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This dissertation investigates the underachievement of gifted women in mathematics. Chapter I examines the sources of societal negative attitudes toward mathematics, why we study mathematics and reasons mathematics is hard to learn. Chapter II looks at obstacles women face in learning mathematics: historical obstacles, socialization obstacles, adolescent development obstacles and psychological obstacles. Chapter III is reflections of the author's teaching career and reflections of conversations with gifted women who underachieve in mathematics. Chapter IV presents classroom practices to help alleviate women's problems with mathematics.

GIFTED WOMEN WHO UNDERACHIEVE: A STUDY OF MATHEMATICS AND GENDER

by

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Approved by

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To my mother and father, Ethel and Joseph Craft, and to my husband, Bob Hudgins.

APPROVAL PAGE

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Looking back, I find myself seeing past experiences in new ways – and I realize what it means to say that I have lived one possible life among many – and that there are openings even today to untapped possibilities. (Maxine Greene, *Releasing the Imagination*)

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CHAPTER I

THE PROBLEM DEFINED

I teach mathematics. Or, like my adolescent daughter so aptly asked, “Mom, do you know what you *do* for a living? You do math *all day long!*” Well, I have a completely different perspective on my occupation. I am thankful that I have the *opportunity* to do mathematics every day *and* I get paid to boot! However, many people have that same amazed (disgusted?) negative, reaction as my daughter when they find out my occupation. They make the sign of the cross and, after recovering their composure, many will “confess” their terrible experience with learning mathematics. I feel like a “math confessor” as people pour out their memories, often decades old, of their trials and tribulations with the subject. One woman emotionally related her woeful experience over forty years ago when a “C” in algebra kept her out of the National Honor Society. Countless people have told me similar stories of the “nightmare” and “torture” of their school experience with learning mathematics. Although you frequently hear these negative comments about mathematics, you seldom hear even remotely similar sentiments about other academic subjects, say English or history. Many Americans have little use for mathematics. They took the subject in school with varying degrees of success. Although some are neutral toward the subject, many still have nightmares about their mathematical encounters.

These negative reactions made me reflect upon the learning of mathematics in America. How did mathematics become so anathema? How does that demonization of mathematics affect the citizens of our country? Does the demonization of mathematics by American society really matter? (i.e., what are the consequences of such negative views?) Furthermore, do these negative views affect women more than they affect men? If so, how is that difference experienced by women? Where did such a negative opinion of mathematics, and by extension, mathematicians, originate? To answer these questions, I first sought the source of these negative attitudes toward mathematics. Three common theories of the negative views of mathematics in American society are the depiction of mathematicians in literature, the philosophy of two intellectual cultures, and the public perception of mathematics.

Sources of Negative Views

Depiction of Mathematicians in Literature

This negative view of mathematics has long been perpetrated in literature. Since before Jonathan Swift satirized mathematicians in Gulliver's Travels as the Laputans, who focused on abstractions to the extent that their ability to communicate and carry on ordinary activities was impaired, mathematicians have been portrayed as absent-minded. The general public who knows little about mathematicians and what they do or the purpose of mathematics shares Swift's satire of mathematicians. This cultural gap creates the same sort of stereotypes people develop about any foreign culture of which they know little (Trow 48).

This cultural gap is seen in more recent literature also. In Pi in the Sky, John Barrow quoted the, humorous but disparaging, definition of a mathematician as “the person you don’t want to meet at a part” (front matter). The mathematician in the movie Jurassic Park personifies the common public perception of mathematician: brainy but nerdy and socially inept. Kennedy, a mathematics educator sums up this popular perception of the absent-minded professor.

> In teen movies it is always the English teacher that had cool insights, the ability to connect with the minds of their students, and the creativity to bring out the creativity in others. These heroic virtues were usually accentuated by inviting the audience to contrast them with those of a teacher, yes, mathematics, who would often be pictured discussing the Pythagorean Theorem with the blackboard totally oblivious to the behavior of his or her students in the background. (5)

The noted European poet, Hans Magnus Enzensberger, compares the mathematician to a “secular high priest, jealously guarding his esoteric grail” living a life exclusively with his problems and withdrawn from the world. He even finds “communication with the outside world is difficult” (Enzensberg 13). Dr. Laura J. Bottomley, the director of the Women in Engineering and Outreach Programs in the College of Engineering at North Carolina State University, conducted a study where he showed students images of famous people, and he asked them to circle the people they thought were scientists. Evidently the students thought scientists were unhappy because they tended to circle people who weren’t smiling (Giovanelli 10). All of these negative views of mathematicians/scientists are myths that persist as what “anthropologists call 'cultural lag,' where a belief about a practice may continue to be strongly held long after reality has irrevocably changed" (Etzkowitz 119). This cultural lag echoes C. P. Snow's observations from fifty years ago that literature changes more slowly than science (Snow 9).

Even more unsettling than this image of a socially inept mathematician, is the common notion that mathematicians are all brain and no heart. To many, the emphasis of science and mathematics on rational thought and logical cognitive processes appears to lack spiritual and emotional dimension, devaluing "the emotional, the intuitive, the spiritual and the unique" (Kirkup 13). Scientists are often distrusted because of this perception of "lack a whole feeling of things" (Griese 73). In fact, the entire culture of science is distrusted because it is seen as a culture which "its members set aside the quality of human relationships (morality, interdependence, and agency, collective social life) in order to participate – in short; it is 'culture of no culture'" (Wyer 81). Philip Davis believes that this negative image of mathematicians as absorbed with abstractions and emotionally disengaged "expresses a truth about the relations between society and mathematical methodology; the spirit of abstraction and the spirit of compassion are often antithetical" (Davis 290). Hence the "science wars" whereby two cultures attack each other on every turn voicing equally harsh judgments of each others' values and/or lack of them.

Philosophy of Two Intellectual Cultures

> *There are two equally dangerous extreme—to shut reason out, and to let nothing else in.* Blasé Pascal

In 1959, C. P. Snow wrote the seminal book, The Two Cultures and the Scientific Revolution, about the schism in academia between the sciences and the arts and their lack of communication: the “intellectual life of whole western society increasingly split into two polar groups…literary intellectuals and scientists” (Snow 4). He argued that the “scientific disciplines and the literary disciplines in academe were sufficiently different in construction, delivery and ethos as to constitute ‘two cultures’…with little in common in intellectual, moral and psychological climate” (Bryne 77). Snow was concerned that the gap would only widen as we try to comprehend the new scientific revolution which will impact the world much more than even Snow could have imagined. This “new” scientific revolution was ushered in by the exponential growth of the use of computers, technology, and statistics. Snow believed that the two cultures have a distorted and destructive perception of each other. Their attitudes are different and they lack understanding of each other (Snow 4). Snow also believed that the two cultures don’t talk to each other. He lamented that this “breakdown of communication between sciences and humanities is a major hindrance to solving the world’s problems” (Kimball 54). This rift that Snow refers to manifests itself with a noticeable incomprehension, often hostility that has developed between scientists and literary intellectuals. The schism between scientists and literary intellectuals (and the general public, too) is steadily growing wider as science has become more complex and its discourse more technical especially in its reliance on abstruse mathematical notation.

When did this division of worldviews occur and how does it affect students? As with many of the conventions of modern society, the origin of these differing views is rooted in the history of Western civilization. Modern Western thought first gained its present form following the Renaissance, during the Enlightenment: the Age of Reason, Rene Descartes and the Cartesian Partition.

Until the Renaissance, Western metaphysics was virtually synonymous with the study of philosophy and theology. The beginnings of science originated with the philosophers of the Enlightenment: Copernicus, Kepler, Galileo, Newton, and Descartes. Copernicus, Kepler and Galileo dealt with the motion of the planets while Newton and Descartes worked in the embryonic physics domain. These philosophers/scientists believed that God used mathematics to plan and design creation. “Their search for the mathematical laws of nature was, fundamentally, a religious quest” (Postman 34). However, this scientific quest would lead to a new concept of knowledge. René Descartes, arguably the single most important thinker of the European Enlightenment, is well known as a great philosopher and for his famous quote, “*Cogito ergo sum,”* "I think, therefore I am**.”** Descartes construed matter and mind as two different forms of reality. This metaphysical split between mind and body is known as Cartesian Dualism**.**

The Greeks had long ago recognized the need for both rational and spiritual understanding, but Descartes’ philosophy of dualism was interpreted as the partition between emotions and science whereas all emotions were extracted from science and mathematics leaving a totally rational discipline. “Cartesian objectivity has as its ideal the rendering impossible of any continuity between subjects and objects. The scientific mind must be cleansed of all its sympathies toward the objects it tries to understand. It must cultivate absolute detachment” (Wyer 45). From that point onwards in European culture, the mind and the body would be separated into different realms: the humanities with the mind and the natural sciences with body. "The divisions between these two realms are extensive: the humanities and the sciences in today's universities are a key example" (Jacques 263).

While Snow was primarily talking about the academic intellectual world, his observations also have relevance to the society at large – a society which feels much more comfortable with literary rather than with scientific-mathematical pursuits (Snow 27). In fact, the two sides in this cultural war have as many names as the protagonist in a Russian novel: humanities vs. science, faith vs. reason, rational vs. irrational. However, all the names reference the conflicting views of humanistic versus rational worldviews. Eileen Byrne references Snow's philosophy in her groundbreaking book, Women and Science: The Snark Syndrome. Byrne uses the more inclusive term technology for Snow's culture of scientific-mathematical. She asserts that in the battle between the literary and scientific-technological cultures that the scientific-technological culture has been the aggressor. The science-technological culture "subjects all intellectual material to their stringent methodology and value system, and it has found the humanistic culture wanting" (Davis 280). Neil Postman echoes Byrne's position in his commentary on the technology culture, Technopoly: The Surrender of Culture to Technology. Postman defines technopoly as "the submission of all forms of cultural life to the sovereignty of technique and technology" (Postman 52). Technopoly, by definition, grants free rein to any technology Postman posits that not only has the technological culture been the aggressor but that the theories of technological culture have left weakened the traditional social institutions governing moral development leaving no "guidance about what is acceptable information in the moral domain" (Postman 79). In fact, Postman believes that, "Technopoly deprives us of the social, political, historical, metaphysical, logical, or spiritual basis for knowing what is beyond belief" which has left our culture with no true moral center. (Postman 58) Furthermore, many people feel that the "spirit of abstraction and the spirit of compassion" are often antithetical. Part of the humanistic culture "takes for granted that applied science was an occupation for second rate minds" (Snow 34).

In his book, Drawbridge Up: Mathematics—A Cultural Anathema, Hans Magnus Enzensberger, the noted European poet, parallels Snow's two culture theory when he addresses the dilemma of alienation of the mathematicians and the nonmathematicians Enzensberger compares the difference to the perception of mathematics as a subject that can only be learned well by extreme intellectuals who retreat to their walled castle and raise the drawbridge leaving non-mathematicians on the outside. In an eloquent and impassioned essay, Enzensberger laments this perception of mathematics and the disdain of some people who see learning any mathematics as useless and a waste of time at least. In his essay, Enzensberger asserts, "…one can state dispassionately that great segments of the population have never progressed beyond the mathematical level of the ancient Greeks. An equivalent backwardness in other fields – medicine, or physics- would arguably be perilous" (Enzensberger 31). He sees this negative attitude towards mathematics as excluding knowledge of the greatest achievements of the human mind and of a rich portion of world culture. Thomas Kuhn calls this attitude the "rigorous ignorance of science" (Kuhn 365).

I will focus on the mathematics subcategory of science for two reasons. First, science encompasses mathematics, and, second, my interest is in mathematics and the problems people have in learning it. Of course, context is required to determine the impact of any potential learning disability. In 2002, The Public Broadcasting Company investigated the increasing problems people have with mathematics, and the ramifications for our rapidly expanding technological society. In a non-technological society, a child's math problem will not limit his success, just as in an illiterate society, a child's inability to read or write will not restrict her development (PBS). Until recently, you could easily avoid mathematics in the professional world; you simply chose a career with limited work with numbers**.** However, our increasingly technological culture makes the lack of mathematical skills a serious disadvantage.

Public Perception of Mathematics

Educated people typically have held an exalted view of science. Together with mathematics, it has stood as the model of what a body of knowledge ought to be. In epistemological discussions in philosophy it has been taken as an important case of "justified true belief" (Phillips 38).

In America, the woeful state of mathematics illiteracy is evident in elementary, secondary, and post-secondary schools. Most writers believe that American high school students lag behind all other industrialized countries in mathematical achievement (Skolnick 2). Tobias claims, "Most students… leave school without the mathematics skills they need to thrive in an increasingly complex, global economy" (49). In The Manufactured Crisis: Myths, Fraud and the Attack on America's Public Schools, Bruce

Biddle and David Berlinger (1998) represent the minority of writers that take issue to these negative assessments of American literacy status. According to Biddle and Berlinger, there have been modest increases in standardized math scores in the past decade "despite the fact that more students are taking the test than ever before whose first language is not English. Biddle and Berlinger conclude that there is no support for the myth that American students fail . . . in any subject" (Marker 324).

American culture has ambivalence about science and mathematics. On the one hand, people who are "mathematical/scientific" are seen as very intelligent and much to be admired. However, on the other hand, they are perceived as "otherworldly" and "not normal." The popular media reflects these ambivalent views in the portrayal of mathematicians and scientist in film. The media shows a positive portrayal of a mathematician in the film Stand and Deliver, an inspirational movie based on fact, about a teacher helping his minority students overcome barrio conditions to succeed in Advanced Placement calculus in high school and later in life. However, the media usually depicts scientists as extremely bright but also a bit absent-minded or eccentric or nerdy. The films, The Nutty Professor and The Absent-Minded Professor and the more recent film Honey, I Shrank the Kids are all examples of media use of these unflattering stereotypes. Even recent media offerings, such as the television series Numbers and Crime Scene Investigations display a more nuanced version of those ambivalent views.

While these caricatures are exaggerated, they do contain elements of the general stereotypes found in American culture. What are these stereotypes? From where did they come? And how do they affect students?

Mathematics has long been the subject that people love to hate. Just the mention of the subject mathematics and it “strikes fear and dread in the heart of millions” (Sutton 56). Some people sarcastically describe mathematics as “answers to questions that nobody asked” (Hersh 18). People generally separate themselves into two groups: the “math people” who find mathematics fairly easy to learn, and the “not math people,” a much larger group, “who find mathematics almost completely incomprehensible” (Devlin 4).

Many people believe that they do not need any mathematical knowledge at all, and that all scientific matters are of little consequence. Therefore, they do not see a need to learn mathematics nor do they have the desire to learn mathematics. However, the connections between pure and applied mathematics is often difficult to see. The usefulness of mathematics is far from obvious (Enzensberger 21). In mathematics there is an enormous cultural time lag between public consciousness and research, often by centuries (Enzensberger 31).

Mathematics has long been considered a man’s field. From philosopher Immanuel Kant’s assertion that “women might as well grow beards as ‘worry their pretty heads about geometry’ to Barbie’s proclamation that ‘I don’t like math,’…the message that math is unfeminine has been loud and clear” (http://www.fix.org). In fact, Alison Kelly views science as “masculine in four senses: “1) the attitudes of teachers and pupils, 2) the image presented by books and other resources, 3) practitioners of science are overwhelmingly male, and, 4) scientific thinking embodies as intrinsically masculine world view" (Kirkup et al. 184). In each sense, the masculine nature of mathematics and science are accentuated.

Paul Ernest, a mathematician in Great Britain, admits that "the popular image of mathematics is that it is difficult, cold, abstract, ultra-rational, important, and largely masculine" (Shulman 413). The public generally considers mathematics to be difficult to learn, emotionally cold, incomprehensibly abstract, unnecessarily rational, unexplainably important, and practiced by largely masculine professional. Science and mathematics are subjects "that are presented as not in a social context and that are not people oriented or people friendly" (Bryne 18). "That universality, that independence of individual, makes mathematics seem immaterial; inhuman" (Hersh 11). "For the Mainstream, mathematics is superhuman – abstract, ideal, infallible, eternal" (Hersh 92). As I mentioned earlier, the mathematician is portrayed in literature and media as nerdy, scatter-brained and absent-minded and almost always male. Not withstanding the occasion female math genius (often a stunningly beautiful, romantic foil for a James Bond type character or the strictly dressed, no nonsense, Baum Hilda type), mathematicians are overwhelmingly depicted as males. From the television series, Numbers to the movie, A Beautiful Mind, the public sees a masculine persona of mathematics. However, these examples reflect the makeup of professional mathematicians in America.

During research on the public opinion of mathematics, The Association of American University Women found that mathematics is still perceived as male domain (AAUW 3). In fact, men usually teach science and mathematics courses. While many secondary and university mathematics teachers are women, high prestige mathematics positions in elite universities and in research are predominantly men. While women have made great inroads into the science community, they are invariably concentrated in the less prestigious and less compensated areas. By no means is this a new trend in mathematics. Even women in the mathematics world would be hard pressed to name a woman who made a contribution to mathematics - any contribution. You would have to really search through centuries of mathematics history to even produce a handful of women mathematicians of note. With the opportunities available to modern women, some may actually be self-selecting to remove themselves from a lifestyle they find to be counter to their priorities of relationships and caring. Part of this female alienation from mathematics is the perception of mathematics as embodying rational thought rather than emotions.

The perceived separation of rational thought and emotions is one of the primary reasons that mathematics is often classified as a masculine pursuit. Belensky even proclaims science to be the "quintessentially masculine intellectual activity" (Belensky 215). Sheila Tobias also found that our "entire society associates mathematics, science, things and data with male pursuits…" (Tobias 36). In concordance with Tobias' findings, Eileen Bryne, who wrote The Snark Attack, finds that subjects rated as scientific (i.e., physics, engineering, computer science, mathematics) are also seen as "masculine, hard, complex, based on thinking rather than feeling" (Bryne 170). Bryne posits that to learn to be a scientist in our culture is to learn the very attributes that our culture calls masculine (Bryne 17). Our culture attributes mental processes that are considered abstract and impersonal to "thinking" and primarily a masculine characteristic, while those processes that are considered personal and interpersonal to "emotions" and primarily a feminine characteristic (Belensky 14).

In schools, students who display a grasp of both processes and expectations of the study of mathematics are considered to be naturally talented. These students are encouraged and the others are not (Marker 67). Students, faculty, and academic administrators all share the opinion that "mathematics is a subject which is impossible for most students to learn, and only the rare genius can learn the subject with any high degree of success" (Datta 80).

All of these negative images of mathematicians and scientists lead to a strong belief that scientists are born, not made. They believe some people have "the math gene, producing an innate ability for mathematical thought" (Devlin xvi). Potential students of mathematics and science often believe they must share personality characteristics with eccentric and unemotional professionals and adopt a non-conformist lifestyle in order to fit in (Etzkowitz 47). Intelligent, curious and ambitious young people conclude that science and mathematics has no place for them unless they are "unusually self-motivated, extraordinarily self-confident, virtually teacher – and – curriculum proof, indifferent to material outcomes, single minded and single track, in short unless they are younger versions of the science community itself" (Tobias 11). People believe that there is only one mathematics. In fact, they believe that mathematics is the only mathematics in the universe. People also believe that mathematics produces absolute truths and that everyone has the same mathematical truth (Hersh 38). Evelyn Fox Keller, American physicist and feminist, believes that acceptance of these disabling beliefs about mathematics are directly related to the negative image of mathematics (Keller 14).

Why Study Mathematics?

Obviously, I cannot think of even one reason NOT to study mathematics. However, I realize that some people would like to hear some justification for studying a subject that many of them find, shall we say, less than necessary. I will limit my discussion to two reasons to study mathematics; to be an educated person and to take advantage of the quantitative literacy used in mathematics.

