women? Learning environments, societal beliefs, experiences with mathematics, and self-confidence issues can all lead to girls to shy away from mathematics, as well as other science-related classes and careers (Hill, et al., 2010).

The statistics discussed above and the report produced by the AAUW demonstrate the need to get more women and girls involved in traditionally male fields, like STEM fields, but there are deeper questions. What causes these gender differences? Why is the change or progress so slow? What is the situation like in classrooms today that produce these results? Researchers have advanced several explanations regarding the differences in participation between genders, ranging from social theories addressing factors that influence students' performance on mathematical assessment tests to highly controversial biological theories of difference. In the next section these theories will be discussed and analyzed. I begin with a review of the literature that questions and critiques the legitimacy of biological accounts of gender differences in mathematical performance before moving to a review of socially-based explanations and then to a discussion of what is being done to address the gender issue in mathematics.

Competing Accounts of Gender Difference in Mathematics

There are two schools of thought surrounding the cause of differences in gender performance in mathematics: biological origins, and social explanations. The goal of this section is to map out the arguments made by both sides, and to provide a review of the critiques of the highly contentious biological arguments. It is important to understand these two points of view to trace the development of research on gender and mathematics. The end of this section will focus the discussion on social differences in performance based on research conducted in mathematics classrooms. Firstly, however, I turn to the biology-based theories.

Biological theories of difference regarding the gender disparities in mathematics participation and performance on evaluations are surprisingly popular given their controversial nature. Although several studies claim to document biological bases for gendered performances in math, no research that claims to have found a physical trait that impacts mathematical performance has been duplicated. Despite the failure to replicate and thereby validate these claims, many proposed theories, such as the one regarding brain lateralization, or the way thoughts are processed across the left and right hemispheres of the brain, are still incorporated in many biology textbooks. In Jones and Lopez's (2006) biology textbook about human reproductive biology, for example, the chapter titled "Brain Sex" lays out all the ways the male and female brain differ, and they hint at cognitive effects of these differences. Jones and Lopez (2006) discuss functional brain differences that occur after the introduction of adult hormones during puberty, and how these hormones have "an activational effect on organized sex differences in the brain" (p. 464). These hormones then supposedly have an effect on how males and females process information, including mathematical information. These theories are not limited to texts that focus strictly on biology. In Blakemore, Berenbaum, and Liben's (2009) textbook discussing gender development, biological theories regarding sex differences are mixed in with social theories, despite contradictory information within the text itself. For example, Blakemore, Berenbaum and Liben (2009) report in one sentence that sex differences based on biology are usually not found when results are analyzed for statistical significance, then they go on to say immediately afterwards that some differences are found depending on what measure of mathematical performance was tested. If such a contradiction occurred in a paper or textbook that was discussing socially-based theories, it would be disregarded by the academic community immediately.

Other theories that have a basis in biology occasionally pop up in research. Beaujean, Firman, Attai, Johnson, R. Firman, and Mena (2011), for example, examined behavioral traits like conscientiousness, extraversion, and openness to experiences in math performance. What they found was that the aforementioned traits are related to each other, and that they are related to each individual person's general intelligence level. Beaujean, et al. (2011) note that empirical evidence concerning these traits is often mixed, yet they still draw conclusions from this data. It is also important to point out that behavioral traits can be biologically based and socially derived, thus further problematizing their research. In *The Mirage of a Space Between Nature and Nurture,* Evelyn Fox Keller (2010) demonstrates that it is all but impossible to determine how much of human behavior is driven by genetic programming and how much is driven by social programming. Andrew Penner (2008) similarly questions how much weight should be given to biological arguments by examining international data on mathematical achievement scores. Penner (2008) concludes that differences in gender performance can and do vary greatly on an international scale, and that strictly biological explanations of these differences cannot account for all of the differences, meaning that social explanations factor in as well.

Some scholars have systematically challenged biological theories. Rebecca Jordan-Young (2010) carefully and methodically challenged biological theories of sex difference in her book *The Flaws in the Science of Sex Difference*, critiquing everything from the types of experiments that are used by biological researchers to the developmental flexibility of our genetics. Jordan-Young questions the answers that the "science of sex differences" provides. She argues that scientists who test for biological differences actually use quasi-experiments instead of true experiments, and draw their conclusions from those results. Often these experiments must be repeated several times, since they are quasi-experiments, and in order to be accurate they should have the same results each time. Jordan-Young emphasizes that "scientific research contributes to, rather than simply reveals, the meaning of phenomena that are studied," (p. 10) including the so-called phenomena of mathematical performance being impacted by a person's biological sex. She also argues that social aspects, such as what types of questions scientists are asking and what is deemed relevant at the time, influence all biological research and thus the published results. Jordan-Young (2010) goes on to point out that while hormones may influence the way the brain is organized, these effects are not permanent. In fact, the transformation of interests into skills is the result of taking an initial propensity for a task or subject, like math, and increasing that trait, which often occurs through social reinforcement. Jordan-Young copious examination of the flaws informing biologistic claims about sex differences in the brain supplements earlier works by Carol Tavris (1992) and Anne Fausto-Sterling (1992). In her contestation of biological explanations, Tavris notes that biological shortcomings or differences can be overcome with effort. They are in no way permanent. Similarly, Fausto-Sterling (1992) takes on a wide variety of biological theories regarding differences between men and women in addition to the issue related to the supposed difference in mathematics performance, questioning once again researchers' objectivity and the validity of scientific results. Wigfield and Byrnes (1999) examined research that was conducted by Royer, Tronsky, Chan, Jackson, and Marchant III (1999) on the different speeds at which males and females are able to recall mathematical information, criticizing the results and questioning their conclusions that math fact-retrieval speeds are the source of gendered performance differences on mathematical assessments.

In contrast to the problematic claims about biological bases of gendered math performance, social theories regarding differences in mathematical performance are better supported by evidence. Researchers suggest that theoretical concepts like stereotype threat, stereotype lift, and math anxiety can explain differences in performances. Moreover, these results can be easily replicated, unlike biological arguments. All three of these concepts were developed after long-term study of students' mathematics performances. Stereotype threat and stereotype lift both focus on the effects of activating students' gender identities prior to requiring them to complete a math test. When student genders are activated prior to testing, female students' performances are lower than their typical scores, whereas male students' scores increase (Hyde, Lindberg, Linn, Ellis & Williams, 2008; Hyde, Else-Quest, & Linn 2010; Walton & Cohen, 2003). Hyde, et al. (2010) further analyze other effects of gender stereotypes surrounding mathematical performance, noting that activating these stereotypes in students can lead to high levels of math anxiety, which impairs performance, and lowers confidence levels. The concept of stereotype threat was developed somewhat later than the conceptualization of math anxiety in the early 1970's (Englehard, 1990; Spencer, Steele & Quinn, 1999). Recently a study conducted by Cvencek, Meltzoff, and Greenwald (2011) revealed that students begin showing gendered ideas of mathematical performance as early as the second grade. In a study published by Neuville and Croizet in 2007, the research showed how the salience of a student's gender identity could impair mathematical performance in seven- and eight-year old girls in the United Kingdom. Neuville and Croizet (2007) found that the children in their study exhibited signs of perpetuating stereotypes regarding mathematical performance, and that they were just as susceptible to the stereotype threat and lift effects as older children.

Classroom-Based Theories

While the above research focused mainly on students and their performance on mathematics tests, another body of research examines the mathematics classroom itself. When the center of research on gender and mathematics shifted from biological to social theories, the classroom became the empirical subject, according to Stephen Lurman (2000). What happened when the central object of study shifted from the individual to classroom atmospheres and experiences? Scholars attended to issues of voice, identity, and agency in math classrooms, linking them to various inequalities, and suggesting strategies for reform. Some studies investigated the influence of peer groups on students' mathematical attitudes. An article by Crosnoe, Riegle-Crumb, Frank, Field, and Muller (2008) spotlighted the effect peers had on course selection. They found that the year before a student graduates is the most crucial time span for future development in mathematics, and since who students associate with is important, this time is an extremely important time to provide extra encouragement and support for girls in order for them to continue enrolling in higher mathematics courses. In another analysis of peer groups in mathematics classrooms, Barnes (2000) discussed the effect masculinities could have on collaborative mathematics groups. Barnes argued that collaborative settings help lower the rate of disaffection in girls, and that they provide a more equitable environment by not allowing male students to dominate and demand the majority of the instructor's attention. Group work also allows for a deeper understanding of the course material (Barnes, 2000).

Another focus of the research into issues inside of mathematics classrooms looks at actual student experiences. In the early eighties Buerk (1982) started the trend on focusing on gendered experiences in the mathematics classroom by focusing on the experiences of women. Seeking to explain why women chose to no longer engage with mathematics, Buerk (1982) found that more often than not women associated feelings of embarrassment with common mathematical tasks that students are asked to do in classrooms everywhere. Competitions at the board, timed tests, and even classroom use of flash cards engendered experiences of embarrassment, which was felt by women years after they had happened. Given the commonality of these types of assignments in math pedagogy, there is a widespread detrimental effect on female students. When asked, the women interviewed for the project described mathematics as "rigid, removed, aloof, and without any human ties, rather than… [something] discovered and developed." Women also tended to perceive math as a "collection of answers rather than a dynamic process that is alive and changing" (Buerk, 1982, p. 20). Realizing that this was a problem, Buerk (1982) suggested that mathematics be taught in ways that allow for creativity, flexibility, and alternative ways of thinking. Renold (2006) found similar findings nearly twenty-five years after Buerk's article was published. Renold also argued that despite recent and major shifts in educational policies, gendered inequalities and stereotypes persist. Despite two decades of research suggesting the harmfulness of gender stereotypes, the stereotypes continued to circulate in math classrooms.

Boaler and Sengupta-Irving (2006) came to a similar conclusion in a study that also focused on girls' experiences in mathematics classrooms. Boaler and Sengupta-Irving (2006) critiqued programs that were aimed at improving girls' performance in mathematics, arguing that such programs root the problem firmly in the girls themselves, instead of the classroom culture. They concluded by saying that the focus of research should be less on the subjects themselves, and more on the systems that are in place that produce inequalities. Similarly, Renold (2006) called for higher awareness of hidden curriculums and the dangerous normalizing nature of classrooms.

With the proposed solutions and reforms focusing less on the students and more on the classroom atmosphere, researchers began investigating those who are in charge of the classrooms: the teachers. While researchers like Wood (1994) and

Nickson (2004) focused on how teachers were actually teaching mathematics, other researchers like Ball and Bass (2000) and Brown, Jones, and Bibby (2004) studied teachers' attitudes towards and knowledge of mathematics. Ball and Bass (2000) argued that adequate mathematics instruction relies on the "the development of pedagogical method" (p. 85) and a sufficient knowledge of the subject being taught. Brown, Jones, and Bibby (2004) took this type of analysis in a slightly different direction, interviewing teachers who were still in training about their relationship with mathematics. In their work, Brown, et al. (2004) found that while teachers want to make a difference in students' lives, they are also aware of the pressure of educational policies that emphasize standardized testing. They were concerned about negative job consequences if they failed to conform to requirements, particularly in mathematics subjects with which they are not always comfortable.

Investigating how teachers were actually teaching mathematics, Wood (1994) contended that inquiry-based classrooms yield better results when it comes to student understanding of the material when compared to traditional classrooms. She argued that inquiry-based mathematics classrooms allowed for different beliefs among students about their roles in the classroom, thus increasing their responsibility to themselves and others in class, and creating the possibilities for deeper understanding. This method of instruction is a way to acknowledge the imbalance in power distribution of mathematics classrooms while addressing it simultaneously. Wood (1994) noted that inquiry-based classrooms, which allowed for open discussion of the material, were uncommon in mathematics pedagogy, but they had unexpected benefits. Wood pointed out that open discussion could create conflict among students, but in the act of resolving the conflict, students were exposed to alternate perspectives and ways of thinking. Nickson (2004) focused her book on traditional teaching and learning in mathematics classrooms, where teachers maintained full authority to elaborate concepts. Presenting mathematical principles and axioms as black and white with no room for flexibility allows no scope for subjectivity in the mathematics classroom, going so far as to call it a problem that should be avoided. Is subjectivity in mathematics classrooms really detrimental to students? What is being lost if subjectivity is left behind?

Wood's (1994) article and Nickson's (2004) book anticipated later discussions of student voices and subjectivity in the mathematics classroom. Subsequent researchers developed concepts of student voices, identities, agency and subjectivity in greater detail. When it comes to the debate over subjectivity versus objectivity in the mathematics classroom, Evans and Tsatsaroni (1994) suggest that if a discussion is taking place on anything other than the material or content, then a move is already being made away from objectivity, towards subjectivity. As a move toward the subjective occurs, the classroom moves away from the traditional nature of mathematics itself. In a study designed to determine whether allowing for subjectivity improves student performance, Evans and Tsatsaroni (1994) found that using language to attribute student positions in regards to the subject could actually be helpful. In doing so, it is important, they argue, that teachers should know more about their students than just their name and their current grade, and they should be aware of the multiple meanings that students could draw from attempts at trying to relate mathematics to students' lives outside the classroom. However, not all researchers believe that there is a place for subjectivity in mathematics classrooms. Gough (2001) argue that objectivity is not something that should be lost in the mathematics classroom, and that using feminist standpoint theory could allow for a more objective analysis of material and data, since more than one viewpoint would be examined. If objectivity were increased at the expense of subjectivity, who would benefit? Anyone? The discourse surrounding objectivity and subjectivity in mathematics will be further explored in chapter two.

Somewhere lost in the objectivity/subjectivity debate is the importance of students' identification with mathematics itself. Walshaw (2005) documented a single female student's experiences in mathematics, tracing how she created an identification with the subject, and showing how conflicting that identification could be. The student discussed her struggle to identify with mathematics, noting how gender differences in treatment in math classrooms played a role in that struggle. Walshaw (2005) argues that the girl's conflicting identification with mathematics was created through a combination of school discourses and practices that are often at odds with one another. In a call for changes in mathematics education, Walshaw (2005) states: "Mathematical understanding is a complex phenomenon, in which gender and history [with the subject] play a major part" (p. 30). Taking the importance of identity formation a step further, Boaler and Greeno (2000) state that traditional teaching methods turn students off of or away from mathematics at a very critical juncture in their intellectual identity development. In their critique of theories regarding how mathematical knowledge is produced, Boaler and Greeno (2000) argue that "the *practices* of learning mathematics define the knowledge that is produced" (p. 172). Contrary to previous lines of thinking that posit that learning mathematics leads to mathematical knowledge, Boaler and Greeno suggest that pedagogical practices matter, being an active agent in the learning process is important to the development of deeper learning and understanding, which in turn leads to more positive experiences and identities with mathematics itself. Boaler and Greeno back up their claims by citing data that the highest scoring math students' "attainment progressively deteriorated as their mathematics teaching became more procedural" (p. 185). Most of the students whose performance deteriorated were female. Traditional pedagogical practices contribute to and preserve inequalities in mathematical attainment. When students are given greater agency and voice in the classroom, like in the inquiry-based classrooms discussed by Wood (1994), deterioration in performance can be avoided.

Very little research addresses the factors that contribute to inequalities in mathematics education and how to remedy them. Yet the few studies available provide thorough and thoughtful discussions of the issue. Robert Mura (1995) analyzed the links between various feminist theories and mathematics, criticizing four approaches and theories: the intervention perspective, the segregation perspective, the discipline perspective, and the feminist perspective (p. 155). The first approach, the intervention perspective, places the problems within mathematics classrooms squarely on the shoulders of the students. The segregation perspective highlights issues that crop up when boys and girls interact in the classroom, citing coeducation as the source of many problems. Mathematics as a discipline comes under fire in the third approach. Mura (1995) describes mathematics as a place where the construction and maintenance of privilege occurs. The feminist perspective analyzes the gendered nature of teaching and learning. Mura (1995) endorses the feminist approach as a means of fostering equality in learning through equal treatment. According to Mura (1995), a radical feminist pedagogy is sensitive to women's psychology, and diminishes the hierarchy between teachers and students, creating a more equal atmosphere.

Elaine Howes (2002) further develops the arguments for a feminist pedagogy. In her book (2002), Howes argued that feminist theories and pedagogies bring certain elements to educational settings that are excluded by mainstream national standards and strategies, such as the experiences and perceptions of women and minorities. In order for "students to feel that their ideas are valued, it is necessary to develop an environment in which all students feel welcome to…speak" (Howes 2002, 6). Howes knows that a feminist pedagogy faces challenges because it would mean upsetting the balance of power between the student and the teacher, as well as other hierarchical systems. Sue Willis (1995) also takes up the question of upsetting that power balance and giving more agency to students as key to gender reform in mathematics. In contrast to mainstream reforms that rely on standardized testing, Willis points out that the bigger issue is "lack of agency encouragement" (187) in students. With little to no agency, students lose the ability to question course materials, and are relegated to sitting and learning in silence. The relative rigidity of this type of mathematics education results in inequalities described by Mura (1995) that are much more dangerous. Challenging these classroom issues by using a feminist pedagogy is extremely important. As Willis

(1995) sees it, change is necessary, and without it, "those already privileged in mathematics can continue to control and define what constitutes mathematics in school" (p. 195).

Conclusion

Mainstream programs have been designed to educate the public on the current status of mathematics and to identify strategies to improve performance in the fields of science, technology, and engineering. *Change the Equation* is one such program. This program is designed to raise awareness of the issues in the STEM fields and to improve their quality within the United States. The organization is attempting to increase corporate philanthropy, and to engage and encourage young students in the STEM subjects to change the low rates of participation. While their goals are aimed at the STEM disciplines at large, *Change the Equation* also provides information and statistics on gender disparities in participation and achievement within STEM fields. The *National Math and Science Initiative* (NMSI) also aims to improve the number of students enrolled in STEM classes and to raise the number of students who eventually pursue STEM careers. They too provide some information on gender issues within STEM fields, but they fail to discuss these issues and promote them in a way similar to *Change the Equation*. Although these programs clearly identify the importance of improving U.S. performance in recruiting students to the STEM disciplines, STEM numbers are not improving, particularly when it comes to the participation of women and minorities in these fields.

Creating a feminist pedagogy designed specifically for mathematics could be part of the solution to the problems the NMSI and *Change the Equation* are trying to fix. Feminist pedagogy could supplement mainstream approaches in addressing gender inequalities that remain ever present in STEM fields. Deploying research findings by scholars such as Boaler and Sengupta-Irving (2006), Buerk (1982), and Renold (2006), feminist pedagogy might succeed in making mathematics attractive to girls and to students of color. This thesis explores the contours of a feminist pedagogy in mathematics education. To begin this exploration, it is important to consider certain aspects of the mathematics discipline to show that mathematics is not the straightforward, objective subject that many people perceive it to be.

Chapter 2

Introduction

Common stereotypes of mathematics held by a large part of society generally paint it as a discipline that is pure, true, natural, and objective. Only the most intelligent people are capable of studying it at high levels. Mathematics is seen as being a firm, unflawed foundation, upon which the other sciences are built. It's seen as scary, intimidating, complicated, and foreign. In mathematics, the answer is either right or wrong, with no middle ground. The question is: do these words accurately describe the discipline of mathematics? The goal of this chapter will be to explore that very question, and to point out issues with gender within the discipline, as well as many contradictions that arise within it.

This chapter will begin with a section that discusses the importance of separating math from the other sciences, specifically in regard to critiques of the sciences, as well as science and mathematics' purpose and symbolism in society. Following that will be an examination of the various types of mathematical inquiry that occur, which will include historical elements. The questioning of mathematics itself will come next, and will be largely built upon the issues mentioned while outlining mathematical inquiries. The chapter will conclude with a section that centers upon the questions that need to be asked in order to create a new, inclusive type of mathematics.

Examining the Extent of the Mathematics-Science Overlap

Science is a vast umbrella, under which fall many categories. The importance and symbolism vary by field. Science in general, according to Bauchspies, Croissant, and Restivo (2006), is a primary source of knowledge, or something from which what society considers knowledge is created and built upon. The scientific method is relied upon to legitimize scientific knowledge. Bauchspies et al. (2006) argue that the results of the scientific method of inquiry tend to come in the form of factual statements, scientific theories, and that science itself is a vast "social institution grounded in an explanatory strategy that does not have recourse to paranormal, supernatural, or transcendental causes" (p. 5). Basically, science is based on field-specific investigations that generate replicable results that can be achieved again by another scientist using the same methodology. What might be controversial about their definition of science would be the labeling of it as a social institution. Science is painted to be this objective, pure pursuit of knowledge that is resistant to outside biases and influences, so Bauchspies et al.'s (2006) labeling of it as a social institution insinuates the very opposite of this concept, and that it is in fact susceptible to societal expectations and manipulations.

Mathematics is also method-driven; yet critiques of mathematics content and methods tend to differ from that of the other sciences. Feminist scholarship across the natural and social sciences has documented gender bias in methodology and in research findings. For example, several years ago, medical research suggested that signs and symptoms of a heart attack were different for women than they were for men, with women's symptoms being subtler than men's symptoms (McSweeney et al., 2003). This research was borne out of critiques of the studies conducted on heart disease, and how results of studies conducted mainly on men were generalized for the entire population despite the lack of female participants. Results of this critique include the institution of many rules and requirements regarding sex and gender based research and analysis in medical studies, particularly pharmaceutical studies (Greyson, Becu, & Morgan, 2010). Can similar critiques be made regarding mathematics? According to Bauchspies et al. (2006), "mathematical objects must be treated as things that are produced by or manufactured by social beings through social means in social settings and given social meanings" (p. 14), but actually doing so can be quite difficult. Critiques of mathematics that are similar to scientific critiques cannot be made as easily, and that is where a separation of mathematics from the other sciences needs to be made.

While mathematics falls under the umbrella that describes all of the sciences as objective, truthful, pure, etc., it is a distinctly different field from the other sciences. Mathematical content, whether it comes from the applied mathematics fields or pure mathematics, does not necessarily deal with content that has a direct impact on living objects. Even in applied mathematics, formulas that deal with probability generating functions can be used to predict the odds of drawing all consonants or four consonants and three vowels in an initial Scrabble tile draw, which is fun, but doesn't necessarily have an impact on society at large. Oftentimes, when people, whether academics or professionals are discussing anything that has to do with science, mathematics is an implied part of the sciences, but it's not always clear if mathematics is indeed meant to be included. Sandra Harding (2004) wrote an article that discussed and critiqued socially relevant philosophies of science, but in doing so, she mentioned mathematics briefly, in passing, or not at all. In her discussions, it was unclear as to just how much of her argument could be applied to mathematics in addition to the other sciences. Feminist scholars, particularly the feminist empiricists, have been working in the field of Feminist Science Studies to point out and eliminate the biases from scientific research, such as those that appear in research questions, research methods, and conclusions drawn from the results (Damarin, 1995). Can feminists document bias in mathematics, given that mathematicians' methods are not always similar to other scientists'? Damarin (1995) suggests that scientific research critiques are sometimes stretched to cover mathematics, and yet this approach tends to critique the science involved in the study of mathematics and gender. That is an important step in addressing the extent of the overlap between mathematics and science, but it is not enough. Mathematics itself merits its own research and criticisms.

Scientific critiques that include mentions of mathematics are not entirely unjust, irrelevant, or inaccurate, given that the sciences can be fairly reliant upon mathematics at various points in research efforts. Mathematicians can also utilize scientific sources in their research, but it's not always necessary. In fact, mathematical research and discovery can exist outside the realm of scientific discovery, but the same cannot necessarily be said for the other scientific fields. Mathematics is the foundation upon which the other sciences are built. As mathematician George David Birkhoff (2004) saw it, there are five ascending levels of what is called science: mathematical, physical, biological, psychological, and social. Mathematics was not placed on the foundational level for no reason. Being at the bottommost level is an illustration of how mathematics is related to the sciences, but yet can function entirely as its own entity, without being reliant upon any other level or type of science. Birkhoff (2004) goes on to say that each level of science has its own language (number, matter, organism, mind, society), and that they are all independent of one another.

Historians of mathematics and historians of science appear to realize the distinction between mathematics and science. Tony Mann (2011) points out that the history of mathematics and the history of science remain unattached at the present moment. This may not be entirely accurate, given that many well-known historical scientific figures worked on scientific and mathematical issues, such as Isaac Newton, who made significant contributions to both calculus and physics. The lack of a connection between the two histories might be due to a lack of mathematics-specific historian projects and job availability when compared to scientific opportunities (Mann, 2011). If these historians recognize the need to provide a distinction between mathematics and science, what is stopping other academics, or even practicing mathematicians from writing about such issues? Mathematics is indeed a science, but it is its own type of science, and many of the popular sciences, such as chemistry, biology, human biology, and physics often rely upon mathematical theorems and equations to conduct their work. There are some cases where mathematics and the sciences are completely unattached, like when it comes to their respective histories, but such separations are rare. Mathematics and those who perform it are unique in the world of science, from their methods to their end product. The next section will discuss the unique methods of mathematical inquiry, as well as what qualifies as mathematical knowledge, and issues within these practices and ways of thinking.

Mathematical Inquiry and Thinking

Mathematical thinking is often viewed to be logical, objective, and thoroughly rational, generating results that are truthful, absolute, and pure. Mathematics itself is thought to be an intense and individual pursuit that is intellectually demanding. To an extent, it is. However, mathematical findings are not always a result of a rigorous effort put into a mathematical proof by a lone mathematician sitting at a desk with only crumpled up papers containing incorrect solutions for company. The results are a combination of many aspects of mathematical inquiry that often include collaboration and cooperation. In this section, those elements of mathematical inquiry will be explored, as well as ways of mathematical thinking, contradictions within those lines of thinking, and how to move towards a cultural approach to mathematics.