The Educated Person

> *Only the educated are free*. – Epictetus

> *It has always seemed strange to me that in our endless discussions about education so little stress is laid on the pleasure of becoming an educated person, the enormous interest it adds to life. To be able to be caught up into the world of thought -- that is to be educated.* Edith Hamilton

What does it mean to be an educated person? Is an educated person one who knows the most facts? Or is an educated person one who attended school the longest? Over centuries philosophers and educators alike have debated the definition of an educated person but with little consensus. In early Greece, Plato posited one of the first definitions of an educated person in The Republic. He limited the appellation to only an elite few who would be entrusted with making decisions for the city. Aristotle believed a generally educated person studies practically all subjects in order to become a good judge. The Russian novelist Anton Chekhov once wrote… "an educated person has a positive influence for good on everybody he or she interacts with, on friends and relatives, and even on strangers" (Richards 98). According to Peter Hilton, topology mathematics professor at the State University at New York, "The educated person is characterized by desire to learn and to understand, by an awareness of what he or she does not know and an appreciation of what is worth knowing . . . and why" (Datta 14), and James Baldwin's version states "a person (with) the ability to look at the world for himself, to make his own decisions" (326).

Many institutions of higher education have a definition of an educated person. In fact, Bucks County Community College in Pennsylvania devotes an entire page of its college catalog titled "A Definition of an Educated Person." In part the definition cites "the ability to analyze and make reasoned judgments . . . a greater understanding of the interdependency of all things" (35). Likewise, Kennebec Valley Community College in Maine, believes that an educated person is "a lifelong learner . . . listens to others' ideas respectfully and thoughtfully and accepts them or rejects them on the basis of clear and logical thinking . . . and possesses the analytical skills needed to solve problems and make decisions" (15). Alfie Kohn, a contemporary critic of the ubiquitous standardized testing in the nation's public schools, questions whether the definition of an educated person can be invariant across cultures and historical eras (Kohn 65).

For Paulo Freire, the originator of critical pedagogy theory, teaching is not the transferring accumulated practical knowledge from generation to generation, nor is learning the absorbing the transferred object or content. On the contrary, "teaching and learning revolve around understanding the world, the objects, creation, beauty, scientific precision, and common sense" (Freire Teacher as Cultural Workers xxiv). Thoughtful participation in the democratic process has also become increasingly complicated as the locus of attention has shifted from local to national and global concerns (Bransford 72).

A primary attribute of each definition is the person should have the ability to use good judgment to make his own decisions. Henry Giroux shared Freire's definition that an educated person was one who had the knowledge not only to function in a larger society, but also to act as a critical agent for transformative action. By transformative action, Giroux was referring to an education enabling a person to "take risks, to struggle for institutional change, and to fight both against oppression and for democracy outside of schools" (Giroux 10). Giroux further broadened the meaning of an educated man to include "the ability to read critically, both within and outside one's experiences, and with conceptual power" (84).

That said what definition of an educated person would be appropriate for the twenty first century? Certainly one would expect reading and writing literacy as absolute minimum skills. Without those two skills, a person could not make informed decisions about the world around him. John Dewey considered the mind without the capability to make informed decisions "at the mercy of custom and external suggestions" (36). A person would rely on others to examine and interpret the social, political, and economic forces behind the increasingly scientific /technologic society.   In his book, Cultural Literacy, Hirsh defines literacy as the ability to communicate "among the educated in our culture" (Postman 175).

Sheila Tobias, a leader in mathematics education research, emphasizes another skill needed for an educated person – quantitative literacy (Tobias xiii). The Quantitative Literacy Program at Mount St. Mary's College in Los Angeles, California defines quantitative literacy as "knowledge of and confidence with basic mathematical/analytical concepts and operations required for problem-solving, decision-making, economic productivity and real-world applications" (54).

Quantitative literacy is an umbrella term applied to different skills related to mathematics, science, and technology such an analytical reasoning ability. In fact, the term science encompasses mathematics without explicit acknowledgement thereof. Research for scientific literacy, mathematics literacy, and quantitative literacy often overlap and are commingled; so, hereafter, I will use the research from all three categories to support arguments for quantitative literacy, using the terms interchangeably. Later, I will parse the term quantitative literacy and focus specifically on mathematical literacy.

Quantitative Literacy

The Industrial Revolution forever changed the landscape of the world. Not only did the form of work change, its marketability changed. The invention of machines freed the mind from the hand. Gradually, the new science came to replace the classics and theology as the basis for definition of what it means to be an "educated person." As recently as the late nineteenth century, liberal arts were perceived as the true mark of an educated person while science, math, and technology were considered mere job traits. But, Sheila Tobias contends, mathematics has become the Latin of our time. Once Latin was the language of learning, now mathematical knowledge is the mark of the scientific age (Tobias 48). Is mathematics so different from other subjects? The British educator Grazyana Baran touched on this difference in an interview for Dr. Marilyn Frankenstein's editor. She said:

> Maths is special because it acts as a discriminator in a much wider way. Everybody is expected to do it and there are so many jobs that require maths as an entry qualification, sometimes to a higher level than is justified by the work. (Frankenstein 13)

While Baran, Tobias, and others perceive mathematics as a problem area in education, others see little need for studying mathematics at all. The ubiquitous student refrain heard in mathematics classrooms voices this sentiment: When am I ever going to use math? However, Dr. Marilyn Frankenstein, a leader in applying critical pedagogy to mathematics education, considers the study of mathematics to be a liberating practice. She also believes that mathematical analysis is a powerful tool which is denied to a majority of students through elitism, mystification and the teaching of irrelevance. She argues that "knowledge of basic numerical and statistical concepts is important . . . as part of the struggle to make the individual and collective lives of students meaningful" (Frankenstein xii). All people need the ability to analyze the numbers presented to them by others about important issues, have the knowledge to make decisions about this numerical data, and acquire the skills to research and use those statistics (Frankenstein 260). Frankenstein feels, "just as reading and writing are more than mere manipulation of letters, syllables and words, so mathematics is more than the ability to calculate" (269). She believes that all citizens will need a "critical mathematical literacy, the ability to ask basic statistical questions in order to deepen one's appreciation of particular issues" (Frankenstein 254) and to empower them by providing the information of to make informed decisions in their lives.

James Clark proposes that graduates of all disciplines need to be efficient, cross-cultural collaborative researchers (2005). Potsdam University requires all their graduates to take mathematics as part of a liberal education experience. Likewise, many educators advocate that mathematics should be considered humanity (Datta 42).

Mathematical literacy becomes the ability to "understand what numbers mean" (Frankenstein xii) in the context of student's everyday life and the larger society. Whereas many people may not use algebra or geometry, let alone trigonometry and calculus, they will be inundated with statistical data: unemployment figures, federal spending budgets, environmental concerns and financial information are all part of data requiring informed decision making. But, while statistics can be mystifying, Frankenstein contends that understanding them can be "empowering and critical tools" (261) in our society. With the ready availability and functional power of hand held calculators, a course in statistics is replacing much of the traditional emphasis on college algebra and trigonometry at the post-secondary level. This trend of teaching more statistics is also manifesting itself as an enlarged topic in secondary classes and even elementary school classes. Thus, being math illiterate in today's society becomes ever more disadvantaging for students

John Brockman in his book, The Third Culture, posits that science is becoming the predominant culture and scientists are taking the place of traditional intellectuals in answering the important questions facing mankind (Brockman). If Brockman's conjecture is true, how does a lack of mathematical competence affect the majority of society who do not have access to this way of knowing?

Our society can no longer tolerate "mathematical illiteracy." Those who control the knowledge control the power. Not to know or to be willfully ignorant of mathematics is to bequest control and power to a small, perhaps, elite group. In the early part of the twentieth century, education focused on the acquisition of literacy skills: simple reading, writing, and calculating. It was not the general rule for educational systems to train people to think and read critically, to express themselves clearly and persuasively, or to solve complex problems in science and mathematics. Now these aspects of high literacy are required of almost everyone in order to successfully negotiate the complexities of contemporary life (Bransford 33). Statistical reasoning is part of the quantitative literacy where ignorance excludes a person from information essential to social issues. Ever since Florence Nightingale first used statistical graphs to persuade the British Parliament to reform field hospitals during the Crimean War, statistics have revolutionized the discussion of health and social issues. Statistics has become ideological tool; not statistics, but how it is used, or misused. To knowledgably argue statistical issues, you must know the fundamentals of quantitative reasoning. The 2002 Public Broadcasting System's documentary, <u>Misunderstood Minds</u>, also alluded to the need for quantitative reasoning in modern society with the statement, "deficiency in basic math skills is more limiting today" (PBS). W. W. Savage says: "The ability to think mathematically will have to become something taken for granted as much as the ability to read a newspaper…" (Tobias 35). We live in a very mathematically complex society. The average person needs much math education to "gain the math knowledge and skills to learn to deal effectively with this complexity" (Moursund 21).

For thousands of years, a person could function adequately in society, making a living and supporting a family, even when he was not considered to be literate. In the nineteenth century, many people who could not read or write were able to function quite satisfactorily, even prosper. The census records of that era even provided information concerning the ability to read and to write. Society moved at a much different and slower pace then, and communication was limited at best. The telephone was considered a "modern marvel," and age of electricity with its equally incredible devices was in its infancy.

At the beginning of the twentieth century, information and knowledge increased exponentially. A person could no longer become an expert in all areas of a discipline, so he had to specialize in one subset of the discipline. For example, medicine was subdivided and these subdivisions proliferated to produce dozens of medical specialties that require a dictionary to decipher their names. In the wake of this knowledge explosion, a person must process countless bits of information in order to make good decisions. Ordinary people lost their ability to assess this barrage of information, and they turned to experts to make decisions for them (Postman 88). Thus, people become further and further removed from the primary source of information used to make these decisions.

Let's consider the ordinary experience of reading the daily newspaper. All of the following headlines are just one day's sample of the leading science stories in the news.

Science: European Space Agency Astronaut Spacewalks

Animal Science: Dinosaur Fossils Found in Australia

Cancer: Pigeons Reveal Heart Problem Solution

Preventative Medicine: Camera May Hold Key to Blindness

Research: Proteins Could Help Boost Immune Response

Medicine: New Genetic Marker Found for Parkinson's Disease

Psychology: Researcher Show How the Brain Turns on Innate Behavior.

Although one needs reading to understand the words, one also needs scientific literacy to understand the impact of each area on our daily lives and on society at large. Jon Miller defines science literacy as "the level of understanding of science and technology needed to function minimally as citizens and consumers in our society" (Hersh 140). Miller further delineates science literacy into three sections: understanding basic science and technology terms; understanding the processes of science; and understanding the importance of science and technology on society (Hersh 140). All three of these areas of understanding are necessary to fully analyze the science headlines mentioned earlier.

Many researchers of science, mathematics, and education regard scientific and quantitative literacy to be a primary concern of all citizens. Sandra Harding, a leading feminist critic of science, believes "to be scientifically illiterate is simply to be illiterate" (58). The boundaries between hard science and soft science and even science and humanities are being extended each day (Tobias xiii). For example, an introductory level Psychology course at the university level deals extensively with the biology of the human brain. Because of this intermingling of hard science and soft science, science is no longer left to the scientists alone. British science writer Paul Smaglik believes that a broader education of how science is shaped, that is, of the culture of science, is necessary to facilitate dialogue among and between scientists and the general populace (Wyer 1). Increasingly our complex society will need citizens skilled at problem solving and analytical reasoning aptitude. This scientific understanding, or scientific literacy, will be needed not just in "the public arena but in one's community, in the family and in personal life" (Giese 15).

Despite this need for scientific literacy, in a study for the National Science Foundation, Jon Miller (1991) found that less than ten percent of American adults qualify as scientifically literate, possessing a basic understanding of science and technology *not withstanding* their impact on society. Moreover, Miller found that the gap between men and women actually widened with increased schooling. Nearly twenty-five percent of college-educated men qualify as scientifically literate, while only seventeen percent of college-educated women do (Miller 1991, 19).

Why Is Math Hard?

For several hundred of years, mathematics has been a problem subject in schools. Many people have trouble with mathematics in school; no other subject has its own self-declared anxiety. Whereas some people consider mathematics to be a recent area of difficulty for students, the traditional methods of teaching mathematics have never achieved mass numeracy. In Ancient Greece, Athenians were discussing "the nature of mathematics and the peculiar difficulties of learning it" (A 21). Approximately the same time [or during the same era] the King of Egypt implored Euclid, the author of The Elements, the oldest known published mathematics book, to find a short cut to teach him geometry. Euclid is alleged to have told him, "There is no royal road to geometry." So, even persons with much power and wealth were not spared the difficulties of learning mathematics.

In 1517, during the Middle Ages, a professor lamented about arithmetic, "I believe that students allow themselves to be frightened away from the art because of their preconceived notion that it is too difficult' (Frankenstein 77), Consider this century old lamentation from Her Majesty's Inspectorate Report of 1876:

> In arithmetic, I regret to say worse results than ever before have been obtained . . . Failures are almost invariably traceable to radically imperfect teaching. (Frankenstein xiv)

However, a small minority of students, "about twenty percent learns mathematics easily while the rest never really get it" (Strong 165). So, why is mathematics so hard for some people and easy for others (Devlin 127)? A related question is, "What makes mathematics 'difficult' meaning hard to teach and hard to learn" (Devlin 76)?

After decades of cognitive research, almost all educators and psychologists have their favorite theory concerning the difficulty people have learning mathematics. The most commonly advanced theories are: misconceptions about the learning of mathematics, neurological factors in learning mathematics, the language and symbolism of mathematics, the abstraction of mathematics, confidence in learning mathematics, socialization and the way in which mathematics is taught.

Misconceptions about the Learning of Mathematics

Students have many misconceptions about learning mathematics. They believe that mathematics is learned like all other subjects and mathematics should not be confusing if it is taught well. They also do not understand that learning mathematics is demanding and everything in mathematics is connected.

Students believe that mathematics is learned like other subjects so they use the same study strategies that are successful in other subjects. They listen in class, take notes, memorize definitions and do the homework. However, this approach does not work in mathematics. These techniques work well for subjects you are learning about. You learn about history and you learn about English. However, in mathematics you learn by doing. Besides the basis skills of reading and writing, mathematics is the only classical intellectual subject that is learned like we learn to ride a bike or learn to walk. At the secondary level, even chemistry, biology and physics are still learned about. “We learn about everything else; we learn to do mathematics” (Kennedy 45).

Students believe mathematics should not be confusing if it is taught well. They do not realize that confusion should be expected when you are learning a new concept in mathematics. When students move from subject to subject in mathematics (i.e., from arithmetic to algebra or trigonometry to calculus), they often learn entirely new concepts. “…it is unlikely that students will understand new subjects completely when they are first presented” (Moursund 4). Even gifted students will reach a point of complete confusion.

Students do not understand that confusion is normal at first: complete confusion becomes hazy understanding and hazy understanding becomes solid mastery. However, this progression from confusion to solid mastery takes the right kind of effort. Students do not understand how slowly this progression may be. These students believe that when mathematics gets confusing that they've been found out. "Time to leave math and head for the humanities. They are not mathematically inclined" (Devlin 77).

American students believe, incorrectly, that understanding mathematics means never struggling or having no clue how to proceed with a problem. "Yet, the only difference between their confusion and a mathematician's is that the mathematician expects it" (Devlin 36). Whereas American students equate understanding with sudden insight, in Chinese schools "understanding is conceived of as a more gradual process, where the more one struggles the more one comes to understand" (Schoenfeld 5). American students believe they can't do well in mathematics because they lack natural ability. Most students just don't know what to do when mathematics gets hard, and eventually it will get hard requiring more focused effort.

Students do not understand that learning mathematics is demanding. They do not anticipate how much concentration mathematics requires. Many subjects require a high level of concentration to do them well; however, mathematics requires a high level of concentration to do it at all. In fact, mathematics "demands above all intense and sustained concentration" (Enzensberger 15). This intense level of concentration is required to construct the symbolic system necessary in learning mathematics. Dan Kennedy, mathematics textbook author and secondary teacher, believes that many students do not become proficient in mathematics because they do not recognize the concentration, determination and effort required to do mathematics and "they assume they just don't have the math gene" (Devlin 131).

And, lastly, students do not understand that everything in mathematics is connected; they believe mathematics is a series of separate, unrelated topics. Mathematics includes many different skills and concepts learned in different ways making natural development hard to determine. Some skills and concepts are sequential and cumulative; the parts build on the whole. The students must master basic concepts before moving to the next level (Chinn and Ashcroft 1998: 4). Paradoxically, "certain skills . . . seem to exist more or less independently of certain other" (PBS). So, a student can master some concepts and still struggle with others. For example, a high school student who regularly makes mistakes in basic arithmetic may do extremely well with the advanced conceptual thinking in calculus (PBS).

If a student does not comprehend the relation between different concepts, his math skills may not be learned in any meaningful or relevant manner. The student's failure to see the connection between concepts make the concepts harder to recall and harder to apply in new situations (PBS). Also, because mathematics is all connected, concepts return in later units "in another form with another layer added, with an additional level of abstraction" (Devlin 87). Thus, the many interrelated concepts makes mathematics singularly challenging to learn.

Neurological Factors in Learning Mathematics

There are several neurological factors in learning mathematics. I will discuss two of these factors: the left brain/right brain dichotomy of learning styles and the brain's use of linguistic ability for pattern interference and memorization.

Researchers agree that children use several neurodevelopmental functions when they think of numbers: memory; language, attention, temporal-sequential ordering, higher-order cognition, and spatial ordering (PBS). These functions are linked with different halves of the brain. Nobel Prized wining psychobiologist Roger Sperry did ground breaking study in split-brain theory and subsequent left brain/right brain studies. In general, the left half of the brain is considered more verbal, logical, sequential and analytic while the right half is considered more visual, intuitive, imaginative and synthetic. Anita Kitchens of Appalachian State University studies the Linking of Cognitive Psychology to the Teaching of Math. She and two colleagues studied this left brain/right brain theory as it applies to learning mathematics. They found that early mathematics courses such as algebra emphasize left-brain skills; so left-brain dominant students are usually successful in those classes. However, left-brain dominant students often have difficulty with the visualizations that become necessary in higher mathematics. Diametrically, right brain dominant students may avoid higher mathematics because they had difficulties with sequential processes of earlier mathematics classes. They never reach the courses which use their strength in spatial ability, imagination and synthesis (Kitchens 4). Consequently, some students leave math too early because of lack of early success, and some students leave math when encountering difficulties after early success. Both types of students believe math is hard. Many educators advocate teaching to different learning styles. However, most subjects, and especially mathematical sciences, advantage left brain thinkers. Roger Sperry himself gave a telling assessment of the American education system:

> The main theme to emerge . . . is that there appear to be two modes of thinking, verbal and nonverbal, represented rather separately in left and right hemispheres respectively and that our education system, as well as science in general, tends to neglect the nonverbal form of intellect. What it comes down to is that modern society discriminates against the right hemisphere. (209)

In addition to the split-brain neurological factor, the brain's use of linguistic ability for pattern interference and memorization also makes mathematics hard. In The Math Gene: How Mathematical Thinking Evolved, Kevin Devlin posits the theory that the human brain developed the ability to use language concurrently with the ability to do mathematics (Devlin 70). Devlin contends that the human brain is such an excellent pattern recognizer that it can perform nearly any symbolic procedure mindlessly. So, you can memorize the procedure for manipulating numbers to add fractions correctly without knowing why the procedure works (Devlin 67). Pattern recognition is also the reason we have difficulty with multiplication tables. We learn the tables linguistically, and the different entries interfere with each other because our memory is so good at seeing similarities, i.e., patterns. So, the brain recognizes a new pattern but uses a previously learned pattern instead of the new pattern to compute an answer resulting in an error. This error is called pattern interference or, in psychological research, as proactive habit interference or proactive inhibition. Devlin gives an excellent example of pattern interference in The Math Gene. "A person takes longer to realize that 2 x 3 =5 is false than to realize that 2 x 3 = 7 is wrong. The former equation is correct for addition (2 + 3 = 5) and so the pattern '2 and 3 makes 5' is familiar to us. There is no familiar pattern of the form '2 and 3 makes 7'" (Devlin 61). Even excellent mathematics students will make this common error.