Mathematical inquiry and thinking are rigorous and logical, but that is not the entire story. First, it is important to recognize the ways in which mathematicians think and operate, as described by mathematicians themselves. Famed mathematician Jules Henri Poincaré (2004) describes the ideal method of mathematical discovery and invention as moments of inspiration that follow moments where the mind is resting and not thinking about anything that is remotely related to the mathematical task at hand. These moments of inspiration and rest are preceded by thorough concentration on a topic or issue, and after exhaustion of the available trains of thought for the mathematician (Poincaré, 2004). In other words, mathematicians work hard on a problem, reach a point where they can go no further, and take a break. The result of the break, in Poincaré's case, was that the next step or complete solution would appear in the conscious part of his brain from his subconscious mind. To Poincaré, the subconscious plays a role in mathematical invention, since the subconscious utilizes intuition, which is something that the conscious brain of the mathematician does not do. Of course, the verification of the results, which is an essential part of proving mathematical theorems and postulates, is the last step in this process, and it involves a second period of rigorous, conscious work.

Poincaré's model of work is often associated with "pure mathematics," which is distinguished from applied mathematics. Mathematician Mary Cartwright (2004) suggests that such abstract thinking is associated with pure mathematics, in contrast with applied thinking, which is the key to applied mathematics. Applied mathematical thinking involves the application of mathematical theorems to real-life situations, or creating mathematics based on its applicability in other fields, such as engineering and business. Cartwright (2004) describes the essential basis of mathematics as the employment of various symbols to interpret the meaning of the universe. Pure mathematics creates those symbols and defines what they represent, and applied mathematics involves operations conducted on those symbols and on objects in everyday life.

The type of thought and the type of mathematics performed depends on what field a mathematician is in. Proficiency in one school of mathematics does not necessarily signify proficiency in the opposite school (Otte, 2007). In fact, students of one school of thought often struggle to learn the mathematical concepts from the opposing point of view (Otte, 2007). What makes the two areas of mathematics so different and difficult to understand? Michael Otte (2007) argues that it is due to contradistinctions and controversies between synthetic and analytic mathematics. Synthetic mathematics would be what Cartwright called applied mathematics, like statistics, analysis, geometry, and mechanics, since they are all based on observations and experience. Analytic mathematics would be pure mathematics that relies heavily on deduction, like ordinary differential equations, linear algebra, and other abstract mental constructs.

This kind of disconnect between subcategories of mathematics can lead to an exclusion of otherwise capable mathematicians from one field or the other, based solely upon their perceived skill set. This only feeds the popular belief regarding mathematics as a lone pursuit. Leone Burton (2004) investigated the ways that mathematicians conducted their work, among other things, and found that the ways mathematicians viewed their methods and how they actually performed their research were very different. She found that although mathematicians might have preferred the fabled solitary pursuit in mathematics, the most common or even normal method was to work collaboratively with another mathematician or two. In fact, the number of complaints among those studying mathematics was positively correlated with the advancement in levels of abstraction (Burton, 2004).

There are many debates among mathematicians and philosophers about the nature of mathematics and its foundation. Mathematical naturalists posit that mathematical knowledge exists in the world independent of the human mind, and that mathematicians discover it through experience (Kitcher 1988). Where Platonists argue that math is discovered through rigorous training of the mind, formalists suggest that math is created (Henrion 1997). Mathematical apriorists insist that mathematical knowledge is deduced at a theoretical level, not through observation or experience (Kitcher 1988). David Hume took particular interest in this topic regarding differences between apriority and induction in mathematical thought. In An Enquiry Concerning Human Understanding, Hume makes it clear that *a priori* arguments are analytical, involving tautological claims that are true by definition. "Pure" mathematics involve only analytical statements (Bayne, 2000). Smit (2010) points out that Hume was skeptical about the power of inductive logic and reasoning, insisting that both were fallible. Induction or generalizations based on observation are central to synthetic mathematics, linking applied mathematics that which is experienced or observed.

The distinction apparent between inductive and deductive methods is a crucial one. Mathematical proofs provide an excellent mechanism through which to see this difference. Inductive proofs, by definition, are those that rely on multiple observations to provide support for their conclusions. In other words, inductive proofs rely on proving that more than one case of the theorem is true. In contrast, a deductive proof relies on inferences derived from syllogisms involving general laws, principles or theorems.

Some philosophers argue that the majority of mathematics is based on deductive methods, but can a mathematical argument utilize both inductive and deductive rationales? Sherry (2006) believes that it is possible, based on the work of Hungarian philosopher Imre Lakatos' three moments of mathematical reasoning. Sherry noted that Lakatos argued that mathematicians first use induction in order to find conjectures, theorems and postulates to prove. Next, mathematicians form and review informal proofs of those conjectures, theorems, and postulates, or put them through a series of "thought-experiments." The third and final step is the formalization of the informal theory in such a way that they are deducible "by formal transformations of the axioms" (Sherry, 2006, p. 490). Using Lakatos' view, inductive and deductive methods can be employed simultaneously, which might then classify a single piece of mathematics that utilizes both as both analytic and synthetic. Mathematicians such as Cartwright might believe that analytic and synthetic mathematics are relegated to two different spheres, which might not always be the case. This is one example of how mathematicians from different schools of thought often disagree with each other on the most basic theoretical levels regarding mathematics. Although popular stereotypes depict mathematics as true, pure, and simple, the field itself is characterized by controversies and debates.

There are also contradictions within mathematical subject matter itself, for example, consider Euclidean and non-Euclidean geometry. Euclidean geometry is what is taught in most schools, and it's based on the concepts of straight lines, parallel lines, angles, and set distances. Non-Euclidean geometry disregards the rules regarding parallel lines set out in Euclidean geometry, focusing on geometric ideas involving elliptic and hyperbolic curves. The laws governing the geometry of curved lines seemingly contradict Euclidean geometric laws, which are based on straight lines and their intersections. However, both fall under the mathematical category of geometry. Furthermore, while non-Euclidean geometry denies particular facets of Euclidean geometry, it still complements and advances other areas, thus they are not completely contradictory to one another.

In addition to these issues, there are ongoing debates concerning the usefulness of histories of mathematics to the entire discipline. Why the debate? Mathematical histories tend to incorporate outside influences in their discussions of mathematical developments, including societal factors of the particular time period they are analyzing that could have influenced that development. Mathematicians often object to mathematical historians' claims that mathematical developments are related to philosophical and social contexts (Fried, 2007). As Michael Fried (2007) says, "the question of history raises the possibility of different ways of thinking about mathematics and the study of history itself highlights different, especially culturally influenced, ways of thinking in mathematics" (p. 205). There are often several ways to solve a particular problem, like the more than one hundred proofs of the Pythagorean theorem ($a^2 + b^2 = c^2$), so why is having more than one perspective on mathematical developments detrimental to the subject? Would it not in fact benefit those who study mathematics, making the subject appear to be more flexible and relatable, instead of fixed and rigid?

In fact, one interesting historical story in mathematics centers on the history of the concept of the infinite, or infinity. As Howes and Rosenthal (2001) argue, the time of the discovery of infinity, from its acceptance to it's split into dualisms of mind and matter, can be closely tied to the creation and evolution of gendered dualisms. They state that mathematical historians date infinity back to the time of the Greek philosopher Zeno, although the interesting conceptual evolutions did not occur until the time of Pythagoras. In the pre-Pythagorean times, the infinite was thought to be "immanent in the physical world as well as representative of the spiritual [world]" (Howes & Rosenthal, 2001, p. 180). Greek philosopher Anaximander led the thinkers at the time, and the physical-divine infinite was not a disjunction of man and woman, but in fact represented a unity. Then the Pythagoreans came along, and split the cosmos and human existence into gendered dualisms, suggesting that the main operating axiom was male and as such, greater than female (male > female), and "elements homologous with the female [were] to be shunned or feared" (p. 181). In this scheme, masculine elements were those that could be classified has having or being a limit, odd, single, right, straight, light, good, and square; female elements were unlimited, even, plural, left, crooked, dark, bad, or oblong (Howes & Rosenthal, 2001, p. 182). Thus the Pythagoreans transformed Anaximander's concept of the infinite or *apeiron*, as an ungendered, wholistic entity encompassing both physical and divine to one structured by binaries of good or bad, dark or light, physical or spiritual, male or female. According to Howes and Rosenthal (2001), Aristotle took up this work and completed the splitting of infinity into two concepts: the potential and the actual (p. 183). Marziarz and Greenwood define the potential infinite as "something which is always becoming without ever reaching a final form" (as cited in Howes & Rosenthal, 2001, p. 183). According to

Aristotle, the actual was necessarily finite. In the process of making his argument, Aristotle separated mathematics from the actual physical world, and banished the concept of actual infinity from mathematics. Because infinity was equated with the feminine, Aristotle banished the feminine from mathematics (Howes & Rosenthal, 2001, p. 183).

The incorporation of values associated with classical Greece is only one possible way of thinking about the effects of culture on mathematical thinking. Many culturally diverse histories of mathematics are possible, especially given the phenomenon of simultaneous discovery. At the same moment that Pythagoras was discovering his most famous theorem, simultaneous discoveries were being made in Africa and China. In an article for The New Yorker, Malcolm Gladwell (2008) points out that not only does simultaneous discovery happen, it actually happens quite often:

> This phenomenon of simultaneous discovery—what science historians call "multiples"—turns out to be extremely common. One of the first comprehensive lists of multiples was put together by William Ogburn and Dorothy Thomas, in 1922, and they found a hundred and forty-eight major scientific discoveries that fit the multiple pattern. Newton and Leibniz both discovered calculus. Charles Darwin and Alfred Russel Wallace both discovered evolution. Three mathematicians "invented" decimal fractions. Oxygen was discovered by Joseph Priestley, in Wiltshire, in 1774, and by Carl Wilhelm Scheele, in Uppsala, a year earlier. Color photography was invented at the same time by Charles Cros and by Louis Ducos du Hauron, in France. Logarithms were invented by John Napier and Henry Briggs in Britain, and by Joost Bürgi in Switzerland…For Ogburn and Thomas, the sheer number of multiples could mean only one thing: scientific discoveries must, in some sense, be inevitable. They must be in the air, products of the intellectual climate of a specific time and place. It should not surprise us, then, that calculus was invented by two people at the same moment in history. Pascal and Descartes had already laid the foundations…For that matter, the Pythagorean theorem was known before Pythagoras; Gaussian distributions were not discovered by Gauss.

Despite these variances, one person is often given credit for these discoveries in school texts. In most cases, a white, European male is credited with major intellectual discoveries. Who is responsible for determining what qualifies as legitimate mathematical knowledge, and who determines who is capable of doing mathematics? In the context of U.S. education, it has been predominantly men who have made such determinations. Male dominance in the field of mathematics can dissuade others, specifically women, from entering the field.

What would it take to make mathematics more welcoming to those who have traditionally been turned away? What would happen if the history of mathematics were a more essential part of mathematics education? Claudia Henrion (1997) argues, "if there is one lesson that is clear from the history of mathematics, it is that questioning even the assumptions that seem most obvious and fundamental can lead to profound new ideas and visions" (p. 262). The next section will build upon this very idea, and the questions that were raised in this chapter, and will further question mathematics itself. Inaccurate stereotypes, the lack of diversity, the notion of truth, and the view of mathematics as objective will all be questioned and investigated.

Creating a New Type of Mathematics

Starting at the theoretical level, the most important question that can be asked is what constitutes mathematical knowledge? As Lorraine Code (1991) has noted, knowledge itself can be defined as a convention rooted in the practical judgments of a community of fallible inquirers who struggle to resolve theory-dependent problems under specific historical conditions. What, then, could be labeled as a mathematical "fact" or mathematical knowledge? Bauchspies, Croissant, and Restivo (2006) analyzed what comprises a scientific fact. They point out that science operates by demarcating between truth and falsity, yet within the realm of contingency, few truths are indisputable. For example, scientists suggest that matter exists in three states: solids, liquids, and gasses. Yet, there are substances that complicate this, such as mayonnaise or Jell-O. They exhibit properties of liquids by taking the shape of the container they are in, yet when removed from the container, they do not become fluid; they retain their general shape. A mathematical equivalent of what many assume to be a fact is that two plus two always equals four. This is not always true, given that the sum depends entirely on the base being used, or if a total summation is not being used, the solution could range from zero to four. So does that mean that all facts are debatable? Possibly. When pieces of information labeled as facts are first introduced, questions tend to arise, but "with the passage of time they generally become unquestioned" (Bauchspies et al., 2006, p. 20). This does not necessarily mean these propositions are inherently true, merely that with the passing of time, they tend to become more accepted, so long as they are able to withstand contestation. In the eyes of Bauchspies et al. (2006), facts of any kind are highly influenced by the community, and yet those who challenge accepted facts are often excluded from the community. In mathematics, some axioms are accepted universally, such as π, or pi, being an irrational number that when written as a decimal, never ends, or that dividing any number by zero is impossible. However, the same is not true for all mathematical axioms.

Earlier in this chapter, Euclidean and non-Euclidean geometry were mentioned. In Euclidean geometry, a main operating theorem states that all the measured angles of every triangle add up to one hundred and eighty degrees. In non-Euclidean geometry, all of the angles of a triangle add up to more than one hundred and eighty degrees. Another example of an indeterminate axiom is Fermat's Last Theorem. Fermat wrote his theorem in the margin of a book in the 1630s, but failed to write a proof, citing a lack of available space in which to write it. The theorem stated that for the equation $a^n + b^n = c^n$, no two positive integers could be plugged in to make it true when the degree of *n* was greater than the number two. For centuries, this theorem was accepted as true, despite the fact that Fermat never provided a proof, and mathematicians worked tirelessly to either prove or disprove it. An acceptable proof was not officially published until 1995, when the British mathematician Andrew Wiles successfully proved the theorem. The full story, however, is that many famous mathematicians could successfully prove portions of the theorem, including Leonhard Euler, Adrien-Marie Legendre, Johan Carl Gauss, Augustin-Loius Cauchy, and Sophie Germain, but only Wiles receives the credit for solving it completely (Singh, 1997; Vandiver, 1946). If someone were to say that it is a fact that Andrew Wiles successfully proved the theorem, would there have to be an asterisk, given that he built upon the successful pieces of proofs from other mathematicians, and relied on the help of others to prove it? When and under what conditions, are certain properties of triangles obtained? Are mathematical properties and their truthfulness dependent upon other conditions?

What is accredited as fact can change over time. For instance, it was not long ago that Pluto was a planet, but that "fact" has changed. There is also the example of pre-Galilean "fact" that the sun revolved around the Earth, which was based on the science of the time. This indicates that what are assumed to be facts or truths have a basis on cultural context, and thus must never simply be accepted without questioning. It is essential to question the idea of truth, especially in regards to mathematics, given that truth is often complex and multilayered (Harrison, 2001). After all, mathematical proofs that are accepted as being true and accurate have been disproven years later, like the four-color theorem. Even famed mathematician Kurt Gödel had a theorem proven incorrect after an error was discovered in his proof.

For many years, it was simply accepted as truth that girls were incapable of performing mathematics. For this reason, they were discouraged early on from its study by parents and university admissions officers as well as by mathematicians themselves (Hersh & John-Steiner, 2011). Harrison (2001) argues that social contexts of the time influence mathematical study, particularly in relation to gender and mathematics, and as those influences change, so do the so-called solutions to the supposed girl "problem" in mathematics.

Recognition of the cultural and societal influences on mathematics is vital, particularly for those who are interested in increasing diversity in the field of mathematics. Wilder (2004) argues that by recognizing these influences, a better understanding of the nature of mathematics would be obtained. A culturally-attuned approach to mathematics could not only generate multiple solutions to pressing mathematical problems, but it could also encourage current mathematical outsiders to continue to engage with the subject. It would change the content of mathematical histories, allowing historians to investigate cultural variances and influences more systematically (Wilder, 2004). For example, the phenomenon of mathematical evolution and diffusion could be thoroughly explored. An example of diffusion can be seen in the borrowing of the concept of zero by the Chinese from the Hindus (Wilder 2004). If it were acceptable for mathematical historians to acknowledge these types of conceptual migrations, it would foster a new understanding of mathematics as a collaborative endeavor. Stereotypes regarding mathematics and mathematicians might disappear, and along with them stereotypes about who has the capabilities to become mathematicians. The types of experiences of mathematics students at various levels depicted by Burton (2004) might change, becoming less anxiety inducing, and more conducive to learning. By creating a more flexible and inclusive mathematics, perhaps feminists would be able to cross the boundary that exists between women's studies and mathematics that Suzanne Damarin (2008) pointed out, and work with mathematicians to create an even better mathematics. To move toward this new mathematics, questioning is not enough. Pedagogical methods need to change as well, which is where a feminist pedagogy of mathematics would come in to play.

Chapter 3

Introduction

Rethinking traditional notions, practices and approaches to mathematics is an essential step in the creation of a feminist pedagogy of mathematics. The realization that there are cultural and historical elements in mathematics opens new possibilities. Mathematical problem solving is a human endeavor. Humans are imperfect. They make mistakes, they miscalculate, and they assume incorrect facts are true. As the human element in mathematical reasoning is recognized, it becomes clear that mathematics is imperfect, fallible, and open to revision.

What this chapter aims to do is to answer the question of what happens when math becomes and is accepted as more fluid and open to contextual variation. What can be done to change students' and teachers' perspectives and relationships in regards to mathematics, to make it more positive? Can a pedagogy be created to utilize this new mathematics, one that includes anyone and everyone? In order to answer these questions, this chapter will first provide an overview of previous pedagogies that have attempted to address classroom inequalities on racial, classed, and gendered lines. Building upon this work, the next section will be where my idea of a feminist pedagogy designed specifically for mathematics classrooms will be created. A section discussing the possible critiques and resistance to such a pedagogy will conclude the chapter.

Previous Pedagogical Revolutions

Popular pedagogical theories are not designed with the goal of advancing white male students by stomping on women and minorities in the classroom, but that can sometimes be the result. Pedagogies that are focused on inclusion and ending cycles of oppression are not a fix-all solution to these pedagogies, but they are certainly a step in the right direction. One of the biggest influences to this day over these types of pedagogies is Paulo Freire's (2011), *Pedagogy of the Oppressed*. In it, Freire (2011) describes ways in which those who are oppressed can take control over their own lives by empowering themselves through education. It involves students acknowledging their status as an oppressed citizen or member of society, and utilizing their own experiences to create their own discourse when describing their situations, instead of using the language and discourse of their oppressors. Freire critiques the methods of education at the time of writing, which is still in widespread use today, describing the lecture and memorization techniques as a banking concept based on making knowledge deposits into the students' brains. The students rely explicitly on the instructor for their knowledge, which requires them to be passive learners, and creates an unequal power dynamic inside the classroom. The way around this dynamic, according to Freire (2011), is through the establishment of dialogue. He argues that dialogue is based on collaboration, union, and organization to undo the division and manipulation utilized by the oppressors. It is up to the oppressed individual to make this change, and to learn from and problematize their status in society in order to change it.

Despite its groundbreaking and highly influential content, Freire's work was not the be-all, end-all of liberatory or critical pedagogical theories. While it pointed out many issues with education, it could be seen as being too generalized, since not all oppressed peoples experience their oppression in the same ways. Sue Jackson (1997) carefully considers Freire's work, and finds it to be both useful and limiting in a pedagogical sense. She critiques Freire's discussion of the universality of the educational theory he proposes in *Pedagogy of the Oppressed*, noting that the book fails to "give sufficient concentration to difference, to the conflicting needs of oppressed groups or the specificity of people's lives and experiences" (Jackson, 1997, p. 464). Jackson (1997) also questions the lack of consideration of the possibility that the oppressed can also be someone else's oppressors: "Oppressed men, for instance, still oppress women; oppressed white women still oppress black women, and so on" (p. 464). Another scholar who takes issue with Freire's work is Kathleen Weiler (1991). She notes that Freire uses his own pedagogical concepts, and bases his knowledge on his beliefs and experiences, but that this pedagogical theory falls a bit short when analyzed with feminist theories in mind. She also addresses Freire's assumptions that see all oppressed people as the same, and how it fails to address the different struggles that various oppressed groups might face. Weiler (1991) addresses Freire's usage of the masculine, mostly in reference to "the immediate oppressor of men—in this case, bosses over peasants or workers" (p. 453). Furthermore, she argues that:

> What is not addressed is the possibility of simultaneous contradictory positions of oppression and dominance: the man oppressed by his boss could at the same time oppress his wife, for example, or the White woman

> oppressed by sexism could exploit the Black woman. By framing his discussion in such abstract terms, Freire slides over the contradictions and tensions within social settings in which overlapping forms of oppression exist. (p. 453)

Freire's work is not entirely problematic, and it in fact provides important concepts to consider when creating a feminist pedagogy. Clearly, however, more is needed in order to expand upon his ideas to create a truly inclusive pedagogy that could bring about social change. That's where other feminist pedagogical theories come in to play.

While some feminist pedagogical theories utilize standpoint theory, others argue for a poststructuralist approach. Sandra Harding (2004) defends the value of using standpoint theory, especially in regards to philosophies of science, since standpoint theory allows for an engagement with the sciences themselves, by pointing out the biases in research and by realizing that some social locations that differ from the norm can actually provide alternate perspectives and advance scientific knowledge. Wylie (2003) also argues for standpoint theory, stating that those who are oppressed "may know different things or know some things better than those who are comparatively privileged" (p. 26). According to Wylie, the goal of standpoint theory itself, outside of educational theories, is to understand "how the systematic partiality of authoritative knowledge arises…and to account for the constructive contributions made by those working from marginal standpoints (especially feminist standpoints) to countering this partiality" (p. 26). In other words, standpoint attempts to understand and address how mainstream knowledge is only deemed important and worth knowing by those who hold the power already, and that members that are lower on the social order scale could contribute knowledge in order to counteract the previous partial knowledge. Standpoint theory is not without it's critics, though. For example, Elam and Juhlin (1998) discuss Sandra Harding's works on standpoint theory, and point out the apparent contradictions within her various texts. The entire chapter that is written by Elam and Juhlin (1998) is spent pointing out flaws in the logic of creating new scientific knowledge based on partial knowledge from different social strata.

In addition to the standpoint feminist theorists, there are also those in the poststructuralist camp. Poststructuralism as a theory focuses on the plurality of things such as gender, instead of dualisms, and separates itself from claims of objectivity made by structuralists. For example, a poststructural argument related to gender education research such as Dillabough's (2001), would look at things that relate to the nature of gender itself, and how gender is taught inside classrooms through educational discourses that are often restrictive. Dillabough (2001) highlights the relationship between a student's identity and his/her concept of difference, and how creating their identity inside of the classroom can reinforce differences. Tisdell (1998) also argues for a poststructuralist approach to feminist pedagogies, since it highlights positionality, and issues that can arise from it, as well as its emphasis on problematizing the notion of truth.

The two feminist theories mentioned above are not always in agreement, and that has, at times, left feminist pedagogies open and exposed to outside criticism. As Gaby Weiner (2006) points out, feminist pedagogical work has raised important questions dealing with issues of power, representation, and authority in the classroom. She notes that these pedagogies have focused on classroom methods, questioning the use of personal experience (or the lack thereof) in the classroom at the individual, student, and teacher level. These pedagogies do not however, come without their fair share of criticisms. Weiner (2006) found that several criticisms pointed out the presumption that there will be similar viewpoints and experiences in the classroom, and that feminist theories themselves could be seen as too broad or as misrepresenting other types of feminists.

Does that mean that a feminist pedagogy of math is not possible, or that it is useless? Not necessarily. In fact, Weiner (2006) even discuses the importance of creating a feminist pedagogy that remains flexible and is dynamic, that way it does not get stuck in one of the problematic categories that is easy to criticize. She argues that an adequate pedagogy would "produce action that is both predictable, arising out of specific social and cultural contexts, and unpredictable due to the variety of circumstances that confront [the dispositions or principles]" (Weiner, 2006, p. 90).

There have been critiques of mathematics pedagogies themselves, although they might not necessarily be labeled feminist. Peter Appelbaum's (1995) book, for example, *Popular Culture, Educational Discourse, and Mathematics*, examines popular culture's influence on mathematical practice, despite popular opinions of mathematics believing it to be an incorruptible discipline. As evidenced by discussions in the previous chapter, all intellectual subjects, even mathematics, are subject to social and cultural influences, and Appelbaum (1995) provides evidence. He cites the concept of the "superteacher" that is thrust upon society in print, film, etc., and notes that a teacher becomes a "superteacher" by getting those so-called "unteachable" students to learn an apparently difficult subject. Once society sees the successes of these teachers, they begin to wonder why all teachers cannot accomplish such tasks. Appelbaum (1995) also raises the question of why these students are labeled as unteachable in the first place. Typically, these students are minorities who would fall under the oppressed category that Freire (2011) describes. The superteacher comes in, gives them a voice and power over their own education, and miraculously discovers that they can in fact be taught. Another work of Appelbaum's (2002) addresses the disparities in education along racial and cultural lines. He argues, in reference to mathematics, that in order for reform to occur, the key must be, "as in other areas of education, they say, are poststructural analyses and semiotics, the incorporation of a range of perspectives and voices that have been previously unheard, and new kinds of questions from different points of view" (Appelbaum, 2002, p. 4). This indicates a combination of both poststructuralist and standpoint theory ideologies.