The interrelating nature of mathematics discussed earlier sometimes mean that "children who have learning difficulties in mathematics may sometimes appear to feel even more lost and disempowered than those who encounter problems in other subjects" (Frederickson and Cline 2002: 342). Therefore, it is very important to "identify any neurodevelopment difficulties early before the students looses confidence or developments a fear of mathematics" (PBS).

The Language and Symbolism of Mathematics

The language demands of mathematics are extensive, and many students have trouble communicating in the mathematics classroom. They have trouble with mathematical word problems, with the language of mathematics and, especially, with the symbolism of mathematics. Before the students actually get to the mathematical language per se, they have problems reading and interpreting mathematical word problems. In fact, a study I remember from an undergraduate methods course, actually showed English teachers are more successful in teaching students to solve word problems than mathematics teachers. It's the English construction of the sentences that the students don't understand, not the mathematics itself. Once the students interpreted the word problem correctly and wrote the corresponding equation, they were able to solve it.

Another closely related problem students have with learning mathematics is the use of the exact same English word by the mathematics teachers and their students but with different interpretations. While this situation occurs in most classes, mathematics classes are especially susceptible to this ambiguity. For example, when the teacher uses the word *understand,* he invariably means "to know what to do and why." However, students use the word to mean they "know the rule to get the correct answer" (whether or not they know why the rule works.) Skemp gives the excellent example of the concept of dividing fractions. Virtually all students know the rule, "turn it upside down and multiply," so they believe they *understand* how to divide fractions (Skemp 89). However, the teacher would say that the student does not *understand* because he can not explain *why* the rule works. This difference in interpretation of the meaning of *understand* explains how an entire class can determine the volume of a rectangular solid (also known as a box) when given its dimensions, but only a small portion of the class can replicate the solution if they are given an actual box to measure and compute the volume. Teachers refer to this phenomenon as "rules without reasons" (Skemp 89).

Another confusing component of mathematics is the use of ordinary English words to represent mathematical concepts. Some of the mathematics words look like ordinary English words; however, many of these mathematical terms are *faux amis*, a French term used to "describe words which are the same, or very alike, in two languages, but whose meanings are very different" (Skemp 89). For example, the French word *historie* means story while the amazingly similar English word *history* has a different meaning. *Faux amis* can occur between English as spoken in two different countries. For example, if an American asked for a *biscuit* in England, he would get what an American would call a *cookie*. Usually the reader can discern the meanings of the words are different because the languages themselves are different, or the country of origin is different, or the context is different. However, in mathematics, the language, country and context are all the same resulting in great confusion for the reader. For example, a *group* in ordinary English means “an assemblage of two or more persons,” while in mathematics, a *group* is a “special set with particular properties” (Webster 492). So, the student believes he already knows the meaning of the word only to find out that it has a new, mathematical meaning.

Not only do students have problems with interpreting the English components of mathematics problems, they find the mathematics terms to be intimidating because mathematicians employ a specialized professional jargon. For most students, reading mathematics is analogous to reading technical plans; the students see a barrage of instructions written in “scientific” terms. Many people cannot immediately understand the meanings of this mathematical jargon, so they believe they will never understand the meanings of the words (Kitchens 12). So, it’s not that the students “don’t understand the mathematics, they never get to it” (Devlin 128).

Not only do students have problems with the written component of mathematics, they have problems with the highly codified notational symbolism of mathematics. Mathematicians use a notation that is “quite different from ordinary writing …and indispensable to their intercommunication” (Enzensberger 17). Most students, “faced with the numbers, symbols, equations, and rules for manipulating them…don’t get beyond the symbols on the paper." If we use the technical drawing analogy from a previous paragraph, just like students would be unable to detect what the drawing represents, they are also unable to detect what the symbols represent" (Devlin 129). Mathematics is much easier to understand "when the symbols mean something to you. Not seeing the meaning is the main reason so many people say that they are 'no good at math'" (Devlin 69).

The Abstraction of Mathematics

Abstraction is also a problem for many students in learning mathematics. Abstraction is the process of generalizing underlying rules and concepts of real world objects to wider applications, i.e. progression from the concrete to the abstract. A simple example of abstraction is the progressive representation of five sheep as five stones, and then representing the five stones as five hash marks on a tablet, and, eventually, representing the five hash marks as five numerals. Thus, the five sheep (concrete objects) are now represented as the numeral 5 (abstract object). Other examples of abstract mathematics concepts that evolved from concrete objects are arithmetic which began with counting objects, algebra which began with methods of solving problems in arithmetic, and geometry which began with the calculation of distances. Abstraction has a great advantage over concrete objects because it reveals deep connections between different areas of mathematics. The ability to reason about abstract objects is the core of mathematics. However, this "constant shifting of view and the accompanying steady increase in abstraction" is one of the features of advanced mathematics that most people find hardest to deal with (Devlin 99).

A student can learn mathematics easily if he has the good abstract reasoning skills. Conversely, a student with poor abstract reasoning skills will have difficulty in truly understanding mathematics concepts (Betts 165). Young children have a great ability and instinct to reason abstractly because that is how they learn to use language. Ironically, by the time they are faced with learning algebra, they have lost their spontaneous ability to master abstraction. Sadly, most children develop the expectation that they also cannot master algebra (Devlin 110).

For most students, abstract concepts are more difficult to learn, and abstraction requires mathematical maturity and experience before full assimilation of ideas can occur. Abstract concepts are difficult for most students to learn exactly because they are separated from the original concrete objects from which they are derived. This difficulty is first demonstrated when a child who can easily divide a pile of twenty coins into four equal piles of five each has trouble with the equivalent abstract numerical equation $20 \div 4 = ?$ In algebra, a student may know the answer to a verbal problem but have trouble solving its abstract representation. For example, a student may have no problem deciding the answer to the verbal problem, "If Johnny weighs 120 pounds now, how many pounds must he gain to weigh 150 pounds?" However, if the question is written in the equivalent abstract algebraic equation, "Solve for x if $120 + x = 150$," the student may have difficulty. He does not see that the two problems are exactly the same problem.

Many students do not realize that mathematical maturity and experience are necessary for abstract reasoning. Most of the coursework in school mathematics focuses on math content knowledge; learning and using arithmetic and algebra procedures to solve math problems. However, mathematical maturity encompasses a large range of mathematical skills from problems solving to learning how to learn math. It refers to the mixture of mathematical experience and insight that cannot be taught, but comes from repeated exposure to complex mathematical concepts. Dr. Dave Moursund, a mathematics education professor, uses a concise and clear definition of math maturity as “what’s left after one forgets the details of the math content that one has studied” (9). Many students learn the math content easily but they encounter trouble when they have to use insight to synthesize those procedures to solve complex, multiple step math problems. Even students who have done well in math classes may become frustrated when they move to this more advanced level of thinking. The students believe that they have “hit the wall” and that they have come as far in mathematics as they can. They have all the tools of mathematics but they are unable to use those tools to construct solutions to problems. This shift is from knowing pure math content to utilizing that content to solve problems marks the transition from more concrete reasoning to more abstract reasoning. A successful transition from concrete to abstract signifies a student’s acquisition of the mathematical maturity needed for higher level mathematics concepts.

Confidence in Learning Mathematics

Confidence is based on how well, or not so well, we have done in previous situations. Confidence in mathematics classes relates to our previous performance and experiences in earlier mathematics classes. Unfortunately, many students have had a bad experience in mathematics causing their confidence in learning mathematics to decline as they progress through school. In fact, Peter Hinton, a prominent United States mathematician, argues that some students have such negative experiences that they are "very likely to . . . avoid mathematics" (Frankenstein17). They compare themselves to their classmates, and they believe they are lacking in the skills necessary to proceed in learning mathematics (Hewitt 67).

Frequently, this loss of confidence is mathematics leads to math anxiety. Sheila Tobias coined the term "math anxiety" over thirty years ago to describe the "emotional reaction to mathematics based on a past unpleasant experience which harms future learning" (Tobias 60). Research has shown that as many as one third of all college students struggle with math anxiety and its subsequent affect on their math grades. Students who are good in humanities may experience math anxiety if their success in humanities does not translate to success in mathematics (Lerder 53).

Sally Wilding and Elizabeth Shear use a "vicious cycle" model to relate elements "contributing to the creation and perpetration of mathematics anxiety" (Wyer 45).

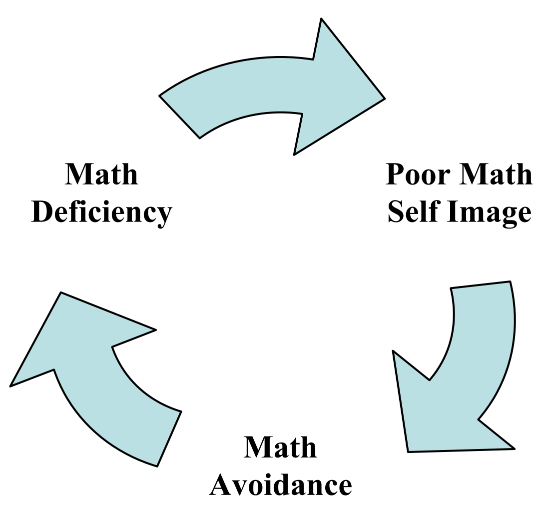

Figure 1. ***Wilding and Shear's Vicious Cycle Model***

Their model shows how a poor self imagine leads to avoidance and avoidance leads to deficiency leads to poor self image (α 45). This "vicious cycle" makes learning mathematics harder and harder for the student.

The Way in Which Mathematics is Taught

> *An interesting fact about mathematics is that it's taught and learned. (Even more interesting – sometimes taught but not learned.)* Reuben Hersh, What is Mathematics, Really?

In Drawbridge Up, Enzensberger hypothesized that the way mathematics is taught is one of the main factors in making mathematics hard to learn. He believes that the average adult has suffered permanent damage in learning mathematical ideas because of having "been run through the conventional academic mill" (Enzensberger 39). He is not alone in his assessment. In The Snark Syndrome, Byrne reports that approximately one fourth of the "variance in science achievement can be attributed to the quality and type of instruction" (Byrne 171). Byrne also believes that teachers and classroom environments contribute to problems of "negative peer attitudes, of the poor image of some disciplines, and of presence or lack of esteem and confidence in students" (Byrne 186). What features of the mathematics "academic mill" are responsible for making math hard? The main features of mathematics that makes math hard and hinders students' learning are instruction methods, teacher preparation and curriculum design.

Many instruction methods hinder students' learning. Marilyn Frankenstein, an advocate of critical mathematics education, says that rote calculation, authoritarianism in mathematics education, and memory dependence are some of the features of the math curriculum that leads students to misconceptions about learning mathematics and to math avoidance. Furthermore, students are angry that the way math is taught makes it seem boring and useless (Frankstein 17). In the articles "Telling Math: Origin of Math Aversion and Anxiety," Susan Stodolsky researched causes of math aversion and math anxiety. She found that instructional methods elementary students experienced strongly affected their later attitudes, expectations and conceptions of math learning (Stodolsky 59). Stodolsky contends that math instruction in American provides students with only one predominant model for learning: "teacher explanation followed by student practice" (Stodolsky 67). Even after years of reform, most mathematics classes are taught in this lecture style with its "one size fits all" mentality. In contrast, nearly all other subjects use more student-centered models for learning: collaborative learning, use of manipulatives and labs. Byrne also notes a strong relationship between the "structure of a subject and the teaching style adopted by most teachers; mathematics is one of the disciplines where student-centered teaching approaches are least used" (Byrne 75).

Teacher preparation often hinders students' learning, or more exactly, teacher lack of preparation. The reform movement in mathematics referred to in the last paragraph is a change from teacher-centered learning to student-centered learning; i.e., a change from teacher-directed instruction to teacher-guided problem solving advocated by the National Council of Teachers of Mathematics in 1989. Admittedly, teaching through problem solving is more difficult, more demanding and more time consuming than traditional teacher-directed instruction. Also, the teachers must be confident in their mathematics knowledge. However, many teachers, especially elementary teachers, "are not wellequipped to adopt this approach" (Kirkup 179). Literature in popular media and scholarly journals also question the mathematics knowledge of many elementary and secondary teachers. In fact, James Rutherford and Andrew Ahlgren contend that many "junior and senior high school of science and mathematics do not meet reasonable standards of preparation in these fields" (Rutherford and Ahlgren 1990: viii).

Curriculum design also hinders students' learning. Many educators consider the mathematics curriculum, as taught, to be poorly designed. The traditional lesson plans are "overstuffed with detail, alienate students and often create confusion about the nature of mathematics" (Culothers 1993: 498). In addition, the fast pace of the mathematics classes is discouraging to some students (Datta 157).

In addition to the mathematics curriculum itself, the entire school curriculum favors left-brain modes of thinking, while downplaying the right-brain ones. Left-brain scholastic subjects focus on logical thinking, analysis, and accuracy. You would think these skills are what mathematics students need most. That assumption is correct to a point. Left-brain skills are especially needed for lower level mathematics courses. Many students do well in mathematics until they reach the higher level mathematics classes which focus much more on problem solving, creativity and synthesis, the characteristics of the right-brain mode of thinking (Kitchens 3). Students who continue to rely solely on left-brain modes of thinking now doubt their abilities to do mathematics; mathematics becomes "hard," and they often end their math educational career.

Focus of My Dissertation

As we have seen, mathematics is a cultural anathema in America. Americans have a negative view of mathematics, they see little reason to study mathematics and they believe mathematics is hard to learn. Is mathematics truly so different to learn than other subjects, especially for women? This dissertation endeavors to investigate that question. I will relate conversations I have had with a subset of students who have difficulty in learning mathematics - gifted women who underachieve in mathematics.

In Chapter II, I will examine the additional obstacles in learning mathematics that are unique to females. I will discuss historical, socialization, schooling, and adolescent developmental and psychological obstacles. In Chapter III, I will reflect on my teaching career and I will relate conversations I have had with gifted women who were underachieving in mathematics. And, in Chapter IV, I will discuss the present state of mathematics education, my philosophy of mathematics education, strategies and evaluation techniques and topics for future inquiry.

CHAPTER II

OBSTACLES WOMEN FACE IN LEARNING MATHEMATICS

Are Men Better at Mathematics than Women?

Are men better at mathematics than women? A review of literature relating to women and mathematics yields thousands of articles and books discussing exactly this question. Research is concentrated in two areas: the under representation of women in mathematics and the underachievement of women in mathematics. Seldom is a difference in innate ability cited as a reason for women's under representation and underachievement in mathematics. Recently, women and mathematics as a controversial topic has gained a very public venue. In 2005, Dr. Lawrence Summers, the former president of Harvard University, sparked the most recent debate, when he conjectured that one of the "potential reasons why women are represented less in math and science professions is that fewer women than men have the intrinsic ability required by such jobs" (Science 43). He also suggested that "one reason more women might not be better represented in the upper tiers of scientific research and industry is because of inherent differences between men and women" (Giovanelli 10). His remarks shocked the education community. Summers' comments were viewed by many educators as particularly troubling since he is the president of a progressive, coed university (Bombardieri 59). Summers' later apologized for his remarks, but he eventually resigned over the controversy. Even after decades of vigorous recruitment of women to mathematics and science, Dr. Summers shows that negative views of the abilities of women occur at the most elite educational institutions.

Are men better at mathematics than women? In The Snark Syndrome, Byrne examines just this very question. She shows that research by Besag and Wahl found no sex differences on maths anxiety or self esteem in a sample of 7,500 students (Byrne 163). Also, in How to Encourage Girls in Math and Science, Joan Skolnick, Carol Langbort, and Lucille Day found that research does not support any assertions of innate female inability of to learn mathematics and science (Skolnick 6). Although research has failed to demonstrate any difference in innate mathematics ability between women and men, the research has also failed to squelch the lingering question: Is there an inherent difference between men and women in mathematics? Yet the debate lingers.

Are men better at mathematics than women? Since 1983, national surveys have documented a sharp decline in the college enrollment in science-related majors. The surveys document that consistently smaller percentages of females compared to men major in science and that a disproportionate number of women leave majors in science, mathematics, and engineering (Eisenhart 5). During the first year of college, Linda Hagedorn and her colleagues found “significant differences in the level of gain in mathematical achievement between male and female…students” (7). Furthermore, Bocher found that “of those who drop out of math, there are a disproportionately high percentage of women and minorities” (5).

Skolnick says that “even among high school girls who do exceedingly well in most advanced courses such as chemistry, physics, and calculus, a great many never consider these fields as majors or careers (Skolnick 43). A majority of college students are now women. Gifted girls are choosing careers in business, medicine, and law in equal proportions to gifted boys. However, gifted girls still have much less interest in engineering and the hard sciences (Bocher 128).

Despite many recent advances in making science more accessible for underrepresented groups, women still face a series of gender related barriers to their entry into the science world (Etzkowitz 2). Women have a characteristic avoidance of mathematics and mathematics related courses which has a "powerful impact on women's career development and participation in today's modern technological society" (Bocher 168). Nearly half of the female school population in America is performing at a lower level in mathematics than their male cohorts.

Clearly, women still have problems learning mathematics. So, what's going on here? If there is no evidence of female disability in learning mathematics, why are women still under represented and underachieving in mathematics? Are there any areas that women demonstrate differences learning mathematics beyond the factors that make mathematics "hard" for most learners? Of particular concern to me, why do gifted women also underachieve in mathematics? Although there are many obstacles to women learning and achieving in mathematics in American society, I will only discuss five major obstacles: historical obstacles, societal obstacles, schooling obstacles, adolescence developmental obstacles, and psychological obstacles. These obstacles are not as clearly defined as my categories suggest; the obstacles have much overlap. However, I will parse and elaborate on each of these obstacles.

Historical Obstacles

When I started my doctoral studies, little did I realize I would be thrown into the bowels of European history and the intricacies of genetic DNA. I thought I was just going to study women and their disproportionate amount of difficulties with mathematics. That study has led me to many diverse locales. In studying why women may have trouble with mathematics, one winds up asking the question: How did science get historically defined as a masculine discipline?

Mathematics has developed mainly in a masculine world. In fact, David Noble stressed this fact in the very title of his book about the development of science, A World Without Women: The Christian Clerical Culture of Western Science. Noble's main theme is the relationship between the history of the Roman Catholic Church, the history of political power in Western Europe and the history of Western education. He postulates how the convergence of the histories of these three seemingly unrelated institutions have produced, sometimes intentionally and sometimes unintentionally, a culture of science that excluded women from the inside circle. He states that the development of science occurred in a masculine education system, and that science and mathematics developed a language peculiarly adapted to the male brain and method of learning. He contends that "the masculine culture of Western science is not simply a legacy of Plato's Academy" (Noble 3) but rather "tied to recurring tension between orthodoxy and revival which marked the entire history of the Christian West" (Noble xvi). Thus, this scientific "world without women did not simply emerge it was constructed" (Noble 43). The ramifications of this history are still being seen in the scientific classrooms of today. Vestiges of this archaic system manifest themselves in some of the problems women have with learning mathematics mainly because this masculine philosophy of mathematics became embedded in the very culture we live in.

Academic feminists believe that females are at a disadvantage in an educational system originally founded for men for the education of men because these institutions devalue “the modes of learning, knowing, and valuing that may be specific to, or at least common to, women” such as emotional, intuitive and personalized ways of knowing (Belensky 6). Rosabeth Moss Kantor, noted Harvard sociologist, studies women and the culture of largely male institutions. She points out that unless half of a discipline is female, “they make little difference in the culture of largely male institutions. Women are expected to adapt to the institutions rather than vice versa” (Irvin 99).

Women have been late coming to the science world, even later than coming to the world of education. Females were excluded from most universities until the nineteenth century, and then they had limited choices for majors. A vast majority of university educated young women of the last hundred years have majored in education, nursing or social work. As little as fifty years ago, women were not encouraged to take mathematics courses or to pursue careers in mathematics. A girl interested in mathematics was directed toward teaching mathematics, usually at the secondary level. For example, I received both the senior mathematics and science awards from my high school, but no one ever discussed career options beyond secondary teaching. The four top mathematics students in my graduating class at college were women, all majoring in mathematics education.