One example of work that is classified as feminist and focuses strictly upon mathematics would be that of Leone Burton (1995). Burton (1995) focuses on addressing the lack of diversity in the mathematics field, and how increased diversity might influence the types of research being conducted in mathematics. This work led her to write a book years later, *Mathematicians as Enquirers: Learning about Learning Mathematics*, which focuses on the processes through which mathematicians learn, and that is compared to the ways in which mathematics is broadly taught to non-mathematicians at lower levels. Burton (2004) found that common pedagogical practices in mathematics rely heavily on texts, which lead the students to be entirely dependent upon the instructor in acquiring the necessary mathematical knowledge. She found that although many mathematicians report that they prefer working in a more isolated environment, they in fact work collaboratively more often than they work in isolation. The contradiction in this approach occurs in the teaching styles of these mathematicians. Burton (2004) found that while they may work collaboratively, the mathematicians interviewed for her research still created and encouraged individualistic and competitive classroom environments. This classroom dynamic was one reason that Burton cited for the students complaining about pedagogical experiences and classroom environments at higher rates that other elements, like subject matter. Significant differences were found in the power distribution between males and females in the mathematics community, which Burton (2004) argues, eventually have consequences on those students learning mathematics. She proposes an epistemological model to address the issues she uncovered in her research that contains five categories: person and cultural-social relatedness, aesthetics, intuition and insight, different approaches, and connectivities (Burton, 2004, p. 182). In her model, learners need to know that they're in control, and that they can express agency over their own learning. Moving forward and building upon the ideas discussed in this section will be imperative to creating a feminist pedagogy for mathematics. The next section will build upon these ideas, as well as the ideas discussed in the section of the previous chapter that focused on a new mathematics, in order to create a feminist pedagogy for mathematics that is inclusive and applicable in classrooms.

A Feminist Pedagogy for Mathematics

Problems with the ways in which mathematics are taught are not a new phenomenon. Mathematician Jacques Hadamard (2004) reflected on how mathematics was taught at secondary levels of education, and was a strong advocate for the heuristic method of instruction. The heuristic method is a method of instruction derived from the Socratic method of engaging in dialogue with students in order for them to learn (Hadamard, 2004). The heuristic method enables the students to discover and learn on their own, so in Hadamard's case, he wanted students to be able to deduce mathematical knowledge for themselves. This is a strict divergence from the typical lecture style of higher mathematics, where students sit at attention and absorb every word the instructor says while taking copious amounts of notes. That style of teaching merely places all the power, authority, and agency over students' educations in the hands of the teacher. In this feminist pedagogy of mathematics, students have more control over their education.

One of the most important aspects of a feminist pedagogy for mathematics is keeping it feminist, since it is labeled as such. Elements typical to a feminist pedagogy for any subject include, but are not limited to: humanizing the content matter, and raising awareness and addressing issues of inequalities in voice, power, and agency (Becker, 1995; Boaler & Greeno, 2000; Maher & Tetreault, 2001). In order to do this in mathematics, it requires a flexible, changing mathematics, similar to the one described in chapter 2. In order for students to have the ability to have more control over their educational experience, and to express their agency over their learning, they need to be able to grapple with a discipline that is not set in stone.

Students need to experience a mathematics where mistakes happen, where a rich history is evident, other than just the Eurocentric version of mathematical history. A feminist pedagogy for mathematics would include historical content, and realize that the Mayans developed some mathematical concepts, such as the concept of zero, before many Europeans, how the Chinese borrowed the concept of zero from the Hindus, and how the Mayans and the Hindus developed their concepts of zero separately (Appelbaum, 1995; Wilder, 2004). Historical perspectives about mathematics can make the subject itself or even specific subsections of mathematics that are particularly abstract more relatable and easier to understand, since that history provides context (Otte, 2007). By hearing about the development of a particular theorem, postulate, or probability, or the methods through which mathematicians themselves conduct work, realizing mathematicians spend years and years working on a single problem or proof, students would realize that if mathematics doesn't come to them easily, it doesn't mean that they can't do it at all (Burton, 2004). The teachers themselves need to be shown to be imperfect and not all knowing, and that they can, and often do, make mathematical mistakes (Becker, 1995).

Mathematics needs a pedagogy that emphasizes inclusion along gendered, racial, and classed lines. An intersectional approach to a mathematical pedagogy would make it a feminist pedagogy. Ways to organize a classroom to include everyone in learning are not simple. Solar (1995) identifies several areas and objectives that are imperative to establishing an inclusive pedagogy: eliminating discriminatory teaching practices (which might first involve becoming aware of such practices), creating an equal learning environment, establishing a balanced curriculum, and encouraging equal participation. These sound vague, or like obvious conclusions, but research has found that the inequalities that exist in the classroom, particularly the mathematics classroom, have not changed much over the past few decades (Solar, 1995). Change is necessary, if only to increase the mathematical opportunities for those who desire them. Maher (1999) makes an argument for a feminist model of educational change, simply because other, previous models have been too male-centric. Other models of progressive pedagogies have proven to be lacking when giving attention to gender issues, which is why they are placed at the forefront of this feminist mathematical pedagogy. In order to create an inclusive, feminist pedagogy, the power dynamics in the classroom need to be explored and explained. This exploration begins with the person who is in charge of the classroom. As Maher (1999) argues, "We need a pedagogy in which the ideals of unity and inclusion are linked to actively challenging the barriers to those ideals posed by the gendered, raced, and classed relationships of power in the classroom. In order to articulate such a pedagogy, we have to look at the teacher" (p. 43). By looking at the teacher, the responsibility of creating social change and an equitable classroom falls to them, and how they set up the power and authority dynamic between themselves and their students.

When examining the teachers' authority in a mathematics classroom, it is important to consider two elements: the development of a particular pedagogical method, and a teacher's comfort and working knowledge of the subject at hand (Ball & Bass, 2000). In order for a teacher to be comfortable with an alternative or radical pedagogy, s/he needs to be comfortable with the content. Without that comfort, they must rely on the old methods of teaching, which distributes the vast majority of the classroom power to them, taking away the agency of the students in the process, turning them into passive, dependent learners. When teachers who are not particularly comfortable with mathematical subject matter, or who are not comfortable with the previously mentioned alternative form of mathematics, are in control of classrooms, they tend to prefer to spoon feed their students mathematical knowledge, since that method appeared to work for them (Boaler & Greeno, 2000). This type of discomfort or unwillingness to veer off from the norm only perpetuates the problems that already exist in mainstream mathematical pedagogies, particularly in reproducing inequalities in the classroom and in attainment levels (Boaler & Greeno, 2000). When teachers are willing to relinquish some of the control and authority in the classroom and engage with alternative pedagogies, positive results emerge.

In this model, power becomes redistributed in the classroom, and more is placed at the disposal of the students. However, it is a perilous balance. Everyone in the classroom, teachers and students, should be given responsibilities as knowers and learners of mathematical content, therefore creating an atmosphere that emphasizes equality and agency over learning (Maher & Tetrealt, 2001). It is possible to teach the content while allowing for the questioning of it, simultaneously (Maher & Tetrealt, 2001). By placing some power in the hands of the students, it also creates a space for what the students deem to be important and what kind of mathematical knowledge they value (Hodkinson, 2005). Learning can often be seen and experienced as an individual phenomenon, so it is important that students have the power to control part of that phenomenon, and that they don't rely entirely upon the teacher.

In order to create a more equitable and accessible mathematical learning environment, Becker (1995) argues that mathematics needs to be humanized. In other words, mathematics needs to be taken down off of the untouchable "objective subject" pedestal and brought down to a level where biases are revealed, and framed in such a way that students can relate to it. In particular, the different voices in a mathematical classroom need to have a space to be heard and appreciated, since different students' voices will come from different places, depending on their social location. By valuing individual voices and acknowledging the various positionalities of students, it makes room for the personal in mathematics classroom, allowing for personal viewpoints instead of requiring that they be left behind. However, it is important to overemphasize underprivileged voices, and to not discount the male voice (Maher & Tetrealt, 2001). When allowing for voices in the classroom, it is important to value all of them, as well as their experiences with mathematics itself. The teachers' voice in the classroom is also important to consider, since the ways in which their voice is used tend to convey power and control inside the classroom (Arnot, 2006). Madeleine Arnot (2006) also notes the ways in which voice expression allows the students in the classroom to express agency over their learning, and become creators, knowers, and authors of knowledge.

In their arguments for the healthy creation of identity and agency in the mathematics classroom, Boaler and Greeno (2000) point out that traditional teaching methods often end up turning students off of mathematics at critical times in the development of their intellectual identities, and this is often a result of the loss of their agency, and results in the loss of their perceived ability to succeed in mathematics. Being an active agent plays an essential role in the deeper learning of mathematics, and that creates more positive experiences and identities in students with the subject itself (Boaler & Greeno, 2000). Why is creating positive experiences through an unconventional pedagogical approach so crucial? Boaler and Greeno (2000) observed, "[the highest attaining mathematics students'] attainment progressively deteriorated as their mathematics teaching became more procedural," (p. 185) and most of those students whose performances declined were girls. In order to retain those girls, as well as encourage others to achieve and maintain high attainment in mathematics, their voices need to be heard, and their agency needs to not be controlled and dominated by the instructor. Being passive learners only serves as a detriment to students' educational potential.

The incorporation of elements of feminist pedagogies as well as mathematical histories into actual classroom practices is not simple or straightforward. A crucial first step in putting this theory into practice would be the initial setup of the classroom. This has a dramatic impact on the overall classroom environment, and establishes the expected roles of the student and the teacher. In order to create a feminist atmosphere, the teacher could begin by laying out the ideal environment that would be achieved, namely one that values each person's voice and agency, and the distribution of power between the students and the teacher. The teacher could work with students to create a set of classroom guidelines and expectations, which would allow for a certain flexibility within the classroom, and for ways for the students to speak up for themselves and their preferred level of participation and style of learning. Working with the students in this way would also let them lay out the expectations they have for the teacher, in addition to themselves. It is also a way that each voice could be heard. Obviously, this would be much harder to do with elementary-aged students, but it could be adapted to accommodate the level of discipline and authority the teacher deems necessary in the classroom. In this instance, the teacher might choose to describe the classroom expectations, and create a list of guidelines that reflect the feminist principles valued in this pedagogical approach.

In addition to the creation of the classroom environment, this feminist pedagogy requires that students experience mathematics as real and relatable. This could be done in a few different ways. The teacher could focus on making mathematical content more applicable to students' lives, incorporating mathematical history into the lessons, or a combination of both. According to Boaler (2000), students need concrete situations in which to learn and apply their mathematical knowledge. The type of activity students would undertake in order to accomplish this would depend on their level in school. For example, Gerofsky (2001) proposes that educators create a relatable mathematics by asking students to create word problems based on recently taught principles that are directly related to real life experiences that they or someone else could face every day. This type of approach would be more suited for more advanced students, such as those in middle or high school. By using this method, students are not simply recreating word problems created by other people in their own terms; they are examining their lives and applying mathematical concepts to them.

While issues of power and authority might not be as complicated at elementary levels as they are in higher levels, the privileging and marginalizing of different voices remains critical, as does creating a mathematics that can be related to by students. Digiovanni (2004) argues that at elementary levels, it is important to look for information, particularly mathematical information, which is often left out or left behind. She argues for the inclusion and representation of women in mathematics, as well as minorities, which can be as simple as hanging posters that paint a diverse picture of mathematics and mathematicians, in order for all of the students to see that mathematics is available to everyone, not just a select few.

The incorporation of historical content into mathematical lessons is also an essential element of this pedagogy. There is a decent amount of work about how this can be done. Fauvel and van Maanen's (2000) book, *History of Mathematics Education*, for example, details the ways in which history could be incorporated into mathematics classrooms. Jankvist (2009) identifies three main approaches to using history in mathematical lessons: the illumination approach, the modules approach, and the history-based approach. The illumination approach is, at its most basic level, more or less about adding historical tidbits to mathematics lessons and stirring. However, Jankvist does describe different scales on which this can be done. On a small scale, which would be more suited to elementary-aged students, examples of including mathematics history include covering things such as names, dates, famous works and events, time charts, and biographies. The medium example would be including things such as “famous problems and questions, attribution of priority, facsimiles, etc.” into mathematics lessons (Jankvist, 2009, p. 245-6). The largest example Jankvist provides is the inclusion of mathematic epilogues to each chapter’s material that covers particular aspects of the history of that particular concept or principle.

The second method Jankvist (2009) describes is the modules approach. This approach contains “units devoted to history, …often based on [particular mathematical] cases” (p. 246). This method also ranges in size, going from short modules that take particular aim at specific categories that are designed to match up with specific sections of the mathematics curriculum, to medium modules that focus on the reading of mathematical texts and/or original sources to learn how concepts were developed, to the large modules, which are full courses dedicated to mathematical history. The modules approach is very similar to the illumination approach, in that the size or scope of the module used is dictated by the ages of the students being taught.