Socialization Obstacles

A study of bright people born after 1945 by Josefina Card and her colleagues found that one of the main factors accounting for sex differences in achievement was early socialization (Kerr 105). In fact, early socialization is the most widely cited factor of female's underachievement in mathematics. This underachievement in mathematics is tied to the general female underachievement documented by Sheila Tobias and Barbara Kerr in their works. "…women's epistemological assumptions were central to their perceptions of themselves and of their world" (Belensky xiii). "Carol Bly coined the term 'cultural abuse' for those elements in the culture that block growth and development" (American Association of University Women 293). Socialization has many components. I will address sex-role stereotyping, parental perception and schooling.

Sex-Role Stereotyping

It is no secret that each culture treats females and males differently. Less clear is how this differentiated treatment affects girls and boys. Although a politically correct world would judge each individual solely on her merits, you need look no further than the aisles of the local Babies'R'Us to see the difference sex makes in the rearing of a child. Today, most parents opt to find out the sex of their unborn child so they can decorate the nursery and purchase clothes for the appropriate sex. Nurseries are boy or girl themes and baby showers are awash in pink or blue gifts. Toddlers are given dolls or footballs and deemed princesses or athletes by doting parents. Girls are "girly girls" and boys are "all boy." Clearly the sex of the child has enormous effects on the expectations of the parents. This early socialization quickly relays to the child what is expected behavior for her sex, and gender identification is firmly established at an early age. Socialization creates sex roles and gives the psychological meaning "of what it means to be male and female" (Etzkowitz 31). So the "problem is far less to do with whether you are born a boy or a girl than with what society makes of that fact" (Skolnick 7).

Much of the early socialization of children involves early gender identification. As the child ventures outside the home, gender difference identification of the infant and toddler age only intensify. The gender identification quickly gets codified to sex-role stereotyping. Webster defines stereotyping as "an oversimplified opinion or belief" (Webster 1081). Sex-role stereotyping refers to a belief about how a person should act based solely on her sex. Now, in addition to the parents and relatives, other people continue the demarcation between male and female roles. Boys and girls themselves internalize sex-role stereotyping at any early age. Research shows that as young as age three "children have already begun to pressure one another to play with sex-appropriate toys" (Skolnick 27). In their study "How Schools Shortchange Girls," The American Association of University found that by age seven boys and girls "can clearly identify careers as male or female" (AAUW 157). Unlike older children of twenty years earlier, the children were more flexible about occupational typing but they still preferred traditional gender-specific careers (AAUW 157). Girls in America are socialized to be "nice." They undergo an "indoctrination into the code of goodness: be attractive, be a lady, be unselfish and of service, make relationships, and be competent without complaint" (AAUW 39).

Even today, there persists a common belief that females are less mathematically capable than males. “Classroom studies have shown that this belief is in place by the time children enter the third grade” (Gutbezahl 1).

Elizabeth Fennema has studied the teaching and learning of mathematics throughout her professional career, and is well known for her work on gender and mathematics. She found that girls, unlike boys, are torn between two behaviors: “being agreeable, complacent, and feminine as opposed to aggressiveness, assertiveness and autonomous. In order to succeed, the latter attributes of aggressiveness, assertiveness, and autonomy are the most desirable” (Keller14). Fennema points out that these attributes of success are exactly those needed to succeed in studying mathematics.

Parental Perception

Parents mirror and reinforce the beliefs of society. Parents have different expectations for their sons and for their daughters. Beth Block (1984) and Hoffman (1977) found parents emphasized achievement, competition, and self-reliance with their sons while daughters are expected to be “kind, unselfish, attractive, loving and well mannered” (Etzkowitz 37). Even when playing the same game with sons and daughters, parents “stress achievement with sons (winning the game) and ‘just being together with daughters” (Skolnick 276). Some parents profess to raise their child in a gender neutral way perhaps even encouraging their daughters to be tomboys – at any rate until adolescence. However, if their daughter doesn’t “outgrow her tomboyish ways and ‘become like other girls’ and especially when she began to show ‘intellectual desires’, her mother at least became anxious about her future" (Piper 24). This differentiated treatment greatly influences the children's perceptions of gender appropriate behavior.

Jacob and Eccles (1985) found that "media reports of sex differences in mathematics influenced parental attitudes toward girls' mathematical ability" (Bocher 191). By the time children enter school, parents expect girls to do better at verbal tasks and males to do better at math, a belief that continues through elementary school (Gutbezahl 1). Parents perceive that "mathematics is difficult and of little value for their daughters" (Etzkowitz 44). This parental perception greatly influences their daughter's self-confidence in mathematics and "her attitude and plans to continue taking mathematics courses" (Etzkowitz 44). While much attention is given to the "correlation between teachers' attitudes and the students, beliefs," the parents have an even stronger influence (Etzkowitz 4).

Schooling

Sheila Tobias believes that many of the problems of female education today are old beliefs about limiting female education "but have simply reappeared in different social clothing" (Tobias 96). The gender identification is exceedingly important in education because "…gender mediates what and how we learn" (Skolnick 8). Schooling presents obstacles to women learning mathematics in two important ways: (1) by treating boys and girls differently and (2) by the language and type of instruction.

Treating Boys and Girls Differently

In Athena Unbound: The Advancement of Women in Science and Technology, Henry Etzkowitz, Carol Kemelgor, and Brian Uzzi contend that women and men are not only treated differently on an individual basis but they are also treated differently at the organizational level (Etzkowitz 12). School and their agents, the teachers, are the first societal organization that most children encounter. “Schools have always treated girls and boys differently” (AAUW 62). However, documentation of this phenomenon and public awareness of the discrimination is increasing through studies such as “How Schools Shortchange Girls” released by the American Association of University Women. Researchers find that, while teachers think they are gender-fair, they do treat boys and girls differently in classroom interaction (Byrne 1993; AAUW, 1999). Teachers are more likely to allow boys to try tasks on their own. When dealing with girls, though, they take over tasks more often, not allowing them the experience of learning for themselves. In Myra and David Sadker’s work of teacher behavior towards males and females found that the classroom offers negative conditions and a ‘chilly climate’ for girls. They state outright that “boys tend to get more attention in classrooms than females” (Sadker and Sadker 386). Ellen Fox Keller’s work supports the Sadkers’ conclusions. She found that “teachers interact more with boys than with girls, praise and scold boys more than girls, and call on boys more than girls” (Keller16). Gifted girls often “give up their own assertiveness and risk-taking behavior in order to earn their teacher’s acceptance” (Sadker and Sadker, 1994) (Etzkowitz 40). Analyses of classroom videos show that teachers even ask boys and girls different types of questions. Boys are “asked more abstract, open-ended and complex questions” than are girls (AAUW 62).

Language of Instruction

You would think that teachers of science would be more equalitarian in dealing with males and females. Or perhaps female teachers would counteract the male / female stereotypes. However, “much of science remains – at best – uncongenial to girls and women. This begins with science education at the lowest levels” (Kirkup 3). The structure and content of the disciplines “differ firstly between arts and sciences, and secondly between predominantly male and predominately female environments” (Byrne 77). The language and style of teaching used in the science community is unique to that discipline: its language and symbolism, its competitive style and its abstraction, to name but a few. “Many of the male academics, who have traditionally constructed the cultural norms of teaching and learning in science and technology, are apparently unconscious that these disciplines have in fact been constructed on a male norm” (Byrne 79). Byrne interprets this phenomenon as Bourdieu ‘habitus’. Bourdieu ‘habitus’ refers to the theory of French sociologist Pierre Bourdieu where the culture of a discipline is understood basically by “tradition” or beneath the level of ideology. Researchers argue that science teachers actually reinforce the masculine image of science rather than counteracting it (Byrne 170). Harding found that “teaching style and individual behavior may be more influential than the sex of the teacher” (Byrne 109). Furthermore, Fox believes that teachers’ behavior “when combined with the organization of instruction made up a pattern of classroom organization that appeared to favor males” (16). Patterns such as competitive activities that encourage boys but that limit cooperative activities that favor girls. Birns contends that teachers encouraged “the exploratory, autonomous, independent mathematical skills associated with males and discouraged them in females" (Etzkowitz 40). Kirkup and Keller believe that "attitudes developed at the primary level ensure that by secondary school girls undervalue their abilities and underachieve in the sciences, technology and maths" (Kirkup 182).

"We found that boys acted [in the classroom] in a way which made science seem more masculine than it really was; the teacher also helped to create the impression that science is a very macho business …Teachers and boys seemed to be unthinkingly collaborating to construct science as an area of masculine endeavor, excluding girls, who quickly took the hint" (Whyte 8; Kirkup 184). Most girls who advance in mathematics conform to the male norm" (Byrne 84). The National Curriculum Council states that, though a common curriculum will help eliminate problems of sex imbalance in science courses, it is "likely that the problems of low expectations of many girls, particularly in physical sciences, will remain" (NCC 1989: A9).

At the post-secondary level, faculties profess gender neutrality in the classroom. However, when faculties treat women the same way they treat men, using harsh teaching methods, rapid curriculum pace, and a rigid assessment system, they are "asking them to perform in ways that are contrary to their socialization (Etzkowitz 54). Women are attracted by discourses that suggest that everyone is treated equally. However, even in an (alleged) gender neutral discourse, women succeeded only "if they worked as if they were prototypical white males" (Eisenhart 12).

Engineer Gary Downey, et al., conducted ethnographic studies of college level science and engineering in respect to the gender imbalance in those disciplines. The studies demonstrated that women who have strong academic backgrounds may still be described "by male professors and students as 'academically weak' or 'not the engineering type'" (Eisenhart 5). Further complicating matters at the university level, many disciplines use mathematics as a criterion of admission. Although mathematics acts as a background role in many disciplines, the schools use of business, economics, engineering and others use these 'weeding-out' courses to serve as a "filter, a way to sort out those who will and those who won't be allowed to get a degree" (Kirkup 101). These "weeding-out" courses are "based upon a competitive model that is designed to eliminate unwanted numbers of prospective students" (Seymour, 1985) (Etzkowitz 49). "Faculty members who teach 'weed-out' classes discourage the kind of personal contact and support that was an important part of high school learning" (Etzkowitz 54). 'Weeding-out' teaching styles are less likely to appeal to even the best female students because these styles produce "feelings of rejection, discouragement and lowered self-confidence" (Seymour 1985). Since women's self-esteem already decreases while they are in college, the "weed-out" classes adversely affect women more than men, and women leave these disciplines in disproportiate numbers.

Adolescence Developmental Obstacles

Adolescence involves biological, social and psychological changes. These changes cause conflict which is seen as normal and not unusual. No parent has to be told of the turmoil involving their adolescent children during this time. However, many researchers see the transition of adolescence as particularly treacherous for girls (Erikson, Gilligan, Belensky, Irwin, Piper, AAUW). In <u>Just Like a Woman: How Gender Science is</u>

Redefining What Makes Us Female, Diane Hales actually calls girls "an endangered gender" (Hales 117). In How Schools Shortchange Girls, the American Association of University Women cites epidemiological studies warning of adolescence as a "time of psychological risk and heightened vulnerability for girls" (AAUW 1991). The American Association of University Women studies show "that girls IQ scores drop and their math and science scores plummet" (AAUW 19). They "drop out of science, and they lose ground in mathematics" (Hales 117). During adolescence, girls are also less inclined to take risks, lose their assertive personalities, lose their sense of self and they become "more deferential, self-critical and depressed" (AAUW 19).

In Reviving Ophelia, Mary Piper contends that adolescent women today face ever increasing stress for which they have "fewer internal and external resources on which to rely" (Piper 158). Piper laments that girls are having more trouble now than they did before the women's movement of forty years ago that produced more women entering traditionally male professions and achieving parity on the sports fields (Piper 27).

Over eighty years ago, Terman and Oden found a drop in IQ scores of both gifted boys and gifted girls; however, the interesting fact was that girls IQ score loses were nearly five times the IQ score drop for boys. Even then, the researchers recognized that "only some traumatic change would alter some hypothetical genetic potential" (Kerr 120).

Certainly, adolescence is a traumatic time for girls. What are the factors of adolescence that cause these changes and affect women's ability to learn mathematics? Factors of adolescence development obstacles for girls are differentiated development, loss of self confidence, abstraction and relationships, need to conform and definition of femininity, culture of romance and perception of mathematics.

Differentiated Development

Adolescence is a time of transition for all young people. Adolescence is the first time you grow up and come to terms with adult roles; where you reconcile your individuality with social expectations. It is the time that divergent gender socializations of childhood "suddenly brought into focus and into practical significance" (Etzkowitz 55). Erik Erikson considered

> adolescence is the time when development hinges on identity. . . . boys and girls arrive at puberty with a different interpersonal orientation and a different range of social experiences. Yet, since adolescence is considered as a crucial time for separation . . . female development has appeared most divergent and thus most problematic at this time. The girls arrive at this juncture either psychologically at risk or with a different agenda. (Lerman 11)

The human developmental theories of Freud, Erikson, Piaget and Kohlberg all based their work on the male model (Freud, 1933; Erikson, 1963; Piaget, 1932/1965; Kohlberg, 1981). Females were portrayed as undeveloped persons (males), or their development was treated no different than male development (Irwin-DeVitis 1995).

> . . . the limitations in an account which measures women's development against a male standard and ignores the possibility of a different truth. . . . women's . . . lives of relationship, their orientation to interdependence, their subordination of achievement to care, and their conflicts over competitive success …a commentary on the society than a problem of women's development. (Lerman 170)

Carol Gilligan posited a different theory of female development in her ground breaking work, In a Different Voice: Psychological Theory and Women's Development. Whereas, male development is centered around issues of separation and individuation, females develop through social interactions and personal relationships (Gilligan 287). Gilligan contends that adolescent girls in Western culture are particularly vulnerable to crisis because they must reconcile their own socialization to an adult definition based on the male model of "independence and abstract principle" (Irwin-DeVitis 46). Whereas Gilligan and Noddings both conjecture that women are conflicted in our society by their struggle to reconcile femininity with adulthood, Piper locates the first occurrence of this conflict in early adolescence. At this juncture in their development, young women are also seeking their identity as they attempt to reconcile responsibility to self and responsibility to others. They seek answers to their questions of relationships while rejecting the abstract reasoning that depersonalizes individuals. This conflict and the energy it consumes in young women, diverts their attention from achievement toward relationships at the very time their male counterparts are traveling a more linear route in their own development. This different development of girls is manifested in several ways. One is by a precipitous loss of confidence of adolescent girls.

Loss of Confidence

Confidence is faith is your own ability. It is "a filter through which all of our life experiences pass" (Bergeron 51). Adolescence exaggerates this filter for girls and they face a confidence dilemma. Many girls have a past experience so devastating that it causes "a negative self-image such as 'I'm not a worthwhile person' or 'I'm just dumb'"

(Kubenek 5). Young girls, who find an encouraging environment for achievement in childhood, find a much more rugged societal terrain upon entering adolescence. In a 1988 report, Rogers and Gilligan found even girls who are self-assured as children demonstrate a difference in persona beginning in preadolescence: “they begin to lose confidence in their abilities, their looks and their personalities” (Kerr 157). In today’s erotic saturated media, adolescent girls have even more extreme body image concerns. “…as Simone de Beauvoir, French philosopher and feminist, writes, ‘to lose confidence in one’s body is to lose confidence in oneself’” (AAUW 57). Several researchers have noticed a marked difference in the confidence and self-esteem of girls as young as age eleven (Bocher 123).

During adolescence, “…assertiveness, independence…and self confidence undermined in female socialization becomes increasingly important to academic success” (Skolnick 21). This loss of academic confidence translates into underachievement and the subsequent slumping grades (Hales 251). The research of Taylor, Gilligan and Sullivan observed that about ages twelve or thirteen years, young girls frequently use the phrase, “I don’t know,” indicating “girls’ uncertainty about what they know and what they don’t know, what can be known and what cannot be known” (Taylor, Gilligan and Sullivan 170). Unfortunately, the girls’ distrust of their abilities may “develop into serious intellectual self-doubt” (Skolnick 15). Counter intuitively, gifted girls are especially likely to doubt their own abilities (Belensky 196).

The American Association of University Women study found that as girls go through school, their self-esteem declines while boys feel better about themselves. Boys and girls attribute success or failure to different factors. Boys attribute failure to external factors and success to ability so their confidence remains high even with failure. However, girls attribute failure to lack of ability and success to good luck or hard work, exactly the opposite of boys. Hence, girls' confidence is eroded with every failure. Consequently, "girls are more likely than boys to say they are not smart enough for their dream careers" (AAUW 63). In addition to the loss in confidence, young girls also face the universal conformity issue of adolescence. However, for girls, conformity relates to society's definition of femininity and womanhood.

Conformity and Femininity

The pressure to conform in American society has long been cited as a negative component of the development of females. Conformity and femininity for adolescent girls has many underlying themes. I will discuss three themes: (1) definition of femininity, (2) pressure to be feminine versus achievement, and (3) conflict between the definition of femininity and adulthood.

Young girls face not only the typical pressure for adolescent peer acceptance but also the increasing need to conform to stereotypical social roles (Etzkowitz 42). Society's attitudes toward girls change abruptly and "social happiness does not come to girls who are different" (Bocher 126). Girls begin the "rigorous training for the female role" and initiation into womanhood. The society's feminization process defines social acceptability for women in terms of appearance and actions (Piper 40). Piper asserts that by early adolescence, "gender roles get set in cement." Young girls are indoctrinated with a "code of goodness" where their worth is judged by their attractiveness, their manners, their unselfishness, their ability to make relationships work and their ability to be competent without complaint (Piper 39). "Juliet wasn't loved for her mathematics ability" (AAUW 39). They learn the appropriate subjects to speak about, to whom it is appropriate to speak and to whom is trustworthy to speak as part of their adolescent development (Taylor 75). Adolescent girls become increasingly confused and conflicted as they try to reconcile their wants and needs to fit into an impossible cultural stereotype of womanhood (Irwin 38). In short, society is not happy if girls are different.

Young girls also discover that achievement is often counter to society's feminine image (Skolnick 42). Barbara Kerr, author of Bright Girls, Gifted Women, contends that girls and women live in a society "mainly oriented toward mediocrity and conformity" and achievement is less valued (Kerr 226). Girls are bombarded by pressures "to be feminine, to settle for less, and to live through others" (Kerr 153). These pressures in adolescent girls lives come at a time when their "emerging identities center on being nice, caring for others and refraining from inflicting hurt" (Belensky 46). Our society raises girls to be "nice" and "nice girls fulfill other people's expectations" (Belenesky 206). Lewis Terman, often called "The Father of Gifted Education" (Kerr 96), found that "gifted girls and women have an even stronger need to please others than average women do" (Kerr 164).

Kerr claims these mixed messages are particularly confusing for gifted girls who are "reinforced for their abilities, but simultaneously taught that the acceptable female role is supportive one" (Kerr 107). In fact, most gifted girls are shocked "when the cheering for intellectual achievement is replaced by steady pressure to be feminine and popular" (Bocher 128). Kerr further claims that "many gifted women are encouraged to take the path of least resistance when they learn that society does not punish for withdrawing from accomplishment" (Kerr 152). Belensky also claims that girls "do not perceive any societal permission to live a nonstereotypical life" (Belensky 67). It takes a girl of considerable inner strength to resist all this pressure to conform.

Many young women cannot find many elements of societal "adulthood" that speaks to their own image of personal integrity. Young girls see that "the code of goodness" is at odds with adult behavior, and they despair at the impossibility of being both feminine and adult (Piper 39). Young men do not deal with the same disparity of expectations because the societal definition of adulthood is couched in the attributes of men. They find no need to reconcile their own male socialization with adulthood. Thus, the transition in our society from adolescence to adulthood is a more grueling endeavor for young women than for young men.