The third and final method is the history-based approach. This approach is “directly inspired by or based on the development of mathematics,” where the historical development of mathematics is not necessarily openly or overtly discussed (Jankvist, 2009, p. 246). The example that Jankvist provides is based on the teaching of number sets. Using the history-based approach to teaching number sets, historical development of those sets would determine the order in which they are taught, with the order being: natural numbers, positive rational numbers, some positive irrational numbers, zero and negative numbers, the remaining real numbers, and finally complex numbers. Jankvist (2009) states that the scope and type of approach used in the classroom is dependent upon the ages of the students. This would indicate that younger students might receive a lower amount of historical content in their mathematics lessons, but that as they advanced, the amount of history would increase as well.

Katz (1997) argues that it is up to the teachers to determine the best historical approach to use with their students. Although in order for the teachers to choose the appropriate method, they must be knowledgeable about mathematical history, that way they are "ale to pull out the details relevant to the particular class and arrange in the best way. One cannot follow the history blindly if one is to use it for pedagogy" (Katz, 1997, p. 63). Furinghetti and Paola (2003) also believe that in order to properly incorporate mathematical history into the classroom, the teacher needs to be competent in several areas. These areas include mathematics, mathematics education, history, education and communication (p. 40).

By incorporating mathematical history into a feminist mathematical classroom environment, several results are achieved. The classroom is a more open, equal, and comfortable environment, and mathematical content becomes humanized, and thus more accessible. Students are granted a certain level of agency and authority over their learning, but yet the collaborative aspect of the feminist pedagogy appears to be lacking. By incorporating historical content into mathematical instruction, group projects or work could be assigned that encourage collaboration between students. For example, examine Clark's (2012) work on understanding concepts from multiple perspectives through history. She focuses on the concept of completing the square, and the proof of this method that was written by al-Khwarizmi. Completing the square is typically associated with algebraic equations and the Greek mathematician Diophantus' algebraic proof, but al-Khwarizmi's proof is a geometrical one. In order to incorporate historical elements as well as encourage collaborative work among students, the teacher could task students to try working with competing algebraic and geometric equations, while assigning students to two groups. The first group of students would solve it using the typical algebraic format; the second group of students would solve the same equation using the geometric method used in al-Khwarizmi's proof. After both groups were finished, they would switch methods and solve a second equation. At the end, a discussion could take place about the benefits of each method, and how it helped increase students' understandings of the concept. Students would be working together in order to solve the problem, be exposed to the ways in which mathematics has evolved, and they would be exposed to multiple ways of finding the same solution (Clark, 2012; Furinghetti, 2007). The multiple methods that students would be exposed to would allow students to find the method that works best for them, thus increasing the likelihood that they will understand the material, and decreasing the need for memorization for the purpose of regurgitation on standardized tests (Clark, 2012). Further implications of this mathematical pedagogy will be explored in the next chapter.

By redistributing power, creating space for marginalized voices, and bringing personal experiences into the mathematics classroom, a new type of pedagogical method is created. It is one that is specific to mathematics, and it is designed to help students overcome the obstacles and inequalities that have been present in mainstream mathematical pedagogies. This pedagogy utilizes a mathematics that has social and cultural history and context, and therefore becomes more relatable and understandable to the students trying to learn it. It allows for students to create an identity in relation to mathematics, and a more positive identity than was possible in the past. The key to this entire pedagogy is enabling students and teachers to become active agents in the creation of mathematical knowledge.

Possible Resistance to this New Pedagogy

Such a radical pedagogy as described in the previous section would not be accepted without resistance. Skeptics of pedagogies that are so far from the norm would be quick to challenge this approach, citing concern about relying on research that uses gender as the main research variable (see Hammersley, 2001), or the ever-popular varying political climate and changing standardized testing. Peter Appelbaum (2002) even goes so far as to identify the three areas that pose the biggest problem to alternative pedagogies, including those that value diversity, in education: assessment methods, classroom management, and grouping practices (p. 41). While these critiques may be justified, since there will never be any such thing as a perfect pedagogy, the above pedagogy is strong enough and flexible enough to overcome those criticisms.

Michael Apple (2000) discusses all the various mathematics reforms that were taking place at the time his work was published, focusing mainly on the shift to neoliberal and neoconservative lines of thinking and resulting movements. He cites the free market ideology that stimulated this shift in thinking, and how it impacted curricular design, development, and implementation. Apple (2000) also points out the limitations of these policies, arguing that these competition-inspiring policies change attitudes regarding students, shifting them from what the school can do for the student to what the student can do for the school. Critics of the mathematics pedagogy might see it as reversing this thinking, putting the focus back on what the school can do for students, which goes against popular politics today. If something isn't working, however, why continue to follow along in that train of thought? Why not try something new and different, and possibly end up with a better solution? Trying new things might be intimidating and unpredictable, but in order to achieve a more equitable society, it might be what is necessary. Previous politics and the resulting policies have only limited opportunities for new ways of knowing, and this raises questions about the availability of "alternative progressive policies and practices in curriculum, teaching and evaluation" (Apple, 2000, p. 257). So while those advocating for a more conservative approach to education might critique this alternative pedagogy, those critiques are coming from a place that is not necessarily receptive to it in the first place.

Critiques from the feminist side of things would also occur. Liz Newberry (2009) in particular questions the use of students' experiences in the classroom in pedagogical theories, mainly through the idea of conflict. She argues that feminist pedagogies themselves are responsible for worsening situations that are already prone to conflict, since many of them depend on the involvement of student experiences. Experiences can vary greatly, and therefore should not be immediately classified as “uncontestable knowledge” (Newberry, 2009, p. 249). Newberry does not deny the value of experience in classroom settings, but merely questions its placement at the forefront of educational policy. This is just one example of many different types of resistance from within feminism itself. Just as there are many fields within mathematics, there are many different types of feminism, and not all of the different types will agree with the others, so resistance to and criticism of this mathematics pedagogy, in some form, will appear.

Conclusion

Feminist pedagogies have been around for a decent length of time, and a select few have broached the topic of mathematics pedagogies with feminist elements. There are different feminist theories used to create feminist pedagogies, such as standpoint theory and poststructuralism, with each having their own issues that they deem the most important. The pedagogy above designed specifically for mathematics will most likely have its problems, but hopefully it is the basis of better work moving forward. The challenge will be in overcoming those problems and tackling the other forms of resistance to it that will appear. Perhaps it is a small step towards bridging the gap that exists between mathematics research and women’s studies research (Damarin, 2008). Perhaps it is a method of teaching that will allow for more women and minorities to participate in higher mathematics. The conversation surrounding women and minorities in mathematics needs to change, and perhaps this pedagogy is one way of changing that conversation. As Suzanne Damarin (2008) argued, “the study of gender by educators and psychologists has been largely a study of female failure to succeed in mathematics [has been pointed out by Mary Beth Ruskai]. If true, this is a serious matter; an understanding of gender and mathematics that has no place for successful women is obviously seriously flawed" (p. 109). Ideally, this pedagogy would be a way of correcting these flaws. Other possible implications of the pedagogy will be explored further in the next chapter.

Chapter 4

Summary of the Previous Chapters

At the beginning of this project, I set out to create and discuss a feminist pedagogy designed specifically for mathematic classrooms. Creating a math-specific feminist pedagogy would be a great start in helping to create and sustain a more equitable mathematics discipline. In order to achieve this goal, I began by exploring and establishing the current status of student achievement in mathematics. While fewer students are categorized as testing at below basic levels today when compared to the same statistic from twenty years ago, more students are failing to maintain basic levels of mathematical achievement, and they fall below basic levels (Aud et al., 2012). Compared to the scores from 1990, this is a change, since twenty years ago, as students got older, fewer of them scored below basic level of achievement (Aud et al., 2012). I then discussed the research that has been conducted that examined gender differences in performance in mathematics, and the resulting theories that attempt to explain these differences. While biological theories continue to circulate, they have been systematically refuted by feminist scholars. Social explanations of these differences are more promising, and they were the main bases of research utilized for this project. These included classroom-based theories that examined everything from student interaction patterns and peer influences to teacher's practices and preferences. Finally, I discussed popular programs that are in place.

Chapter two was an exploration of the relationship between math and the other sciences, and just how much of an overlap exists between them. It attempted to answer the question of just how applicable critiques of science are to mathematics, and why critiques of science might not always cover mathematics as well. Mathematics is the foundation upon which the other sciences are built, yet its biases are not pointed out or addressed nearly as often as it occurs in for the other sciences like human biology and physics. I then considered claims about methods of mathematical inquiry and thinking, relying on opinions advanced by mathematicians themselves, or research conducted with mathematicians as the main participants. Mathematical thinking puts a premium on rigor, and anything that looks as though it was not rigorously explored or explained, or generated an inadequate proof has been marginalized as falling short of the mathematical ideal. I pointed out that mathematicians have a habit of ignoring the role that insight and intuition play in their work, focusing instead on the conscious efforts they devote to their problems, even though they rely heavily on subconscious thoughts and intuitions (Burton, 2004). I also demonstrated that the field of mathematics is less stable than sometimes imagined, introducing different types of mathematics, such as Euclidean and non-Euclidean geometry, as well as contradictions between the ways mathematicians believe they work and how they actually work. The usefulness of mathematical histories was also analyzed. By disregarding mathematical history, or marginalizing it, social and cultural influences over the subject are being ignored and overlooked; creating the illusion of a discipline that is objective, pure, and full of unquestionable absolutes. By exploring mathematical histories and supporting them, mathematics becomes culturally diverse, erasing the Eurocentric view that has been painted for decades. I then suggested the benefits of culturally-attuned mathematics that would be flexible, aware of fallibility, contingency, and change, and accessible to everyone, regardless of race, class, or gender.

The third chapter focused mainly on pedagogical strategies, particularly feminist ones. Past attempts at revolutionary pedagogies were discussed, paying particular attention to Paulo Freire's (2011) book, *Pedagogy of the Oppressed*. Freire (2011) criticized traditional approaches to teaching, addressing the issues surrounding the dependency of students upon their teachers for knowledge. While his ideas were revolutionary at the time, feminist scholars like Jackson (1997) and Weiler (1991) critically assess Freire's work, and point out issues with the generalizations made about the oppressed. I then examined other feminist pedagogies developed outside the field of mathematics. Yet I also introduced mathematics-specific pedagogies, which might not be labeled feminist, but address issues of diversity in mathematics education. I then outline and discuss my feminist pedagogy for mathematics, basing it on emphasizing equality, inclusion, power relations, teacher and student agency, and voice. This pedagogy was also built upon the concept of the culturally-attuned mathematics. The application of a pedagogy requires a certain maturity of students, but particular elements can still be applied to elementary aged classrooms. A brief discussion of possible sources of and reasons for resistance to this pedagogy concludes the chapter.

Possible Implications

My feminist pedagogy for mathematics education clearly has potential to shape educational practices. However, it is important to look at the possible implications it could have at a theoretical level as well. For example, Paul Ernest (1995) outlined the cycle of gender inequalities in mathematics in order to illustrate the impact gender inequalities can have on students' lives. The cycle can technically start at any point, given that it is circular, but for discussion purposes, I will start at the top of the diagram. At the top is "gender stereotyped cultural views, including *maths=male*," (Ernest, 1995, p. 457, Fig. 1).

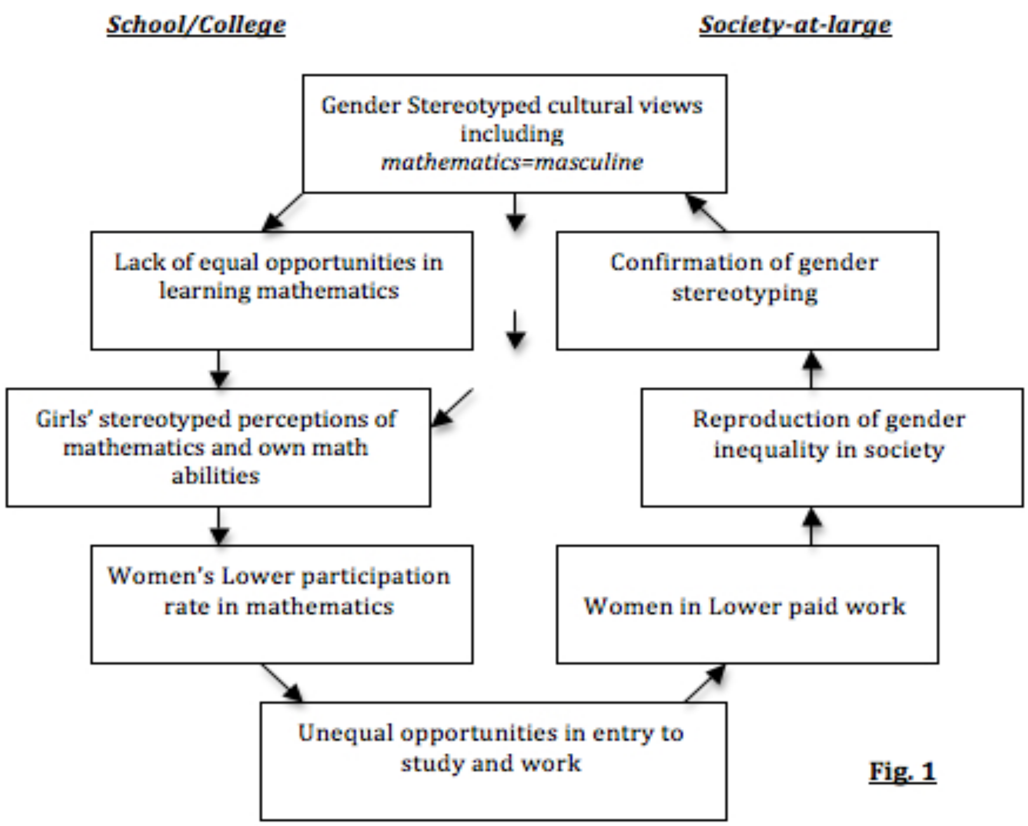

Fig. 1

The cycle, as seen in the figure above, creates a lack of equal opportunities to learn mathematics, which then creates stereotypes surrounding girls and mathematics, impacting their performance. This in turn impacts the participation rates of women in mathematics, causing them to be lower, leading to inequalities in the opportunities in higher levels of school and even job opportunities. Thus, women end up with lower wage jobs, which further reproduces gender inequalities in society at large. Those resulting inequalities serve as a confirmation of sorts of the gender stereotyping that had been taking place, which then circles back around, and causes mathematics to be stereotyped as a male subject (Ernest, 1995).

If the feminist pedagogy for mathematics were implemented in classrooms, girls might not face unequal mathematical learning opportunities, which would prevent them from developing mathematical identities that are built upon stereotypes that tell them that they cannot do something just because they are females. This could encourage them to continue on with their mathematics education, carrying them to higher levels of mathematics, and opening up more higher paid job opportunities. This would counteract the aforementioned reproduction of gender inequalities in society, and thus fail to confirm particular gender stereotypes that are so prevalent in society. Circling back to the beginning, the failure to confirm those gender stereotypes could impact the continuing belief of mathematics as being a gendered subject. In other words, it could undo the entire cycle. As Damarin (2000) states:

> [T]he development of mathematical interest and skill is seen as promoting an individual's status within the society as well as her or his contribution to national economics, security and progress. From this perspective, the relative absence of women from mathematical endeavors is seen as evidence for the lesser power of women. (p. 74)

This is merely speculation, but if mathematics were made available to everyone, instead of just a select portion of the population, the chances of this happening are not entirely nonexistent. In fact, changing how mathematics classrooms operate could prevent the question of why gender stereotypes in math continue to exist from ever needing to be asked (Cheryan, 2012).

Taking this a step further, if a more diverse group of people were to be encouraged to continue on in their mathematics education, or if they realized that they need not fear the advanced mathematics required at higher levels of science education, the diversity in the scientific fields could also change. The numbers of women in the STEM fields outside of mathematics remain dismal, as reported by the AAUW, and this pedagogy might just be one way that more women and minorities can be encouraged to seek out higher degrees in physics and chemistry (Hill et al., 2010). Suzanne Damarin (2000) highlighted the ways in which the mathematically able are marked, with those who succeed in mathematics who are not supposed to succeed (read: women) being labeled as deviants. After all, mathematicians themselves are labeled by society as being different, which marks them as being not normal, so when a competent woman in mathematics comes along, she falls under the marked categories of being a mathematician as well as being a woman, which combine to make her an undesirable person to society and to the mathematics community (Damarin, 2000). If a feminist pedagogy were installed in mathematics classrooms, both males and females could avoid the distinction of being marked different or as deviant, and change the power constructions that are related to mathematics.

The research conducted in the classrooms that examines students' experience with mathematics could experience a radical shift, as well. Previously, such studies have found that in traditional classrooms, the mathematical experiences of girls has been negative, even traumatic, and the construction of their mathematical identities is negatively impacted, often resulting in a failure to pursue higher mathematics (Buerk, 1982; Lim, 2008). Instead, results reported from feminist mathematics classrooms might resemble those found by Anderson (2005). In her work, Anderson (2005) performed a case study, where she interviewed teachers involved with a summertime mathematics program that had explicitly stated feminist pedagogical practices. The program was an all-girls program that placed an emphasis on individual responsibility for learning, as well as creating a collaborative environment in which the girls could learn. The students interviewed for the project reported at the end of the program that they felt as though the teachers worked with them and provided constructive criticism and encouragement instead of negative responses, and the overall atmosphere was less stressful than a typical mathematics classroom (Anderson, 2005).

The application of a feminist pedagogy of mathematics, on a grand scale but basic level is important, merely for the sake of improving society's mathematical literacy, or numeracy. Numeracy is extremely important and necessary to function as a useful and informed member of society (Crowe, 2010). Crowe (2010) argues that numeracy is particularly important to issues related to social studies, as the manipulation of data and percentages is common, and if members of society are unfamiliar or uncomfortable with this particular type of mathematics, they will fail to see through the shroud of misinformation. This is particularly relevant in the world of politics, given the overload of information that is thrust upon the populace over time. Numerical breakdowns of how tax dollars are spent are published, analyzed, and criticized by politicians, and voters have a tendency to rely on various interpretations (whether they are accurate or not), and base their decisions off of those instead of doing the work for themselves.

The examples of the impact of a feminist pedagogy of mathematics discussed above, both theoretical and practical, are only a small portrayal of what could happen. To paraphrase the chaos theory, changing one relatively small thing, such as the way in which mathematics is viewed and taught in schools, could cause ripple effects, and change things in ways that no one could ever predict. Further research into the matter could reveal more implications. Other research could apply this educational theory in an actual classroom, and track the results. Perhaps other feminist scholars could critique it, add to it, and build it into a truly powerful feminist pedagogy for mathematics. The possibilities are nearly as endless as the possible implications of putting it into place in a classroom.

Conclusion

Throughout this project, ideas surrounding gender and mathematics research have been explored. Previous attempts at correcting the problems facing mathematics students have helped, but none have broken through to the mainstream, and have been problematic. The emphasis of a process-oriented mathematics over a results-oriented mathematics has been tried before, but not necessarily with other feminist elements in play as well (Rodgers, 1995). This project is merely one possible solution to a problem that needs to be solved. The implications of a feminist pedagogy for mathematics that is actually implemented in a classroom are important to consider, and although at this point they are only theoretical, they could still indicate the profound impact on mathematics education that this pedagogy could have. It is only one cog in the wheel of the movement that is striving for a more equal society, but who knows the impact that it could have. With this pedagogy, the opportunity is there to change the narratives of otherwise marginalized students, and that in itself is invaluable.

Bibliography

Anderson, D. L. (2005). A portrait of a feminist mathematics classroom: What adolescent girls say about mathematics, themselves, and their experiences in a "unique" learning environment. *Feminist Teacher, 15(3)*, 175-194.

Appelbaum, P. (1995). *Popular Culture, Educational Discourse, and Mathematics.* Albany, NY: State University of New York Press.

Appelbaum, P. (2002). *Multicultural and Diversity Education*. Santa Barbara, CA: ABC-CLIO, Inc.

Apple, M. (2000). Mathematics reform through conservative modernization? Standards, markets, and inequality in education. In J. Boaler (Ed.) *Multiple perspectives on mathematics teaching and learning* (p. 243-259). Westport, CT: Ablex Publishing.

Arnot, M. (2006). Gender voices in the classroom. In C. Skelton, B. Francis, & L. Smulyan (eds.) *The SAGE Handbook of Gender and Education* (p. 407-421). Thousand Oaks, CA: SAGE Publications.

Aud, S., Hussar, W., Johnson, F., Kena, G., Roth, E., Manning, E., Wang, X., & Zhang, J. (2012). *The Condition of Education 2012* (NCES 2012-045). U.S. Department of Education, National Center for Education Statistics. Washington, DC. Retrieved October 2012 from http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2012045

Ayoub, R. G. (2004). *Musings of the Masters: An Anthology of Mathematical Reflections*. Washington, DC: Mathematical Association of America.

Ball, D. L., & Bass, H. (2000). Interweaving content and pedagogy in teaching and learning to teach: Knowing and using mathematics. In J. Boaler (Ed.) *Multiple perspectives on mathematics teaching and learning* (p. 83-104). Westport, CT: Ablex Publishing.

Barnes, M. (2000). Effects of dominant and subordinate masculinities on interactions in a collaborative learning classroom. In J. Boaler (Ed.) *Multiple perspectives on mathematics teaching and learning* (p. 145-169). Westport, CT: Ablex Publishing.

Bauchspies, W. K., Croissant, J., & Restivo, S. (2006). *Science, Technology, and Society: A Sociological Approach*. Malden, MA: Blackwell Publishing.

Bayne, S. M. (2000). Kant's answer to Hume: How Kant should have tried to stand Hume's copy thesis on its head. *British Journal for the History of Philosophy 8(2)*, 207-224.

Becker, J. R. (1995). Women's ways of knowing in mathematics. In P. Rogers & G. Kaiser (Eds.), *Equity in Mathematics Education* (p. 163-174). Bristol, PA: Taylor & Francis.

Birkhoff, G. D. (2004). Intuition, reason, and faith in science. In R. G. Ayoub (Ed.), *Musings of the Masters: An Anthology of Mathematical Reflections* (p. 95-114). Washington, DC: Mathematical Association of America. (Original work published 1938).

Blakemore, J., Berenbaum, S., & Liben, L. (2009) *Gender Development*. New York, NY: Psychology Press.

Beaujean, A. A., Firman, M. W., Attai, S., Johnson, C. B., Firman, R. L., & Mena, K. E. (2011). Using personality and cognitive ability to predict academic achievement in a young adult sample. *Personality and Individual Differences, 51*, 709-714.

Boaler, J. (Ed.). (2000). *Multiple perspectives on mathematics teaching and learning*. Westport, CT: Ablex Publishing.

Boaler, J. & Greeno, J. G. (2000). Identity, agency, and knowing in mathematics worlds. In J. Boaler (Ed.) *Multiple perspectives on mathematics teaching and learning* (p. 171-200). Westport, CT: Ablex Publishing.

Boaler, J. & Sengupta-Irving, T. (2006). Nature, neglect, and nuance: Changing accounts of sex, gender and mathematics. In C. Skelton, B. Francis, & L. Smulyan (eds.) *The SAGE Handbook of Gender and Education* (p. 207-220). Thousand Oaks, CA: SAGE Publications.

Brown, T., Jones, L., & Bibby, T. (2004). Identifying with mathematics in initial teacher training. In M. Walshaw (ed.) *Mathematics Education Within the Postmodern* (p. 161-179). Greenwich, CT: IAP Information Age Publishing.

Buerk, D. (1982). An experience with some able women who avoid mathematics. *For the Learning of Mathematics, 3(2)*, 19-24.

Burton, L. (1995). Moving towards a feminist epistemology of mathematics. In P. Rogers & G. Kaiser (Eds.), *Equity in Mathematics Education* (p. 209-225). Bristol, PA: Taylor & Francis.

Burton, L. (2004). *Mathematicians as enquirers: Learning about learning mathematics.* Norwell, MA: Kluwer Academic Publishers.

Cartwright, M. L. (2004). Mathematics and thinking mathematically. In R. G. Ayoub (Ed.), *Musings of the Masters: An Anthology of Mathematical Reflections* (p. 3-16). Washington, DC: Mathematical Association of America. (Original work published 1970).

Cheryan, S. (2012). Understanding the paradox in math-related fields: Why do some gender gaps remain while others do not? *Sex Roles, 66,* 184-190.

Clark, K. M. (2012). History of mathematics: Illuminating understanding of school mathematics concepts for prospective mathematics teachers. *Educational Studies in Mathematics, 81(1)*, 67-84.

Code, L. (1991). *What Can She Know?: Feminist Theory and the Construction of Knowledge*. Ithaca, NY: Cornell University Press.

Crosnoe, R., Riegle-Crumb, C., Frank, K., Field, S., & Muller, C. (2008). Peer group contexts of girls' and boys' academic experiences. *Child Development, 79(1)*, 139-155.

Crowe, A. R. (2010). "What's math got to do with it?": Numeracy and social studies education. *The Social Studies, 101,* 105-110.

Cvencek, D., Meltzoff, A. N., & Greenwald, A. G. (2011). Math-gender stereotypes in elementary school children. *Child Development, 82(3),* 766-779.

Damarin, S. (1995) Gender and Mathematics from a feminist standpoint. In W. G. Secada, E. Fennema, & L. B. Adajian (Eds.) *New Directions for Equity in Mathematics Education* (p. 242-257). New York, NY: Cambridge University Press.