Gilligan frames this conflict between feminine and adulthood as an internal moral conflict that women undergo when they feel a tension between the part of them that wants to remain "passionate and sensitive," but feel that objective endangered by the pursuit of professional advancement. They cannot see a possible mode of reconciliation between femininity and adulthood (Gilligan 97). A corollary to the pressure to conform is the "culture of romance" (Kerr xiii) that permeates female adolescent American society.

Culture of Romance

Many researchers find a crucial shift in early adolescence from strong achievement needs to even stronger needs for social relationship and romance (Groth

1969; Holland and Eisenhart 1990; Gilligan 1992). In fact, much of the socialization between girls during adolescence is about romantic relationships. To achieve, a girl must "compete directly with the very males from whom she is trying to win social acceptance" (Skolnick 40). Even gifted girls fear their social life will suffer if they accelerate in mathematics (Skolnick 41). Kerr contends that "society's emphasis on the impossibility of combining love and achievement forces many gifted girls to become preoccupied with their relationships rather than with personal achievement" (Kerr 123).

Holland and Eisenhart also studied young people's peer culture. Their findings confirmed the research of other researchers who found that men and women achieve status in their peer groups in different ways: men through activities, accomplishments or relationships but women "only attained status through relationships with high prestige men" (Kerr 103). Considering their findings, you can see why some girls use romantic relationships as a route to prestige so "giving up one's own interests, activities and plans make sense" (Kerr 104). Even compensatory educational measures were "not powerful enough to overcome the allure of social affairs and romantic relationships" (Eisenhart 88). So, young girls learn the unwritten rules of society for the value of romantic relationships and status over achievement. Besides "culture of romance," Carol Gilligan notes that young women during adolescence are also vulnerable to moral crisis of reconciliation of relationships with others.

Abstraction and Relationships

Adolescent girls must reconcile three main issues regarding abstraction and relationships. These issues are reconciliation of abstract reasoning versus relationships, the abstraction of mathematics itself and moral issues from the perspective of abstraction and relationship. During adolescence, Gilligan believes young women enter a stage of reflective thought where their identities are tied, not to abstract reasoning, but to relationships with others (Gilligan 170). She says that this experience differs significantly for women and men with women being more concerned with an ethic of care and men with an ethic of rights (Gilligan 164). Many young women are not consciously aware how the conflicts between relationships and abstraction affect the decisions they make during adolescence. If young women are aware of the negative effect of this conflict of reconciliation, they cannot articulate their awareness. If they are not aware of the problem or cannot articulate their concerns, young women attribute their underachievement in mathematics to a myriad of other causes. “Ironically, bright and sensitive girls are most at risk for problems” (Piper 43).

Further complicating young women's ability to achieve in mathematics is the drastic loss of confidence they confront, as they become alienated from the abstraction of mathematics. Young women recognize that science and mathematics is not neutral as they presumed. They see a masculine, scientific construction emphasizing abstraction with no mention of relationships (Gilligan 6). Allowed to choose between relationship-oriented academic courses, e.g. the humanities, and abstract oriented academic courses, e.g. science or mathematics, young women choose relationships.

Adolescent girls also struggle with reconciliation of moral issues from the perspective of abstraction and relationship. Gilligan places this reconciliation in the moral development domain as young women struggle with the concepts of selfishness and selflessness for an understanding of care and relationships (Gilligan 138). Noddings casts this same issue as a decision of the ethical self that recognizes the relatedness that connects the young women with others (Noddings 49). Whereas young women in adolescence consider moral issues from the perspective of relationships, young men establish moral truths through abstract thought and logic (Gilligan 32). They base their judgments on deductive reasoning producing a common frame of reference. Consequently, young men are more confident in their moral decisions because they use formal logic (Gilligan 25). Noddings says boys are "diverted to more impersonal and abstract worlds" turning away from their inner selves (Noddings 122). By setting moral dilemmas in the context of mathematical problems, boys judge their relationships logically, keeping all their fields of endeavor in the same domain. Their development follows a more linear path conserving psychological and emotional energy. They have no conflict between relationships and abstract thought. How does differentiated development, loss of self confidence, abstraction and relationships, need to conform and definition of femininity, culture of romance all affect young girls and their perceptions of their mathematical ability?

Perceptions of Mathematic Ability

Most researchers agree that gender differences in mathematics appear about the eighth grade (AAUW, Piper). After middle school, many girls have decided they are not good at math. Consequently, half as many girls as boys show an interest in mathematics and science careers (Catsambis 1994; Etzkokwitz 43). Simply stated, girls have changed their perceptions of their mathematic abilities. Adolescent girls base their perceptions of their mathematic ability on three basic beliefs: their resolutions of interpretation of sex-role pressures, their lack of confidence and their beliefs about the subject of mathematics.

Skolnick found that "what roles mathematics and science will play in young girls' plans depends on how they resolve sex-role pressures in adolescent years" (Skolnick 39). Girls begin to believe that science is a masculine subject and that boys are better at mathematics. In primary school, most children considered science as a neutral subject. However, Sadker and Sadker (1999) found that by the time they leave middle school, both girls and boys agreed that science belonged to boys (Sadker& Sadker 123). This belief affected girls' participation in science and mathematics. Eileen Byrne found disciplines labeled as sex-abnormal became a major barrier to "cross sex" choices because adolescents are especially "unwilling to indulge in behavior not seen as appropriate for their sex or for their age or within their peer group" (Byrne, 171). In mathematics classes, females also believe that males are the best students. Females associate class participation with command of the subject; i.e., "the males asked the most questions and seemed to know what they were talking about" so they must be the best students. Hence, females underestimate their own abilities in mathematics (Leder 119).

Piper suggests that girls have trouble with math because "math requires exactly the qualities that many junior high and high school girls lack: confidence, trust in one's own judgment, and the ability to tolerate frustration without becoming overwhelmed" (Piper 63). Adolescent girls often interpret a "C," or even a "B," in mathematics as failure. This typical characteristic symptom of perfectionism leads many girls to believe that they are just not good at math (Skolnick 40).

Female students often see mathematics as a more difficult course than male students perceive it. Females see mathematics as a course to be feared while males see mathematics as just another subject (Kelly 119).

The sciences are based on an achievement model depending on competitive success. However, for females, "competitive success is often accompanied by great emotional costs based on family attitudes and their early experiences in the classroom" (Etzkowitz 47). They choose to absent themselves from mathematics classes rather than compete and risk relationships.

While women face historical obstacles, societal obstacles, schooling obstacles and adolescence developmental obstacles to learning mathematics, they also face unique psychological obstacles. Those psychological obstacles include patterns of underachievement, learning differences and growing self-doubt about learning mathematics.

Psychological Obstacles

Psychological Patterns of Underachievement

Several psychological patterns contribute to women's underachievement in mathematics. Kerr notes that as women enter college their self-esteem is at the lowest point ever and that they loose confidence in their opinions (Kerr 132). This dramatic decrease in confidence, achievement, and self-esteem manifests itself in the demonstration of tremendous self-doubt diverging into several widely recognized psychological patterns such as stereotype threat, the Fear of Success Syndrome (also known as, the Horner Effect), the Impostor Phenomenon, and the Cinderella Complex.

Several studies have found that stereotype threat affects womens' performances on math tests, and it is partly responsible for observed gender differences in math ability (Spencer 1999, Brown 1999, Keller 2002). Psychologist Claude Steele's concept of stereotype threat involves the fear of a person identifying with a negatively stereotyped group has of underperforming to conform to that stereotype (Steele 46). Women who believe the common stereotype that women do worse in math than men will actually score lower on math tests. Thus, stereotype threat acts as a type of self-fulfilling prophecy.

Matina Horner coined the term Fear of Success Syndrome in the early 1970's to describe women's underachievement when competing with men; the syndrome today depicts women's tendency to "negotiate and avoid conflict or competition when friendship or intimacy is at stake" (Kerr 162). Women in competition with men will compromise to preserve the relationship. Sadly, Kerr found that gifted girls are most vulnerable to this phenomenon as they "anticipate the consequences of too much success" (Kerr 164). They are more aware of their underachievement and "holding back one's effort and dampening one's enthusiasm" (Kerr 164).

Women showing manifestations of the Impostor Phenomenon demonstrate a denial of achievement. The women with this internal pattern "maintained a strong belief that they were not intelligent…and they convinced that they had fooled everyone" (Kerr 166). Even a woman who enters college with extremely high SAT scores may feel she is "the dumbest girl here" (Belensky 196).Women who felt intelligent and confident of their abilities began "to question whether they 'belonged' in the sciences at all, and whether they were good enough to continue" (Etzkowitz 59).

Colette Dowling observed that some women avoided achievement combining the fear of success and the need to be cared for into a psychological dependency that she called "The Cinderella Complex." Dowling claims that even today, when women are more independent that ever, they still have an unconscious desire to be taken care of by others. Dowling contends that this complex is a chief force that suppresses today's women leading them to wait for something external to change their lives (Kerr 164).

Learning Differences

Research does show three areas where women do demonstrate learning differences: (1) spatial skills, the mental rotation of three dimensional figures, (2) cognitive skills, the different make up of the brains of males and females, and (3) the interpretation of mathematical language.

Most educators consider spatial skills to be the most dramatic gender difference in learning mathematics. Why is spatial ability so essential for learning mathematics? There are three fundamental reasons that spatial ability is essential for learning mathematics: spatial ability makes problems easier to "see" saving time and frustration; spatial ability works because a verbal representation is not always effective; and, spatial ability allows representation of an extensive amount of data content pictorially (Skolnick 30). Education, experience, and context are extremely important factors in learning spatial skills (Hales 248). Most women have their first experience spatial ability in geometry, and geometry is fundamentally based on spatial imagination. Girls, especially high achieving girls, “begin to develop the differences that eventually deter them from mathematics” (Skolnick 28).

Another area of learning differences between boys and girls is cognitive skills. Even psychologists are surprised of the existence of The Psychology of Learning Mathematics, a magazine devoted to how to learn mathematics and to why some people have trouble learning mathematics. In the study of gender and mathematics, the cognitive science perspective is recent development. However, researchers anticipate studies that will add much insight into the underlying mechanisms that cause gender differences in mathematics (Keller 16). These cognitive skills related to two differences between males and females: the structure differences in the brains of males and females, and the onset of complex reasoning for problem solving. Cognitive research shows that “women’s brains are dense with more neurons which is advantageous to read” while male brains are more ‘lateral’ and divide tasks between hemispheres” thus permitting “compartmentalization which enhances the ability to focus intensely” (Hales 243). In Chapter I, we showed that this ability for intense concentration is a great advantage to do math. Meta-analyses results of work on gender differences in the United States, Australia, and Canada indicate that “while gender differences in mathematical achievement might be decreasing they still exist in tasks that required functioning at high cognitive levels” (Keller 16).

Lastly, the interpretation of mathematics language is different for boys and girls. Math teachers have long observed that males try to visual numerical relationships and draw pictures while females tend to “talk their way through” math problems (Skolnick 30). In The Snark Syndrome, Byrne asserts that there are pronounced differences between scientific and technological disciplines which are highly structured and codified versus those which are more enquiries based where the students have more discretion to pursue their own interests. Scientific and technological disciplines appeal to males who generally "prefer an authoritarian and directional style with relatively little 'negotiation' involved" while females prefer a more free-floating style (75). Byrne also argues that the codified language of mathematics presents additional challenges for women. The "culture, language, and discourse interaction" of mathematics produces a process where "more female students than male students need to expend initial energy (mental and psychological) in adapting to a new and more alien form of discourse…instead of being able to use the energy for immediate intellectual growth;" a process that disadvantages girls in learning mathematics (Byrne 77). In addition to patterns of underachievement, women's ways of knowing and learning differences, women also must reconcile collateral developmental issues.

Growing Self-Doubt about Learning Mathematics

In college, most women experience a continuing erosion of their self-confidence in general as well as a growing self-doubt about learning mathematics. A woman entering college has several negative attributes: her self confidence is at its lowest point; she feels she is continuing to lose confidence, she is not likely to assert herself in class, and she is not likely to stand up well to criticism. She becomes less sure of herself and more easily intimidated (Bocher 132). Women doubt their intellectual competence, and they speak frequently of gaps in their learning (Bocher 4). Researchers of self-confidence in college women found a disturbing phenomenon; while one-fourth of freshman women reported lack of self confidence, that number had doubled by the time the women became seniors (Kubenek 31).

Dianne Hales claims in her book, Just Like a Woman: How Gender Science is Redefining What Makes Us Female, that while many studies document women's tendency to underestimate their intelligence, they "most consistently underestimate or misjudge their abilities at tasks considered typically masculine" (246). Research consistently shows that "in certain domains, such as mathematics, men were more confident than women" (Lundeberg 153). Most women lacked confidence in the kind of learning and thinking that the instructor demanded. Women find this lack of confidence "not only painful but crippling" (Leder 193). Although women understand math concepts as well as males do, they tend to doubt themselves more (Fennema 342). Female students think that it is their fault if they don't understand. Or at least they believe it is their problem if they don't understand. Earlier we discovered that self-doubt and loss of confidence creates a "vicious cycle" accelerating the growth of self-doubt. Etzkowitz suggests that an insecure person is particularly vulnerable if problems arise and negative feelings take over her thinking. He even argues that this "depletion of confidence is a signal of impending disaster" (Etzkowitz 92). The woman truly believes she cannot learn mathematics.

CHAPTER III

REFLECTIONS AND CONVERSATIONS ON LEARNING AND TEACHING

> *Being a professional educator takes time -- time to plan, time to practice, time to grade, time to communicate -- and I never have enough time. However, I now realize that adding reflection and research to my agenda have made my life as a teacher easier, not more difficult.* -- Judith Koenig, Project teacher

I have taught mathematics for "thousands of years." I am from the "old school" of mathematics teaching. I got my undergraduate degree almost thirty-five years ago and my master's degree almost twenty years ago. I was a mathematics major BC, before calculators. My current students cannot even image such an era; it's right up there with the Roman Empire and the American Revolution. I have actually taught about twenty five years; however, I have taught literally thousands of students in that time. In those twenty-five years, I have encountered students of all different "stripes"; smart ones, determined ones, frustrated ones, fearful ones.

Reflections

My Educator Autobiography

I first became interested in becoming a mathematics teacher early in high school. I was good at mathematics and science, so I was encouraged to become a teacher. My first teaching experience in teaching mathematics was my student teaching at North Pitt High School in Bethel, North Carolina. I actually taught for two different teachers. I taught algebra one with a regular classroom teacher and a lab class with another teacher. Evelyn

Jenkins, the teacher of the laboratory class, was my mentor teacher. She was a great inspiration to me. The lab approach to teaching mathematics was considered to be a "new" method of teaching mathematics to secondary students. Ms. Jenkins was very "sold" on the lab approach, and she loved to discuss the approach. We'd often linger long after the students left discussing various aspects of teaching and education in general. Looking back, I see that this lab approach was my introduction to a different way of teaching mathematics than the one I had learned.

My first teaching assignment was at an urban school composed of only ninth graders. The city school system had recently been integrated by court order so racial tensions ran high in the school. Only someone who has taught that age group can fully understand the challenge of that experience. To add to the challenge, I had appendicitis the first month of school, and I was out over a week, not good timing. I endeavored to treat the students like I would like to be treated. I addressed them name and treated their individuality with respect. I made games that year, I rewrote worksheets as crossword puzzles, and I used interesting historical mathematical tidbits to start lessons. As all teachers can remember vividly, I learned much more than my students did. I contemplated not returning to teaching. However, Pat Rice, the English teacher whose classroom was across the hall from me, suggested I not judge my entire teaching career based on my first year in the classroom.

That summer I married and moved. I started the next school year at a rural county high school, the only high school in the entire county. I taught five classes of geometry. In fact, with the exception of one general math class, I taught five classes of geometry every year for six years. Need less to say, I know geometry. After seven years of teaching, I left to raise my family. I stayed away nine years.

I returned to teaching at a small, rural high school. I taught there three years. Then I taught as an adjunct instructor at Forsyth Technical Community College. When my daughter became a senior in high school, I taught at the same school as the second year I taught. I taught there one year before returning to Forsyth Technical Community College as a full time instructor. I taught five years as the post-secondary level. Then I became a secondary school teacher again; however, this time I taught only Advanced Placement classes in calculus and statistics. So, you see, I've had a very varied teaching career.

I am going to reflect on my early teaching, on my interest in women and learning mathematic, and on conversations I have had with a unique group of women who had problems with mathematics, gifted women. I will begin by examining the meaning of reflection.

What is Reflection?

What constitutes reflection and what significance does it have for me as an educator? A teacher's reflective process usually means to systematically observe, analyze, critique, and reflect on classroom practices. Whereas reflection is commonly used as synonym for thoughtfulness about teaching, I needed more information to support my reflective process. According to Webster's New College Dictionary, the third definition listed for reflection is "careful consideration; mediation" (Webster's New College Dictionary 931). Does "careful consideration" refer to consideration of teaching philosophy or of teaching practices? Does "careful consideration" refer to my teaching or to the teaching of others that I have observed? Does that "careful consideration" also include my students? To clarify the focus of my reflection, I consulted some education references.

When considering reflection we immediately think of John Dewey, his book <u>How We Think</u>, and the impact on education. He wrote this book for teachers and it has serviced as "the" resource for American progressive educators. Whereas Dewey may not have coined the term, "reflective process" and there are ongoing questions about the model proposed, his definition does provide a good starting point for looking at the reflective process. Dewey defined reflective thought as 'active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends' (Dewey 1933: 118). Since Dewey wrote these words in 1933, educators have endeavored to use the definition for use in many diverse contexts thus producing a myriad of different interpretations. I will endeavor to present a sampling of the recent usage of reflection in educational literature.

At the Fifteenth International Commission on Mathematical Instruction Study Conference, Timothy Boerst and Wil Oonk examined the reflective process in their presentation, <u>Reflection for Teaching: Nurturing and Noticing Reflection in Practice-based Professional Learning Experiences</u>. They addressed the popularity of work on reflection in various fields, such as learning theory, and educational domains such as mathematics education and teacher education. Boerst and Oonk also noted that reflection is "a way in which teachers are able to learn from experience and connect formal knowledge and practice" (1). They also emphasize that "There is important work yet to be done to closely describe and compare reflection in the professional education experiences …and in different professional educational settings" (Boerst and Oonk 2).

Paul Cobb, Ada Boufi, Kay McClain, and Joy Whitenach also address the reflective process in the article, "Reflective discourse and collective reflection." They offer an extensive list of possible questions to consider during the reflective process such as "How can the learning environment help all students become mathematical thinkers?" and "What are your beliefs about how mathematics should be learned and taught?" I will incorporate several of these questions both in my own reflective process and in my philosophy of mathematics teaching in Chapter IV.

The most recent source I consulted was Understanding and Promoting Transformative Learning by Patricia Cranton, published in 2006. Although Cranton deals mainly with adult learners, the transformative learning aspect complements my understanding of critical pedagogy. In fact, she uses the term critical reflection to be "the act of becoming conscious of our beliefs and assumptions (Where do they come from? Are they valid? What are their limitations?) and either expanding, validating or discarding them" (140).

I will incorporate all these views of the reflective process in my reflections of three decades of teaching. I want my past experiences to inform my present and lead into future experience. These personal reflections are eclectic, thoughtful, explorative, and far ranging. I will start with reflections on the first year teacher, go to reflections of the journeyman teacher, and then to reflections of the transforming teacher.

Reflections of the First Year Teacher

As a new teacher, I mainly taught the way I had been taught. I explained the lesson to the students, assigned homework problems from the textbook, and gave regular quizzes and tests. My students sat in nice straight rows facing the front of the classroom. Due to my inexperience and lack of confidence, I relied heavily on the textbook for content, ordering of topics, and for test questions. In fact, I often chose test questions that were very similar to homework problems or problems I had worked in class. Basically, I showed the students how to do something, they practiced it, and I tested them to be sure they got the "right answers." The old saw, "Tell them what you're going to tell them. Tell them. Tell them what you told them." I was firmly entrenched in the "teaching-as-telling" paradigm.

Looking back on that first year, I see many things I did wrong but also many things I did right. I did attempt to show my students the fun side of mathematics. Even with my exposure to the laboratory approach during my student teaching, I lacked the experience to implement nontraditional teaching methods. I did try. I made card games for learning fractions and a bingo game for factoring in algebra. From the beginning, I strived to treat each student as a respected individual. However, I was mainly concerned that the students understand the mathematics, not with them as individuals. As every beginning teacher learns, the teacher learns much more than the students and I certainly learned a lot about myself as a teacher and as a person that year.

Reflections of the Journeyman Teacher

I taught six more years during this earliest teaching phase. I became more experienced in the classroom and I was more confident in my mastery of the mathematical content I taught. My teaching evaluations were excellent. I explained concepts in plain, easy to understand words, I offered different explanations of troublesome concepts, I offered copious amounts of additional help, and my students knew I wanted them to succeed. Most of my students learned the mathematics I taught them, and I thought I was a good teacher.

I was absent from teaching for nine years. During that time, I concentrated on raising my children. When I did go back to teaching, I believed that my experience as a mother helped me develop more patience and more understanding. I relished the opportunity to be back before a group of students. Other teachers warned me about the dreaded "end of course" tests that the students would take in the spring to access their progress in the course they were taking. In my case that meant geometry. The first year I returned to teaching was my introduction to standardized tests. I had never heard of end-of-course tests, so I did not know how to approach teaching my classes to accommodate any added learning that may be necessary to prepare my students for this test of their geometry knowledge. My only preparation was to get a list of the objectives for secondary geometry as taught in North Carolina public schools. My students performed extremely well on their tests, so I continued to think of myself as a good teacher. However, my evaluations did not reflect the work I was doing in the classroom. The administration did not share my opinion of myself as a good teacher. Consequently, I left that school after only three years with my confidence in shambles.

This incidence was the first time I had ever questioned my teaching ability. That questioning also seeped into my opinions of myself as a person. I could not shake the negative thoughts in my head. I became an adjunct mathematics instructor at Forsyth Technical Community College. I truly enjoyed teaching the adult learner. I threw myself into my work, and I was nominated for the adjunct excellence in teaching award. All this time, I was still the good teacher. However, I felt something was missing in my life. My mother's death the next spring galvanized my resolve to learn more about myself as a teacher and as a person. I decided to return to school.

Reflections of the Transforming Teacher

I had actually considered pursuing a doctorate in Education Research Methodology. That department seemed a good fit with my background in mathematics and statistics. I even went to the University of North Carolina at Greensboro to interview the members of that department. However, I could not "see" myself in that discipline. The discipline seemed too cold and impersonal to me. It just wasn't me.

I went to talk with Dr. David Purpel, and I wound up in the Educational Leadership and Cultural Studies Program. What a wonderful happenstance! Having come from a scientific/mathematical background, I was unfamiliar with many of the educators/philosophers and their theories that I encountered in my graduate studies, or more exactly, maybe I had heard of at least some of these educators before but I had not been ready to receive their messages. Quite frankly, I was totally contented to teach mathematics and mathematics only. However, even at Forsyth Technical Community College, I realized that my philosophy of teaching mathematics differed considerably from those of my colleagues. I did find a kindred spirit at Forsyth Technical Community College who shared some of my “unorthodox” education ideas (at least by most math teachers thinking.) Allow students to take retests? Never!!! The process is much too time consuming. Give copious amounts of help outside class to struggling students? Unthinkable! If students are so ill prepared, let them take lower level classes for several semesters to “build up their skills.” If our job as teachers is to have the students learn the mathematics, do we continue to use the same old techniques: the techniques that work for the twenty percent of students who are going to learn no matter how we teach them? Well, if you want to start a college algebra class with thirty students and wind up with five maybe, but, how about all those students who need mathematical guidance? Maybe they didn’t come from the college preparatory classes, or from the schools where the vast majority of the student body pursued a post secondary education. Have they forever lost their right to move forward, to achieve, and to seek a better life: a life that, at times, requires a certain level of math proficiency to pursue?

I have long been interested in the difficulties experienced by many students taking mathematics classes. Of course I’m not talking about those students who revel in solving multivariate calculus problems; mathematics has never been particularly difficult to them. How about the practical nursing student who must learn to convert medications? Or how about the undergraduates who “need” to pass college algebra for their humanities degrees? Or consider the potential graduate student who must score well enough on the Graduate Record Exam, which includes a large portion of math, to enter graduate school

Or consider the graduate students who must pass statistics for their masters program. And I'm not talking about people who have "math anxiety" and avoid mathematics in any genre at all costs; I'm talking about many otherwise high-achieving students who underachieve in mathematics. So, the question becomes, "Is math different from other subjects?" If so, how is it different; and, how can that difference be addressed to mitigate its impact on student scholarship? Now the task became how to integrate social change elements into my practices in teaching mathematics.

In the midst of my doctoral studies, I accepted a job of teaching Advanced Placement Calculus to secondary students. I mainly sought this job change as an opportunity to expand my knowledge of mathematical content. My position at Forsyth Technical Community College was well-defined and that definition did not include higher levels mathematics classes. That decision shows the undeveloped transformation in my teaching. I thought I was still teaching mathematics. I realize that the job change brought into sharp contrast the different types of teacher required for adult learners and for academically advanced teenagers.

I had been gradually changing from a "teaching as telling" mode to a more conversational approach, a significant change in my teaching from former practices. At least, that is what I thought I was doing. Actually, I was still engaging in old habits that "worked." My students still sat in rows, they talked very little to each other, and I did most of the talking. I was reminded of the saying, "The person doing the most talking is doing the most learning.” I have had a hard time letting go of "control" of my students' learning. Epistemologically, I believe that students learn mathematics by engaging in mathematics discourse, by talking about mathematics. However, my practices belie that belief. So I began with small steps. I restructured the classroom with four desks pulled together to make semi-permanent groups. I started each class with the students discussing their homework assignments, actively engaging in “math talk” in their groups. I strive to challenge my students in an environment that combines a push for excellence with a nurturing, positive atmosphere. I want us to be able to struggle together in a safe environment. With this learning environment, my students learned much and performed well on standardized tests. However, could there be more to teaching than students being able to perform mathematics well? As Rafe Esquith says, “I can do better” Like Esquith, I want to address the “real” questions of education. “I always remind my students that life’s important questions are never asked on standardized tests. No one asks them questions regarding character, honesty, morality, or generosity of spirit” (Esquith 83). In that direction, I go.

My reflections have brought to mind several areas of interest I explore. I am interested in the history of mathematics, the learning of mathematics, and women and mathematics. I will elaborate on my thoughts and reflections about women and learning mathematics. I will conclude this chapter with reflections on conversations I have had over the years with gifted women who experienced trouble learning mathematics.

Conversations

Women and Learning Mathematics

I came up with the idea of combining my interest in women's studies with my ongoing study of students' difficulties with mathematics. I decided to examine a small subset of these underachieving students: gifted women who underachieve in mathematics. I chose gifted women because I had recently read three books that had piqued my interest in the lives of gifted females: In a Different Voice by Carol Gilligan, Smart Girls: A New Psychology of Girls, Women and Giftedness by Barbara Kerr, and Women's Ways of Knowing by Mary Field Belensky and others. Later, I read an article by Pat Rogers who suggested that the theoretical stances of feminist pedagogies might be useful in "maths pedagogy." She argues for a pedagogy which "allows women and girls to see themselves as producers of mathematics as opposed to consumers of a predetermined / and absolute body of knowledge. The shift from consumer to producer represents the shift from voiceless to communicator" (Chronaki 308). This literature echoed my own beginning thoughts about women and learning mathematics.

In the ongoing discourse concerning mathematics education in America, the voices of the students are seldom heard. In fact, the opinions and the insights of students are seldom solicited or even less frequently heard. Most frequently, the voices you hear in the mathematics educational community is not from the students. The voices are those of college professors long removed from the mathematics classroom. They offer new techniques that proclaim improved test scores for standardized tests - the tail that wags the contemporary educational dog. I will reflect on conversations I have had with women students. Through these conversations, I will seek to give a voice to the concerns of women students. I will also ponder the reasons they perceive in the difference in learning mathematics.

What is a conversation? According to Webster's Dictionary a conversation is "a spoken exchange of opinions, thoughts, and feelings" (WNCD 247). That definition conveys exactly the sense that I will use the word conversation. Upon considerable reflection of what has occurred in my interactions and conversations with my students, I will use these conversations to investigate the thoughts and feelings of gifted women who underachieve in mathematics.

In their book Education as Adventure, John Nicholls and Susan Hazzard explore students' understandings of the idea that students are valuable critics of their own learning. "Few [researchers] contemplate students as collaborators in the formation of the means and ends of education.... Whether or not we acknowledge it, students are curriculum theorists and critics of schooling. If they are drawn into conversation about the purposes and practices of education, we may all learn useful lessons. Education can become an adventure in which teachers, researchers and children together learn new questions as well as answers, so that their lessons are never complete" (Nicholls and Hazzard 8).

Throughout this dissertation, I will share student comments. I will frame these comments in the context of a series of conversations with gifted women who underachieve in mathematics. Considering time and volume constraints, I will limit these conversations to women students I taught at Forsyth Technical Community College. I will draw on memories of interactions with students. Where a majority of students communicated a particular perspective, I speak in generalities about my overall impression of the comments. These conversations will be constructed pictures in which different kinds of women respond to different things.

The gifted women were highly articulate, and, consequently, their comments are very compelling. To categorize the entire collection of conversations, I searched for common elements among the women's comments. I especially looked for "turning points" in the commentaries, where the women perceived a change. I also looked for common metaphors that the women used to talk about mathematics. Each of these investigations yielded rich sources of interpretation.

The women had been out of high school approximately seven years or longer. Even after a decade, their voices conveyed the remembered pain of their high school mathematics learning experiences in telling detail. As I remembered the conversations, I could "hear" the women's voices relating anecdotes and poignant memories of their experiences learning mathematics as clearly as if the conversations had occurred this week. I could hear the nervous laugh when a woman was not quite sure what to make of her experiences and the drop in her voice when she discussed a painful memory from long ago. The women's remarks will appear in italics.

Common Themes in the Conversations

As I mentioned earlier, I have taught thousands of students, so I had copious amounts of remarks with which to work. Several themes showed up repeatedly in the conversations. Some themes, like method of instruction, harkened back to those I discussed in chapter one on cultural perceptions of mathematics I found several common themes to the women's comments: who they blame, turning point, schooling, and psychological issues.

Who Do They Blame?

Some women sounded unsure of exactly what caused their difficulties in learning mathematics, they all attributed their problems to various reasons, and their remarks did cluster into a handful of distinct areas. Some women basically blamed their problems on not understanding the basics in prealgebra. Others even attributed their lack of success in learning mathematics to their laziness and lack of initiative as young students. One woman attributed nearly all of the success that a person has in mathematics to the individual. *I think it's the person. You've opened the door but it's up to the person to walk through it; the person's got to do that.*

Other women blamed their problem in mathematics to not studying correctly. *I pretty much learned it from day to day, enough to pass the tests.* Even though they had passed prior courses, they felt they did not have the foundation they needed to proceed in a college education. Basically, they blame themselves for not being a more serious student in their math classes. Some women attributed prior poor performance to the fact that they *didn't realize that I was going to need it later.* A few women blamed the teacher for their problems in mathematics.

In Chapter II, I showed that "female students believe that their lack of understanding is their own fault or at least their own problem" (Leder 120). Most of the women think their lack of understanding is their own problem or they believe their actions contributed to their problem learning mathematics. Besides locating the blame for their problem with mathematics, the women also talked about a specific event that marked the beginning of their math problem.

Turning Point: Math Becomes a Problem

Most women noted a definite turning point, or epiphany, when they first realized that math was a problem. Although the women experienced their epiphanies at various times, all of them students indicated that about the seventh or eighth grade in school that they became aware of their diminished ability in mathematics - a turning point in their perception of their mathematics prowess. Many women remembered pre-algebra in middle school as the first math course that was particularly difficult to master. One woman remembered that in the seventh grade that she did not understand *the x, y axis thing.* She went into the eighth grade and started pre-algebra instead of algebra. Many women had a similar experience. Although they had no problem with mathematics in elementary school, they indicated their problem *"obviously goes back to high school…I just thought, 'This is something I can't do and I'm not going to even try it'.* They categorized themselves as not math people, and they concentrated on subjects they did well such as English or history.

Other women indicated that motivation became a problem in learning mathematics. One woman remembered that started the first year of high school. Although she thought prealgebra was not hard, she felt her problem started then because she *wasn't motivated at all. And I wasn't into school. I was the typical teenager, rebelling and everything else and didn't listen to anybody.* Another woman recalled doing fine in mathematics in elementary school, but experiencing trouble when she took a test and placed into a transitional math class in the seventh grade. Transitional math was algebra on a eighth or ninth grade level that the students took in seventh grade. *I was always an "A" honor roll student in elementary and middle school…I got a "C." That was one of the first "Cs" on my report card.* Virtually all the women believed that early adolescence marked the time they first had problems with mathematics.

This timing of the women's first experience with math problems corresponds to the loss of confidence that Piper refers to in Reviving Ophelia. More importantly, the women noted that prealgebra or algebra was the first course in which they experienced trouble with mathematics. Students who have been good at mathematics until algebra often find that algebra is different. Algebra is different because instead of dealing with the concrete concepts of arithmetic, algebra deals with abstract concepts.

Schooling: Method of Instruction

Many of the women shared several comments concerning less than positive experiences with teachers. Most to the women had an unsatisfactory experience with a mathematics teacher. One woman had a negative memory of her high school math teacher: *My teacher told me, I never will forget, he said, 'If you don't want to do anything, that's fine, but just don't disrupt the class.'* So, she slept every day in his class and did absolutely nothing. Her teacher was definitely using the banking technique discussed by Paulo Feire. He was not engaged with the students; he just wanted to teach the material and to have a nice, quiet class regardless of the learning not occurring.

Some women had a definite preference for women mathematics teachers. One woman's comment echoed many other women's opinions of male teachers:

> *I think men seem to think, 'I can get this so surely they can.' I think that they think, 'As long as I can teach the general part of it, and then they can get the rest.' I'm not saying that about every subject, just about math.*

Other women remembered a male math teacher who made them feel stupid for asking questions. This negative feedback only reinforces the woman's doubt about her qualifications to be in that math class. When they did not get positive feedback from the teacher, they stopped asking questions.

In addition to the negative experiences mentioned by the women, they also stressed their desire to have teachers who cared about them. Many talked about their teachers at Forsyth Technical Community College holding them accountable for attending class. They felt the teachers cared about them. Many women felt a caring teacher was necessary for them to do well in a class. They would look for that attribute right away. One woman said, *The very first day I could tell who the teachers were who really care; the teachers who know life, they know things happen*. The women look for teachers who are sincere and show sympathy if you're in a car wreck and do not hold fast to *the policy that if your paper is late you get grade points off.*

One woman talked about a answering a question wrong in class but getting very encouraging response from the teacher. *'That's very creative, but it's wrong. It's very interesting so at least you're thinking.'* Although she does not use the term caring in her descriptions, she recognized those qualities.

The negative feedback from a former teacher had not faded in their memories. The women showed much perseverance for continuing in math classes after such hard blows in their self confidence especially during their vulnerable adolescent years. At that stage in their educational careers, they perceived the teacher as the ultimate authority in the subject. To believe that the teacher thought you were "stupid" must have been devastating to a young girl. Teachers do have a tremendous impact on the learning of their students whether good or bad. Many women also expressed their "need" to take mathematics.

Schooling: Need for Mathematics

Many women come to realize that they "need" to take mathematics in order to accomplish their educational goals. They are often perplexed over the reason they "have" to take the course for the completion of a degree or the exam in order to study for an advanced degree. One woman told me of the following story recounting when she first realized the limiting nature of her lack of success in mathematics and her understanding of the consequences of that limitation:

> *In geometry class, I did absolutely nothing. I went there every day and just slept...I got an "F" in that class. So that left me deficient in my requirements in math to graduate. So they set up this course where you could take things like balancing your checkbook. It counted as a math, but it wasn't really a math per se…So, I took that class, and it got me through my requirements to graduate.*

Many women experience a similar revelation. They do not plan to go to college, so they do not take the college preparatory classes in high school. However, when they do begin college work they had to take developmental mathematics courses that do not count toward their college degree. Even when they finish the developmental classes, they are face with taking college algebra in order to get their degree in all majors. One woman poignantly described her reaction to finding out she had to take college algebra for an associate's degree. *.I had to have that class to go to school; I had to have it I was on an emotional roller coaster at that point because everything was hinging on this class. If I don't pass this class, I can't go to college.* She finally passed the college algebra class on her third attempt:

Many women passed college algebra and believed they were finished with taking mathematics. However, their relief was short-lived if they were education majors. They had to take the Praxis I exam with a substantial mathematics section. Once they pass the Praxis I exam, the women only have to take classes in their majors; most of them thrived and achieved high grades. In fact, many of these gifted women decide to go to graduate school and get a Master's Degree. They had to take the Graduate Record Exam, and once again, they were confronted with a "need" for mathematics. For women who underachieve in mathematics, their problems with mathematics come back to haunt them. Even students with extremely good grades and outstanding recommendations, must do well on the mathematics portion of the Graduate Record Exam to get into graduate school. One woman lamented that *I just don't want to go through that again*.

Whereas most of the women talked about needing mathematics to farther their education, one woman talked about being embarrassed by her lack of math skills after college. She believed that she should be able to do basic math, and she felt embarrassed because it took her a long time to figure it out. To illustrate her point, she recounted an episode of the television show Frazier where the characters are admitting embarrassing things, and Frazier's dad admits he can not do math in his head. Frazier and his son are aghast that Frazier's dad can not do math in his head. When she finished, the woman said, *And I feel that way sometimes. 'Why can't you do this?'* She accurately summarized her feelings when she lamented, *Am I an educated person or am I not an educated person?*

Schooling: Math is Different

One area all the gifted women agreed on, math is different. It is different to read, different to study, and different to learn. Many of the women used the word "challenging" when they referred to their math classes. When they compared mathematics to their other subjects, mathematics fared poorly. They spoke of how in other classes they saw more of the process. *You see how interesting that is and how engaging and intriguing.* Obviously, the women did not use those adjectives when they talked about their math classes. The women talked about loving history and world geography and world cultures and English. Some noted that even if they didn't enjoy the class they were good at it and it was easy to understand. One woman would like mathematics classes to have more explanation. *I like to know why, or how, or those kinds of questions.* She does not hear these questions or their answers in her mathematics classes.

Many women contrasted mathematics to other subjects like history because history was *just a memorizing subject.* One woman made "A's" in her other classes effortlessly because they came naturally to her. However, she felt that math really challenged her use logical thinking skills and critical thinking skills. *I couldn't do the math without really studying and really working at it.*

Many women also noted that they were better in other subjects because the subjects were more verbal in nature or they spoke of being just outright more interested in other classes. One woman elaborated on her interest in her architecture classes.

> *Definitely in the architecture classes, the interest is there. I get so excited… 'Oh boy, I get to design something.'…Even if I didn't study for a single test, I'd want to study just because I'm interested in it and I enjoy it….I love the creativity that it requires…you see all those causes and effects; that's so great. I love to see that; I love being part of that.*

She did not see any enjoyment in mathematics.

Psychological Issues: The Role of Emotion

As I note earlier, mathematics seems to touch an emotional chord with many people. The memories of long pass negative mathematics experiences elicit strong feelings for literally decades. Melissa Rodd at the University of London studies the relationship of emotions to learning mathematics. Her research demonstrates the "significant role that emotions have in learning mathematics" (1).