Damarin, S. (2000). The mathematically able as a marked category. *Gender and Education, 12(1)*, 69-85.
Damarin, S. (2008). Toward thinking feminism and mathematics together. *Signs: Journal of Women in Culture and Society, 34(1)*, 101-123.
Davis, P. J., & Hersh, R. (1986). The ideal mathematician. In T. Tymoczko (Ed.), *New Directions in the Philosophy of Mathematics* (p. 177-184). Boston, MA: Birkhauser.
Digiovanni, L. W. (2004). Feminist pedagogy and the elementary classroom. *Encounter: Education for Meaning and Social Justice, 17(3)*, 10-15.
Dillabough, J. (2001). Gender theory and research in education: Modernist traditions and emerging contemporary themes. In B. Francis & C. Skelton (eds.) *Investigating gender: Contemporary perspectives in education* (p. 11-26). Philadelphia, PA: Open University Press.
Earnest, P. (1995) Values, gender and images of mathematics: A philosophical perspective. *International Journal of Mathematical Education in Science and Technology, 26(3)*, 449-462.
Elam, M. & Juhlin, O. (1998). When Harry met Sandra: An alternative engagement after the science wars. *Science as Culture, 7(1)*, 95-109.
Englehard, G. (1990). Math anxiety, mothers' education, and the mathematics performance of adolescent boys and girls—Evidence from the United States and Thailand. *Journal of Psychology, 124(3)*, 289-298.
Evans, J. & Tsatsaroni, A. (1994). Language and "subjectivity" in the mathematics classroom. In S. Lerman (Ed.) *Cultural perspectives on the mathematics classroom* (p. 169-190). Norwell, MA: Kluwer Academic Publishers.
Fausto-Sterling, A. (1992). *Myths of gender: Biological theories about women and men* (2nd ed.). New York, NY: Basic Books.
Fauvel, J., & van Maanen, J. (Eds.) (2000). *History in Mathematics Education: An ICMI Study*. Norwell, MA: Kluwer Academic Publishers.
Forgaz, H. J., & Leder, G.C. (1996). Mathematics classrooms, gender and affect. *Mathematics Education Research Journal, 8(1)*, 153-173.
Freire, P. (2011). *Pedagogy of the Oppressed* (30th Anniversary ed.). New York, NY: Continuum International Publishing Group.
Fried, M. N. (2007). Didactics and history of mathematics: Knowledge and self-knowledge. *Educational Studies in Mathematics, 66(2)*, 203-223.
Furinghetti, F. (2007). Teacher education through the history of mathematics. *Educational Studies in Mathematics, 66(2)*, 131-143.
Furinghetti, F., & Paola, D. (2003). History as a crossroads of mathematical culture and educational needs in the classroom. *Mathematics in School, 32(1)*, 37-42.
Gerofsky, S. (2001). Genre analysis as a way of understanding pedagogy in mathematics education. In J.A. Weaver, M. Morris, & P. Appelbaum (Eds.), *(Post) Modern science (education)* (p. 147-175). New York, NY: Peter Long Publishing.
Gladwell, M. (2008, May 12). In the air: Who says big ideas are rare? *New Yorker, 84(13)*. Retrieved from http://www.newyorker.com/
Gough, A. (2001). Pedagogies of science (in)formed by global perspectives: Encouraging strong objectivity in classrooms. In J.A. Weaver, M. Morris, & P.

Appelbaum (Eds.), *(Post) Modern science (education)* (p. 275-300). New York, NY: Peter Long Publishing.

Greyson, D. L., Becu, A. R., Morgan, S. G. (2010). Sex, drugs and gender roles: mapping the use of sex and gender based analysis in pharmaceutical policy research. *International Journal for Equity in Health*, 9(26). Retrieved from http://www.equityhealthj.com/content/9/1/26

Hadamard, J. S. (2004). Thoughts on the heuristic method. In R. G. Ayoub (Ed.), *Musings of the Masters: An Anthology of Mathematical Reflections* (p. 31-43). Washington, DC: Mathematical Association of America. (Original work published 1905).

Hammersley, M. (2001). Obvious, all too obvious?: Methodological issues in using sex/gender as a variable in educational research. In B. Francis & C. Skelton (eds.) *Investigating gender: Contemporary perspectives in education* (p. 27-38). Philadelphia, PA: Open University Press.

Harding, S. (2004). A socially relevant philosophy of science? Resources from standpoint theory's controversiality. *Hypatia, 19(1)*, 25-47.

Harrison, W. C. (2001). Truth is slippery stuff. In B. Francis & C. Skelton (eds.) *Investigating gender: Contemporary perspectives in education* (p. 52-64). Philadelphia, PA: Open University Press.

Henrion, C. (1997). *Women in mathematics: The addition of difference*. Indianapolis, IN: Indiana University Press.

Hersh, R., & John-Steiner, V. (2011) *Loving + hating mathematics: challenging the myths of mathematical life*. Princeton, NJ: Princeton University Press.

Hill, C., Corbett, C., & St. Rose, A. (2010). *Why so few?: Women in science, technology, engineering and mathematics.* Washington, DC: American Association of University Women.

Hodkinson, P. (2005). Learning as cultural and relational: Moving past some troubling dualisms. *Cambridge Journal of Education, 35(1)*, 107-119.

Howes, E. V. (2002). *Connecting Girls and Science: Constructivism, Feminism, and Science Education Reform.* New York, NY: Teachers College Press.

Howes, E. V. & Rosenthal, B. (2001). A feminist revisioning of infinity: Small speculations on a large subject. In J.A. Weaver, M. Morris, & P. Appelbaum (Eds.), *(Post) Modern science (education)* (p. 177-192). New York, NY: Peter Long Publishing.

Hyde, J., Else-Quest, N, & Linn, M. (2010). Cross-national patterns of gender differences in mathematics: a meta-analysis. *Psychological Bulletin 136(1),* 103-127.

Hyde, J., Lindberg, S., Linn, M., Ellis, A., & Williams, C. (2008). Gender Similarities Characterize Math Performance. *Science, 321,* 494-495.

Jackson, S. (1997). Crossing borders and changing pedagogies: From Giroux and Freire to feminist theories of education. *Gender and Education, 9(4)*, 457-467.

Jankvist, U. T. (2009). A categorization of the "whys" and "hows" of using history in mathematics education. *Educational Studies in Mathematics, 71(3)*, 235-261.

Jones R. E. & Lopez, K. H. (2006). *Human reproductive biology.* San Diego: Academic Press.

Jordan-Young, R. M. (2010). *Brain storm: the flaws in the science of sex difference*. Cambridge, MA: Harvard University Press.
Katz, V. J. (1997). Some ideas on the use of history in the teaching of mathematics. *For the Learning of Mathematics, 17(1)*, 62-63.
Keller, E. F. (2010) *The mirage of a space between nature and nurture*. Durham, NC: Duke University Press.
Kitcher, P. (1988). Mathematical Naturalism. In W. Aspray & P. Kitcher (Eds.), *Minnesota Studies in the Philosophy of Science* (Vol. XI- History and Philosophy of Modern Mathematics). Minneapolis, MN: University of Minnesota Press.
Lerman, S. (2000). The social turn in mathematics education research. In J. Boaler (Ed.) *Multiple perspectives on mathematics teaching and learning* (p. 19-44). Westport, CT: Ablex Publishing.
Lim, J. H. (2008). Adolescent girls' construction of moral discourses and appropriation of primary identity in a mathematics classroom. *ZDM Mathematics Education, 40*, 617-631.
Maher, F. A. (1999). Progressive education and feminist pedagogies: Issues in gender, power, and authority. *Teachers College Record, 101(1)*, 39-59.
Mann, T. (2011). History of mathematics and history of science. *Isis, 102(3)*, 518-526.
McSweeney, J. C., Cody, M., O'Sullivan, P., Elberson, K., Moser, D. K., & Garvin, B. J. (2003). Women's early warning symptoms of acute myocardial infarction. *Circulation, 108(21),* 2629-2623.
Maher, F. A. & Tetrealt, M.K.T. (2001). *The Feminist Classroom: Dynamics of Gender, Race, and Privilege*. Lanham, MD: Rowman and Littlefield Publishers, Inc.
Mura, R. (1995). Feminism and strategies for redressing gender imbalance in mathematics. In P. Rogers & G. Kaiser (Eds.), *Equity in Mathematics Education* (p. 155-162). Bristol, PA: Taylor & Francis.
Newberry, L. (2009). It's about time! Repetition, fantasy, and the contours of leaning from feminist pedagogy classroom breakdown. *Gender and education, 21(3)*, 247-257.
Nickson, M. (2004). *Teaching and Learning Mathematics: A Guide to Recent Research and its Applications* (2nd ed.). New York, NY: Continuum.
Neuville, E., & Croizet, J. (2007). Can salience of gender identity impair math performance among 7-8 year old girls? The moderating role of task difficulty. *European Journal of Psychology of Education, 22(3)*, 307-316.
Otte, M. (2007). Mathematical history, philosophy and education. *Educational Studies in Mathematics, 66(2)*, 243-255.
Penner, A. (2008). Gender differences in extreme mathematical achievement: An international perspective on biological and social factors. *American Journal of Sociology, 114,* S138-70.
Poincaré, J. H. (2004). Mathematical invention. In R. G. Ayoub (Ed.), *Musings of the Masters: An Anthology of Mathematical Reflections* (p. 17-30). Washington, DC: Mathematical Association of America. (Original work published 1908).

Renold, E. (2006). Gendered classroom experiences. In C. Skelton, B. Francis, & L. Smulyan (eds.) *The SAGE Handbook of Gender and Education* (439-449). Thousand Oaks, CA: SAGE Publications.

Rodgers, P. (1995). Putting theory into practice. In P. Rogers & G. Kaiser (Eds.), *Equity in Mathematics Education* (p. 175-185). Bristol, PA: Taylor & Francis.

Royer, J. M, Tronsky, L. N., Chan, Y., Jackson, S. J., & Marchant III, H. (1999). Math-fact retrieval as the cognitive mechanism underlying gender differences in math test performance. *Contemporary Educational Psychology, 24(3)*, 181-266.

Sherry, D. (2006). Mathematical reasoning: Induction, deduction and beyond. *Studies in History and Philosophy of Science, 37(3)*, 489-504.

Singh, S. (1998). *Fermat's Enigma*. New York, NY: Anchor Books.

Smit, H. (2010). Apriority, reason, and induction in Hume. *Journal of the History of Philosophy, 48(3)*, 313-343.

Solar, C. (1995). An inclusive pedagogy in mathematics education. *Educational Studies in Mathematics, 28*, 311-333.

Spencer, S., Steele, C., & Quinn, D. (1999). Stereotype threat and women's math performance. *Journal of experimental Social Psychology, 35(1)*, 4-28.

Tavris, C. (1992). *The mismeasure of women*. New York, NY: Simon & Schuster.

Tisdell, E. J. (1998) Poststructural feminist pedagogies: The possibilities and limitations of feminist emancipatory adult learning theory and practice. *Adult Education Quarterly, 48(3)*, 139-156.

United States Department of Education (2011). *Bachelor's, master's, and doctor's degrees conferred by degree-granting institutions, by sex of student and discipline division 2009-10* [Data file]. Retrieved from http://nces.ed.gov/programs/digest/d11/tables/dt11_290.asp

Vandiver, H. S. (1946). Fermat's last theorem: its history and the nature of the known results concerning it. *The American Mathematical Monthly, 53(10)*, 555-578.

Walshaw, M. (2005). Getting political and unraveling layers of gendered mathematical identifications. *Cambridge Journal of Education, 35(1)*, 19-34.

Walton, G. & Cohen, G. (2003). Stereotype lift. *Journal of Experimental Social Psychology*, *39,* 456-467. Hyde, Else-Quest, & Linn, 2010

Weiler, K. (1991). Freire and a feminist pedagogy of difference. *Harvard Educational Review, 61(4)*, 449-474.

Weiner, G. (2006). Out of the ruins: Feminist pedagogy in recovery. In C. Skelton, B. Francis, & L. Smulyan (Eds.) *The SAGE Handbook of Gender and Education* (p. 79-92). Thousand Oaks, CA: SAGE Publications.

Wigfield, A., & Byrnes, J. (1999). Does math-fact retrieval explain sex differences in mathematical test performance?. *Contemporary Educational Psychology, 24(3),* 275-285.

Wilder, R. L. (2004). The cultural basis of mathematics. In R. G. Ayoub (Ed.), *Musings of the Masters: An Anthology of Mathematical Reflections* (p. 129-148). Washington, DC: Mathematical Association of America. (Original work published 1950).

Willis, S. (1995). Gender reform through school mathematics. In P. Rogers & G. Kaiser (Eds.), *Equity in Mathematics Education* (p. 186-199). Bristol, PA: Taylor & Francis.

Wood, T. (1994). Patterns of interaction and the culture of mathematics classrooms. In S. Lerman (Ed.) *Cultural perspectives on the mathematics classroom* (p. 149-168). Norwell, MA: Kluwer Academic Publishers.

Wylie, A. (2003). Why standpoint matters. In R. Figueroa & S. Harding (Eds.) *Science and other cultures: Issues in philosophies of science and technology* (p. 26-48). New York, NY: Routledge.