Many times throughout the conversations, the women expressed varying degrees of emotion. While some women only mentioned a little of their feelings about mathematics, others spoke at length about their emotional experiences. For some women, mathematics was very emotional because they could feel their goals being comprised by mathematics requirements. Many women actually hated mathematics because they were not good at it. A typical remark was *I just hated to do the homework…that was just too much to ask.*

Many women admitted that they experienced fear of mathematics. A representative remark was *I had such a fear factor and anxiety*. Some women even experienced physical manifestations of their fear. One woman remembered the time she panicked on a math test. *When I was taking the second test, I was starting to sweat. I was getting real nervous and I was starting to panic. I was scared of the test*. Another woman had a truly heart retching emotional response to mathematics.

> *When I went into eighth grade and instead of being able to start in algebra, I had to start in pre-algebra…So, I felt like a loser. (She formed a letter L with her right hand, and held it up to her forehead.) because I was in pre-algebra with the slow people.*

This exceedingly bright and accomplished woman had no confidence in learning mathematics: Mathematics definitely produced great emotional angst for these women.

Psychological Issues: Negative Self-talk

Negative self talk was a recurring theme in the conversations. The women expressed many examples of negative self-talk: *I got it wrong. I'm going to get it wrong on the test, The insecure thoughts, they just don't go away, I set in my mind that I couldn't do it, It was just like pulling teeth,* and *I dreaded it. I dreaded taking it a lot.* The women realized that their emotional responses were impinging on their math performance, but they were unable to break the cycle of negative self talk that generated that anxiety. *You tell yourself that for ten years so it's hard to take yourself out of that after you've been saying it.*

Psychological Issues: Fear Factor

Many women spoke about fear of failure. They very much feared making a mistake. Typical remarks were: *I just had such a fear factor from the beginning. I'm going to fail this class* and *This is going to be the class that breaks me. I just can't do it.*

One woman had recurring thoughts of failure. *I think I've told myself for too long that, 'You're not going to do good (sic). You're going to fail.' I think I have believed that.* She delayed returning to school because she dreaded taking the placement test. *I got so scared of that test because I knew what it was going to tell me….I was just so scared and just so afraid of failing.* Each time she experiences trouble in mathematics, she begins to worry about failing. *I see those numbers stuck there, 'Well, it's a math problem. RUN!' That's exactly my first instinct.* She did not like to fail, she liked to be successful and she did not feel successful in math classes.

Unsolicited Comments

When women found out the topic of my dissertation, some of them volunteered their own math experiences. I have included their remarks to demonstrate the emotional chord strummed by the math experience that reverberates for years beyond the person's last encounter with the learning of mathematics. The majority of the women told of their negative experiences with mathematics, and even the two positive comments also contained negative remarks. However, this one-sidedness of responses is quite normal. Statistical research has demonstrated that people with negative emotions are much more likely to take action on those feelings whether through answering call in surveys, writing letters to the editor, or relating past experiences to others.

I'll begin with the two semi-positive comments. Both young women said they had good math experiences because of good teachers. One woman said, "I like math better now because I understand it better now." When I asked her why she understands math better, she attributed her better understanding to having a teacher who cared. She contrasted the caring teacher to a "bad" teacher she had "who ignored questions and turned her against math." The other young woman had a similar experience. She compared her positive, "fun" high school math teacher to her negative, eighth grade teacher who "turned her off" to math. And those were the positive comments!

The other three unsolicited comments were totally negative. A colleague and I were exchanging small talk during a lull in activity at a fall preregistration session. Even though she had not stepped in a math classroom in over a decade, the counselor told me how she "dislikes math" and how she "got lost in precalculus." Just recently, at a first of the year faculty meeting, the media coordinator at my school recounted that she "never was good at math." Surely she would not have said that had she not anticipated a receptive audience. And last, I return to the confessor of chapter one. A fellow student in a graduate education class spent over thirty minutes relating to me how she was denied membership in the her high school National Honor Society just because of a math grade; an event that occurred over forty years ago.

Conclusions and Connections

I was seeking a better understanding of the way mathematics is perceived as different by women who achieve in every academic subject except mathematics. How did they understand their performance differences in mathematics as opposed to their performance in other subjects? Now I will reexamine those inquiries in context of the conversations.

All the women sought a reason for their problems with mathematics. Some blamed their prior experiences in mathematics for their ongoing trouble with math. They definitely believed that they did not get the quality of mathematics instruction that they needed to be a truly “educated person. Some of the women blamed themselves for their problems whether perceived laziness or not study correctly. Although the women all “blamed” something for their problems, one woman probably spoke for them all when she admitted, *I don’t know. I just don’t know*.

All the women noticed the onset of their problems with mathematics during early adolescence; they decided they were not a “math people.” At approximately the same time, the mathematics being studied becomes more abstract adding a layer of complexity to studying mathematics.

I used the compiled data from all the conversations to formulate connections for a more holistic picture of the women and their perceptions of their mathematics experiences. A majority of the women talked at length how language affected both their understanding of mathematics and their academic success in mathematics. Most assuredly none of them had read Snow’s book but all of them recognized the gulf created between the math haves and the math have nots by language. The women, perhaps subconsciously, acknowledged the existence of two cultures.

If the intellectual world is truly divided into two distinct cultures, literary and scientific as Snow posits, how can students become bicultural? Obviously, language is the bridge between these two cultures and the key to biculturalism. How can and how should this issue of language be addressed in the mathematics educational community and in the mathematics classroom? One possible approach would be better use of metaphor and analogies to help students to link mathematics to their existing web of knowledge. Memory studies show that these linkages between new knowledge and previous knowledge greatly enhance the student's understanding of mathematical concepts. Linkages would reduce feelings of math being a "whole new language." Clearly, instructors need to help their students to learn how to learn mathematics. The instructor can become the cultural translator to enable students to function in two worlds, literary and scientific. As American culture becomes increasingly technological and the population becomes increasingly diverse, this need for cultural translators will become ever more important. The technological world cannot discount entire segments of the population because they "cannot speak the language." The gifted women in these conversations form but a minute proportion of the mathematics students in America. However, their comments give voice to the silent students who are seldom, if ever, asked for input into how they receive knowledge. The women speak loudly that language is a vital ingredient in mathematics—an ingredient not considered in mathematics curriculum construction. Nel Noddings says the "no subject inspires greater fear in more people than does math" (Noddings 192). However, mathematics teachers are not trained as mathematics counselors. They are not trained in ways to reduce this fear in their students: physically by relaxation exercises and psychologically by allowing the students to talk about their negative experiences with mathematics and to expose how universal these negative experiences are. Mathematics teachers can also provide multiple evaluation opportunities for students to demonstrate that they have mastered the essential material (Noddings 192).

In the next chapter I will address the present state of mathematics education in America, I will state my philosophy of mathematics education, I will tell of practices I use in my classroom which have developed out of my philosophy, and I will offer suggestions for future inquiry.

CHAPTER IV

WAYS OF LEARNING

In chapter one, I examined the place of mathematics in American culture, and I asked, is mathematics truly so different to learn than other subjects, especially for women? In chapter two I showed the many obstacles women face in learning mathematics, and in chapter three I presented reflections of my teaching experience and conversations with gifted women who underachieve in mathematics. Now I will discuss the present state of mathematics education in America, my own philosophy of teaching mathematics, and my practices of that philosophy. Lastly, I will state my conclusions from reflections and conversations.

Present State of Mathematics Education

> *It is, in fact, nothing short of a miracle that the modern methods of instruction have not entirely strangled the holy curiosity of inquiry.* Albert Einstein

In America, the woeful state of mathematics illiteracy is evident in elementary, secondary, and post-secondary schools. Most writers believe that American high school students lag behind all other industrialized countries in mathematical achievement (Skolnick 2). Tobias claims, "Most students… leave school without the mathematics skills they need to thrive in an increasingly complex, global economy" (Tobias 49). In

<u>The Manufactured Crisis: Myths, Fraud and the Attack on America's Public Schools</u> (1998), Bruce Biddle and David Berlinger represent the minority of writers that take issue to these negative assessments of American literacy status. According to Biddle and Berlinger, there have been modest increases in standardized math scores in the past decade "despite the fact that more students are taking the test than ever before whose first language is not English. Biddle and Berlinger conclude that there is no support for the myth that American students fail …in any subject" (Marker 25).

What is the problem with mathematics anyway? There is certainly no lack of theories in educational literature. Falling standards are often touted as the reason performance in mathematics is declining in national tests. But Frankenstein contends that "the real problem is not 'falling standards.' It is not that most students fail maths, but that school maths 'fails' the majority of students who pass through it – and had always done so" (Frankenstein xv). She claims that most people are angry when they remember how the mathematics they were required to take in school was taught to make it seem so useless and boring (Frankenstein 27). Most the mathematics done is school "bears little resemblance to the activity of mathematicians" (Betts 16).

Many states and school districts have special high schools for mathematics. David Drew, sociologist and educator, sees "their existence reinforces the idea that mathematics and science are not for everyone, and their high degree of selectivity strengthens the perspective that only a fraction of the population has the ability to master these subjects" (Thompson 34). In fact, Drew sees "a more fundamental cause for the failure of United States education: the low expectations we have of our students and, as a consequence, the limited demands we place on them." Drew invokes the famous study at Harvard University by psychologist Robert Rosenthal, more than three decades ago, which showed just how powerful expectations can be. The Pygmalion effect, Rosenthal effect, or more commonly known as the "teacher-expectancy effect" refers to situations in which students perform better than other students simply because they are expected to do so. Rosenthal posited that the behavior patterns and attitudes of teachers had greatly enhanced the performance of the students who the "experts" had told them had extraordinary intelligence, a self-fulfilling prophecy. However, "teacher-expectancy effect" can also work to the detriment of the students who the teacher believes cannot learn the material. "Many teachers who mouth the words 'all children can learn' show little evidence of a genuine belief in the concept in their classroom behavior" (Thompson 41).

In Computational Thinking and Math Maturity: Improving Math Education in K-8 Schools, Dave Moursund asserts that much of the math curriculum is being taught at a level of abstraction too far above cognitive developmental levels of the students. He believes this situation leaves many students to merely memorize and regurgitate information with little understanding of what they are doing. "Such mathematical knowledge is fragile and tends to disappear over time. It provides a very weak foundation for a student's future studying of math (Moursund 68).

Most people find the current math education system is very unsuccessful. Michael Battista summarizes the situation in a 1999 article:

> For most students, school mathematics is an endless sequence of memorizing and forgetting facts and procedures that make little sense to them. Though the same topics are taught and retaught year after year, the students do not learn them. Numerous scientific studies have shown that traditional methods of teaching mathematics not only are ineffective but also seriously stunt the growth of students' mathematical reasoning and problem-solving skills. Traditional methods ignore recommendations by professional organizations in mathematics education, and they ignore modern scientific research on how children learn mathematics. (Battista 1999)

These educators believe all be it for different reasons that mathematics education as practiced in American schools is failing American students. Obviously, I am not the only one who feels that something is wrong and that a change is necessary.

My Philosophy of Teaching Mathematics

My philosophy of teaching mathematics has changed considerably since I taught that first general math class over thirty years ago. When I first became a teacher, and many years afterward, I thought of education as the “filling of a pail.” I actually had a quote to this affect that I kept in my desk for years: "Education free for the taking...Bring your own container." I emphasized the “education” element of learning - education according to Webster: “to cultivate and discipline the mind by teaching.” Surely, if I could only explain the information well enough, the students would have an “educational enlightenment” and grasp the knowledge previously beyond their reach. I learned a lot about teaching and a lot about me that first year, and even more in the decades since. Only after years of experience and frustration, on both my part and the students’, I came to see education as more of educing: “to develop that which is latent.” Now, I have a different quote on my door: “Education is not the filling of a pail, but the lighting of a fire" by William Butler Yeats. When did my concept of education change, why did it change, and what am I going to do about that change

My mathematics education classes did not include readings by Maxine Greene, Paulo Freire or Nel Noddings. Obviously, my undergraduate education predated their philosophies. I completed my master's degree from this very institution. In fact, I had a class with Dr. David Purpel almost thirty years ago. Unfortunately, I was not ready to hear his message. I was still stymied by a conservative home background, a conservative college career and I just was not open to the idea of a different philosophy of education.

Years passed. I left teaching to be home with my children. When I did return to teaching ten years later, I had a different perspective of what it means to be a good teacher. Perhaps becoming a mother had changed my perception of learning. I had three small "students," and I had become well aware of the teachable moment. I emphasized that the students actually learn the mathematics. I allowed the students to retake tests to demonstrate their mastery of the subject. I introduced group learning activities into my classes. I experimented with alternative assessment tools. But I had still not become the teacher I was striving to be. No matter what I tried or how hard I tried some of the students just didn't "get it." Like Judith Sowder wrote in her editorial for the Journal for Research in Mathematics Education, I saw "Something was wrong, and I wanted to be among those who worked on fixing the problem" (Sowder 1998).

So, I returned to the University of North Carolina at Greensboro twenty years later to study for a doctorate in education. At first I considered studying testing. I even visited with the department chair. However, my heart was not in testing. I found it to be just too dry and impersonal. Unsure where to go from there, I went to talk to Dr. Purpel. I'm not sure what I expected Dr. Purpel to say, but I surely was not expecting what he did ask me: "What do you enjoy reading? What do you what to study?" No one had ever asked me those questions before; I had to really ponder those questions before I could answer them. I wanted to study philosophy and liberal arts type courses, classes that I had not studied in depth in my previous educational career. So Dr. Purpel suggested I take the Philosophy of Education course with Dr. Fritz Mengert. What a wonderful class!!! I felt my intellectual juices flowing for the first time in years, maybe ever. I was hooked. I entered the program in Cultural Studies.

I pursued my interest in theology by taking Dr. Glen Hudak's class of Theology and Critical Pedagogy. Although I had taken the course for the theology aspect, I found that the study of critical pedagogy really piqued my interest as an educator. Many of the concepts of critical pedagogy seemed to coincide with the techniques I use in teaching mathematics: listening to the student to determine his perspective, incorporating the student's perceptive into the lesson and structuring the lesson around the student's needs Whereas, I realize that critical pedagogy, as with all theories, is an ideal to be aimed for rather than achieved, I began to see a way of connecting the perspective of the teacher and the perspective of the student through honest discourse and structuring the area of study to the interest of the student. So my philosophy entails an amalgamation and extension of ideas.

Originally, I had several topics that, in themselves, would suffice as the content of a book. However, I realized that I had to narrow the focus of this last chapter. So I decided to address three main topics: the learning environment, making mathematics more relational, i.e., more user friendly, and learning to learn mathematics. I chose these three topics because these are three components I feel that an individual teacher can address most expediently by herself, with the least physical resources and with the most effectiveness for the learner. I will also discuss some strategies I have used successfully in my own classroom practice.

Putting Philosophy into Practice

I wrote a paper for Dr. Hudak's class about mathematics and critical pedagogy; two subjects which are not usually linked. I also asked Dr. Hudak about other writers that he might be aware of that connected the two subjects; he suggested Dr. Marilyn Frankenstein as an educator who linked these two subjects. So, that's how I came to hear of Dr. Frankenstein and her work. I also discovered that I agree with a vast majority her theories. I will briefly discuss Dr. Frankenstein's approach to mathematics pedagogy and outline my own approach.

Dr. Marilyn Frankenstein, the mathematics educator, like Mary Shelley's Dr. Frankenstein breathes new life into a seemingly lifeless body…that of mathematics education. She sees a different math than that usually perceived by students and teachers alike. Where they see obstacles and difficulties, she sees opportunities and understanding. As a radical theorist, Dr. Frankenstein claims that "maths can only be understood as a historical, social, and political construction" (Frankenstein xi) and that mathematics literacy becomes as important as reading and writing. In fact, Dr. Frankenstein argues that you cannot separate reading and writing from the learning of mathematics and in her textbooks she emphasizes all three disciplines as very powerful ways of knowing. She sees the traditional methods of teaching mathematics to be separate from the lives of the students and, actually, from the way mathematicians do mathematics. She further argues that mathematics is communicated in textbooks and in the classroom in this same separate, unconnected, way (Frankenstein 55). Frankenstein's approach involves a redefinition and restructuring of the basic place of mathematics in the school curriculum.

I must say I was very excited reading Dr. Frankenstein's theories. She elegantly articulates the mathematics I know and love: a dynamic, relevant and liberating discipline. I especially agree with three themes that Dr. Frankenstein uses in her approach to teaching mathematics: the use of historical perspective to teach mathematics, the demystification of mathematics by debunking common misconceptions about mathematics, and the role of study and recreation in the learning of mathematics. I will integrate these themes into the three major areas that I will address: the learning environment, making mathematics more relational, i.e., more user friendly, and learning to learn mathematics.

The Learning Environment

> *…in true education, it is always the teacher who learns the most.* - Martin Heidegger

> *How you teach is more important than what you teach.* Robert F. Fiehler

I truthfully had not considered the environment in my own classroom until my daughter was old enough to attend school. When she was about to enter kindergarten, I asked my sister, who taught elementary school, what attribute was most important for her teacher to have. My sister said caring; definitely I wanted my daughter to have a caring teacher. Not only did Katherine get a caring teacher, she got a teacher who created a joyful environment for the students: an excellent catalyst for learning. When I returned to teaching several years later, I remembered my sister's advice, and I tried to be that caring teacher who created a good learning environment in the classroom. What does it mean to have a "good" environment in the classroom? Several elements combine to create that environment. I will discuss only two: the teacher and the atmosphere that the teacher creates in the classroom. I include the teacher as the main agent for both establishing the learning environment and maintaining the everyday atmosphere of the classroom. In fact, the role of the teacher is so integral to the environment of the classroom that I cannot talk about one without the other. The teacher has a myriad of roles in the classroom. She is a performer, an intellectual transformer, and care-giver to name a few. "

Bell hooks talks of teaching as being a performance art. She is quick to point out that teachers are "not performers in the trade sense of the word in that our work is not meant to be a spectacle" (Hooks 11). Rather, the teacher serves as a catalyst that gets everyone involved in learning, gets everyone to be an active participant. She knows that "student involvement is more powerful to success than ethnicity or the academic preparation students' bring with them to the classroom" (Angelo 47). In her role as catalyst, the teacher changes, invents or shifts teaching methods as she reads the class to ascertain their level of understanding of the concept she is teaching (Hooks 11). The teacher fosters mathematics classroom communication by encouraging students to ask questions and to engage in “inquiring dialogue with the purpose of getting to know,” with or without the teacher (Sfard 340).

I also use this same method in all my classes to establish an environment where questions are welcomed and each individual has value and will not be humiliated. I even rehearse with the students how to ask questions in mathematics class: “I don’t understand the question,” or “I was listening but I still do not understand,” or “Could you give another example?” I am always humbled by the number of students who ask me, “Can I ask a question?” Because you have to conclude that they have not felt comfortable asking questions in earlier classes…at least, not math classes.

Not only is the teacher a performer, the teacher also has the role of “transformative intellectual.” Aronowitz and Giroux use the phrase “transformative intellectual” to describe the teacher’s role of “effecting transformation on one’s self, one’s students and one’s culture through one’s teaching” (Davis 153). One aspect of that transformative role is to develop the voice of the students. In order to do that, several things are necessary. One is to “remove the teacher from position of intellectual authority in order to encourage student thought” (Strong 171). That may be easier said than done, because students are taught throughout school that the teacher knows all the answers, especially in math classes. However, the teacher’s main objective is to “empower the student by helping her believe in her ingenuity, creativity…and analytic process” (Skolnick 236), i.e., becomes a mathematical thinker instead of performing memorized algorithms by rote. Another element necessary for students to gain voice is that the student must trust the teacher to listen to her voice. “Knowing one’s voice and using one's voice, particularly from a student's perspective can only happen when there is a relationship of teacher and student that nurtures the development of a student's voice" (Jordan 94). Paulo Freire called this process "problem posing" where the teacher and student talk out what they are thinking (Belensky 219). This new voice is a practice of freedom for it allows students to assume responsibility for their own learning (Hooks 19). The students become independent learners as they are able to read and learn math by themselves (Datta 33).

The teacher is also the care-giver in the classroom. She values the learning of mathematics but she also acknowledges that the student's learning is a "the interplay between students' emotional, cognitive and social reasons for how they choose to engage in mathematical activities" (Hewitt 31). She respects talents and abilities of her students, and she "makes it safe for students to risk themselves in new and different situations" (Noddings 189). She is interested in her student's lives, and she uses her knowledge of her students "to bring the material to life for the students and engage them more deeply" (Sholnick 45). And always the teacher must let the student know that he is always "more important, more valuable, than the subject" (Noddings 174).

In addition to the aforementioned roles, the teacher is the creator of learning environment in the classroom. She sets the tone for the class by her epistemological stance, her assumptions about the knowledge and human behavior (Schoenfeld 174). Mathematics educator Alan Schofield believes that "…what one thinks mathematics is will shape the kinds of mathematics environment one creates and thus the type of mathematical understanding one's students will develop" (Schoenfeld 276). That environment is dictated not only by her philosophy, but also by the actions of the students. Nel Noddings suggests this learning environment should be a caring community of learners that is caring to all, where everyone acts responsibly together to create an interesting class. The students speak but they realize it is important to listen respectfully to others. The learning environment needs a community of learners who help each other by explaining concepts to each other so that both the student explaining and the student being explained to will learn more effectively. The classroom is “a social classroom that encourages student exchanges and shared learning” (Betts 70). The learning environment also needs a community of mathematicians. The students become mathematicians by “making math” instead of receiving math from the teacher or text. During class, I give the students many opportunities to work together to determine answers. For example, the students work with a partner to solve a problem. Then the class “votes” on the answer. Invariably, there will be multiple answers to the same problem. This variance leads to opportunities to discuss the possibility of different interpretations of the problem producing different solutions or how to resolve a situation when students get different answers to determine the correct answer for the situation. And, finally, the learning environment needs a community of growth where each student can grow as a person; a place to share in the intellectual and spiritual growth of students.

Bell hooks elaborates on the meaning of learning community. She contends that “everyone’s presence is acknowledged …and there must be an ongoing recognition that everyone influences the classroom dynamic, that everyone contributes” (Hooks 8). Grau uses the term holistic to describe this type of environment, one that develops the entire whole person. He believes that the holistic approach "can improve academic ability and performance and nurture 'the human spirit'" (Grau 45). Grau further suggests that "students of color, women and older students may be best served by holistic approaches" (Grau 45).

I found an example of a similar learning environment adopted by The Mathematics Department at the State University of New York at Potsdam for over twenty-five years. The department wanted to include more undergraduates in mathematics classes so they admitted students into the course Set Theory and Logic without requiring a placement test. They truly believed the philosophy that everyone can do math, and they acted accordingly. Their aim was to inspire each student to maximize their ability to work independently in mathematics by "protecting and strengthening their self-esteem" (Datta 46). This philosophy proved "especially assuring to female and other minority students" (Datta 32), and Potsdam produced more female mathematics graduates than male graduates in the twenty-three years prior to 1993. The success of this program rested on the dedication and genuine belief of every member of the mathematics department that "It is not the responsibility of students to learn in the style of the professor; it is the professor's responsibility to teach the students in the style in which they can learn" (Datta 84). The school summarized their approach as the Potsdam Way:

> Be kind
> Aim high
> Promote independent learners
> Go fast slowly
> Do not punish: reward. (Datta 128)

Whereas all these suggested elements for creating a model supportive learning environment have been used successfully by many educators, you should select the ones that fit into your personal philosophy of teaching. Many years ago I took a class in cooperative learning with Judy Dixon. I was excited about implementing the ideas into my own classroom so I tried nearly all of the methods the next school year with mixed results. The next time I saw Judy, I told her about my efforts. She said that I should only implement the methods that worked for me. So that reinforces the advice that "…sometimes only selected elements of a desired model can reasonably be translated into classroom practice" (Schoenfeld 277). In addition to the learning environment, making mathematics more relational involves showing the history of mathematics and the fun of mathematics.

Making Mathematics More Relational

> *…to teach math without connecting it with its history is to teach math as if it were dead.* Torkill Heiede, Danish educator

Many students find mathematics to be quite impersonal especially in comparison to their classes such as literature and psychology. One way to make mathematics more relational, that is more personal, more connected and more humanistic, is to use the history of mathematics. In Running Ahead: Aesthetics and Mathematics Adding an Aesthetic Image to Mathematics Education, Paul Betts and Kathryn McNaughton propose that students "should be exposed to the heroic efforts of mathematicians" (Betts, 20). An increased emphasis on biography would bring mathematics "alive" for the students (Kelly 191). Each year I tell my students the story of "The Boy and The Fly," a story about Renee Descartes and his invention of the coordinate graphing system, the x-y plane we all used in Algebra. My students may not remember derivatives or integrals but they always remember "The Boy and the Fly."

Students need to know the historical and cultural influences on the development of mathematics and from mathematics itself (Betts 4). They need to know that "Mathematics, far from being infallible formal knowledge, is a human enterprise..." (Noddings 1985: 130). Dr. David Pengllery of New Mexico State University believes that "…students need to understand the contexts in which math ideas were developed, argued, agreed upon" (Journal 3). Dr. Frankenstein uses cultural history of mathematics to show how mathematics, the science, is constructed in political, economic and social systems. This historical context of mathematics also shows how the mathematical paradigms created by human beings are continually changing to meet their needs.

Cultural trends that influence development is mathematics, such as the development of the computer and cryptography developed from code breaking problems in World War II, can be used to provide the students with "greater meaning to the activity of doing mathematics" as well as the value of mathematics for society (Betts 21). Students can see when they have reinvented mathematical procedures that parallel historical developments. Further, the context of the cultural history also shows students the underlying ideologies which have formed the traditional classroom approach to teaching mathematics. Students begin to conceive of themselves as capable of not only learning mathematics but of making mathematics.

Marilyn Frankenstein's use of mathematics culture combats the common notion that mathematics is useless and boring by situating mathematics and its interrelationships with art and literary culture (Frankenstein 27). Students learn of the mathematical theories that have been developed for purely theoretical, almost esoteric, reasons are slowly assimilated into the general scientific community and later into the larger population. One good example of such a theory is the development of purely imaginary numbers. The Swiss mathematicians Euler defined the square root of negative one to be the number *i*. ($\sqrt{-1} = i$). Imaginary numbers were first theorized so all numbers, even negative numbers, would have square roots. This extension of the definition of square root allowed all quadratic equations to have two solutions directly supporting Gauss' fundamental theory of algebra: a polynomial equation has the same number of solutions as its degree. Today imaginary numbers show up in the equations for the design of airplane wings and in electrical engineering problems; two applications hardly dreamed of when imaginary numbers were defined.

In addition to "The Boy and the Fly," I also use other historical information in my classroom. The very first class meeting I ask my students questions about their understanding of mathematics. Together we redevelop the real number system that they have studied so many times before. I emphasize the way the numbers were "invented" to meet a need. I also present the origin of Arabic numerals and especially the numeral zero: one of the very first technological inventions. When they leave class, I ask them to find out the origin of algebra and how long it has been a subject.

I regularly present mathematicians and their contributions. When I teach calculus, I tell of the great controversy in Europe when England supported Isaac Newton's notation for calculus while the rest of the continent used the notation of Wolfgang Leibniz, a dispute that lasted over fifty years. I tell how calculus was invented to solve the physics problems of optics and motion. It is not a coincidence that when these problems were solved, scientists were able to develop the technology that resulted in the Industrial Revolution. All of these stories make mathematics more human. In addition to using the history of mathematics, the fun of mathematics can be used to make math more relational.

Marilyn Frankenstein uses the creative venues of mathematics from recreational puzzles to "maths-magic tricks, maths-visual-arts, maths-music and maths-poetry" to challenge students' concept of mathematics (Frankenstein 30). She "focuses on the more creative aspects of mathematics, from understanding the structure of the number system to solving and posing complex math problems" (Frankenstein 36).

Bell hooks has some of my favorite quotes ever about fun in the school: "Pleasure in the classroom is feared…to prove your academic seriousness students should be almost dead, quiet asleep, not up, excited and buzzing, lingering around the classroom" (Hooks 145). She also talks about the classroom being an exciting place (Hooks 154). She fondly remembered a "teacher who nurtured and guided me, who offered me an opportunity to experience joy in learning" (Hooks 202). While these statements are true of most classrooms, they are particularly true of the mathematics classroom. Betts and McNaughton noted that J. D. Phillips (1996) "suggested that students should appreciate the creativity, imagination, artistry and pleasure of doing mathematics, in conjunction with the utility of mathematics" (Betts 20). This pleasure of doing mathematics is often missing from the classroom. Ever since the first year I taught school, I have endeavored to bring a little fun into the classroom. I love mathematics, and I want to share that love with my students by letting them see the fun side of math. I have used soap bubbles, candy, puzzles, and games as learning motivators. At my current school, I initiated the celebration of Pi Day on March 14 (3.14). We play games such as "Recite the most digits of pi" and "Draw a circle free hand on the board." We eat real, delicious, homemade pies, sing "Pi" songs and generally have fun. However, my efforts were not always seen as a good use of class time. In fact, one of my former department heads told me that she "didn't play games with her students."

> *You can't learn mathematics, unless you have a teacher who loves math.*
> John Conway

Potsdam also used the fun factor in teaching mathematics:

> Another important strategy the teacher adopts is to teach by the way they behave. They always make it a point to show the students that they love math and that they are having fun teaching it. So, as far as the teacher is concerned; there is never a dull moment in the classroom. This kind of love and enthusiasm is bound to rub off on the kids. (Datta 33)

Finally, I try to show the fun, aesthetic side of mathematics: the weird topology of the Mobius strip or the complexities of a seemingly simple counting game. We view the visual aesthetics of optical illusions or the mathematics found in the art of M. C. Escher. We discuss mathematics in movies, like the Scarecrow's recitation of the Pythagorean

Theorem when he gets his brain in the Wizard of Oz or the prominent role Chaos Theory played in Jurassic Park. With all these techniques, I strive to relate mathematics to the world of my students: to place mathematics in the context of their daily world, in context of their entertainment world, in the context of their other classes, and in the context of their aesthetics world…always offering a powerful way of knowing.

In addition to using history of mathematics and using the fun side of mathematics, an even more important component in helping students learn mathematics is teaching them how to learn mathematics.

Learning to Learn Mathematics

> *Once you have learned how to ask relevant and appropriate questions, you have learned how to learn and no one can keep you from learning whatever you want or need to know.* Neil Postman and Charles Weingarten. Teaching as a Subversive Activity

Renee, Mona, Anna and Sheryl are all very gifted women. They are very academically successful, and they clearly know how to learn. However, the women all acknowledged that mathematics was different from their other subjects; different in the sense that they did well academically in every subject expect mathematics. They were perplexed because the study techniques they used so successfully with other subjects were not working with mathematics. Their experience is not unique. Many students are also perplexed when their study strategies do not work for mathematics. Some students actually panic because they have a sense of "out of control" about their learning in mathematics. Sheila

Tobias labeled that feeling as “math anxiety.” Whereas, some students do experience math anxiety, most students who underachieve in mathematics are just confused because their study strategies do work well in mathematics - up to a point. However, when mathematics changes from memorizing, acquiring facts and using skills to the more complex tasks of making sense and relating mathematics to the real world, many excellent students find their study strategies to be inadequate.

While the students may not articulate their beliefs, they all demonstrate a particular epistemological belief about mathematics: they believe they cannot learn mathematics because their learning strategies are not working. It is at this juncture in their mathematics careers that many students decide they are “not math people.” Most students first notice that mathematics changes when they take a class requiring algebraic techniques, usually beginning algebra. A majority of students take this class in eighth grade or their first year in high school. Not coincidentally, all four women cited their problems with mathematics started approximately at this same time. However, the women did not realize that they needed to change and adapt their learning strategies to mathematics, or they did not know how to modify their learning strategies for mathematics. The students need to a theory of learning that can help them know how to adapt their success study strategies in other subjects to learn mathematics; a learning theory that will change their epistemological belief about learning mathematics.

The learning theories of Bruner, Gagne, Bandura and Vygotsky are well known to all educators from their study of psychology. Many disciplines have a long history of implementing their learning theories in their curriculum. However the processes of learning itself have only begun to be understood and applied more fully in mathematics education in the last two decades, especially as practiced in the classroom. In 2004, the National Science Foundations announced the multiple million dollars funding of Learning to Learn Center that will “focus on the interrelationships among mathematics, language and cognition in the learning process” (NSF abstract). This National Science Foundation project focuses on one learning theory that I have used successfully in my classroom, metacognition.

Metacognition refers to a “person’s ability to predict their performance on various tasks and to monitor their current levels of mastery and understanding” (Bransdon 32). A fundamental tenet is that different kinds of learning goals require different approaches to instruction (Bransdon 42). Alan Schoenfield was among the first educators to recognize that metacognition may play an important role in mathematical problem solving (Schoenfield 1985). Research has shown that this may be especially true for many under achieving learners who have dysfunctional metacognitive systems (Silver & Marshall, 1990).

In Computational Thinking and Math Maturity: Improving Math Education in K-8 Schools, Dave Mousand talks at length about math maturity and math cognitive development, two areas closely tied to the learning of mathematics. He emphasizes that “math development is highly dependent on learning to learn math” (6). In fact, Mousand contends that one of the jobs of a mathematics teacher is “to help your students gain increasing knowledge and skills about how to learn math” (25). Teaching a metacognitive approach to learning would include a focus on understanding and reflection on what worked and what needs to be improved (Bransdon 64). As mathematics classes become increasingly more diverse, teachers will need to acknowledge and cultivate the metacognitive abilities of all learners, and the teaching of metacognitive skills should be integrated into the curriculum.

However, Alison Elliott, of The University of Western Sydney Napean presented a paper at the 1993 meeting of the Australian Association for Research in Education Conference where she lamented that "despite their amenability to classroom instruction, metacognitive strategies are seldom explicated in mathematical teaching" (2). Lerman also believes that "metacognition training is rare in mathematics instructors" (Lerman 746). Consequently, many students do not learn the skills they need to become successful mathematics students.

While I do not claim to do an in-depth study of metacognition in my classes, I do incorporate the teaching of metacognitive skills. I discuss various theories of memory so students can understand how their minds work. I spend much time discussing how to study mathematics, and how studying mathematics is different than studying other subjects. I also developed levels of learning for mathematics after listening to my students' despair about the ineffectiveness of their studying to increase their performance levels on tests. I wanted to develop a tool to help me and my students communicate about their understanding of basis concepts and to help the students assess their own understanding of the concepts. Note that with my levels of learning I pay homage to Bateson's theory of levels of learning as well as levels of understanding by Bloom and

Gagné. I presented a session for the American Association of Two Year Colleges called "Levels of Learning: Communicating Expectations of Mathematics Performance." I present those levels below.

Levels of Learning: Communicating Expectations of Mathematics Performance

Much research has been conducted regarding expectations in the classroom. The Pygmalion effect is the idea that one's expectations about a person can eventually lead that person to behave and achieve in ways that conform to those expectations. Other research shows how student expectations may be more important as a source of influence in student performance than teacher expectation. Clear expectations about the teaching situation leads to better performance. In classroom studies, subjects performed better when they knew which test type to expect. The indication is that different test expectations lead to different study strategies and organizational schemes. Teachers' attitudes and rated competence are affected by their expectations regarding the student, and the students' attitudes are affected by their expectations about the teacher. Obviously, much complex psychology goes on in every classroom.

Students often would come to me after a test very upset by their test scores. "I don't know why I failed the test. I did all my homework, and I got it all correct." I too was puzzled by what seemed to be a contradiction between effort and performance and certainly between student expectation and result. I would console the student and implore her to get more help for the next test and "try harder." I realized my students and I had a communication problem. I needed a method that goes beyond the student's perceived level of understanding. Obviously, the aforementioned students thought they "knew the material" but they did not. The students needed clear expectations for how their hard work would translate into performance on a test. Increments were needed to enable the students to indicate their skill level before testing occurred. For years I pondered this problem.

Then I heard a sports psychologist on the radio one night. He discussed the importance of the correct form of practice for playing golf. He reminded the listeners that golf pros would come to a tournament early in order to play the actual course where the tournament would be played. He said that practicing your swing in the backyard or practicing at the driving range or even practicing on a par three course was not adequate preparation for playing golf on the actual golf course. The only way to have an expectation of good results on the golf course would be to actually play a practice game under the same conditions as the tournament. I had a plan for a method.

I developed a hierarchy of levels of understanding to provide a common language to measure the understanding of a concept. The hierarchy has four levels:

Level One: The student has no understanding of the concept.

Level Two: The student has understanding of the concept while in the classroom.

Level Three: The student has understanding of the concept to work problems with resources.

Level Four: The student has understanding of the concept to work problems without resources.

Let's select "finding the domain of a function algebraically" as the concept to be learned.

John may come to class, take notes and still not comprehend the “hieroglyphics” on the board. He appears to be an alert, industrious student taking copious notes, certainly a potential “A” caliber student. John can “read” the notes he takes; however, he has no clue of how to solve the problem himself. In fact, he did not even understand how the teacher derived the “Voodoo” math on the board. He misses the concept entirely on the test. John has level one understanding of finding the domain of a function.

Jill also takes great notes. She actually understands the problem as it is worked in class, either by the teacher or in group work. However, when she gets home with just herself and the book, her notes are “cold.” Everything looks different. The terrain has shifted and nothing looks familiar. The problem that has looked so easy in class when worked by the experienced professional and helpful classmates now looks like gibberish. Jill can not work her homework assignment even using her textbook and her class notes. Jill has level two understanding of finding the domain of a function.

Marcus also takes notes, and he understands the problem solving in class. When Marcus gets ready to do homework, he refers to his book and notes to use as examples. He checks his answers with BOB (back of book), and, if his answer does not agree, he reworks the problems using his book and notes as resources to determine the difficulty. With diligent effort, Marcus completes most of his assignment successfully. Marcus has level three understanding of finding the domain of a function.

Maria takes notes, understands the class explanations, and completes her homework without using her textbook or her notes. She definitely feels confident of finding the domain of a function. Marie has level four understanding of finding the domain of a function.

When John, Jill, Marcus, and Maria come to the test item about finding the domain of a function, only Maria can have an expectation for good results. John, Jill, and Marcus have never worked the problems without their references so they will be lost on the test, and they will answer the question incorrectly, if at all.

Now I have a communication method to help my hard-working students. I can ask them daily what their progress level is for the class objective. While I do not claim to affect math education with these levels as Piaget has affected psychological theories with his stages of intellectual development or Belenky has affected feminist theory with her "Women's Ways of Knowing," I do feel a satisfaction I being able to have a unambiguous communication method to help my student's align their expectation of test results with their level of understanding of the concepts being tested. When a student tells me she is at level two-and-a-half on a concept, I realize she needs more help, and I can direct her to additional resources outside of class: individual help in my office, group tutoring, study groups or a study buddy. Now, when Barbara comes to take a test, and she says she is at level four on everything, she and I both know she can expect to do well. In fact, Barbara made an "A" on that test.

I suppose I need to point out Anna, Sheryl and Mona were in my classes before I developed these levels of learning. I believe they are exactly the students who would have benefited most from studying metacognition skills.

Conclusions

In this dissertation, I started out to answer the question, "Is mathematics truly so different to learn than other subjects, especially for women?" I believe I have accomplished that goal. I explained why math is hard to learn, and I enumerated the obstacles that women had with learning mathematics. When I analyzed the narratives of the four gifted women who underachieve in mathematics, I found four shared themes in all of the women's stories. First, they had the perception that their schooling in mathematics was inadequate in some way. As seen through the student's eyes, the mathematics education system had failed them. Secondly, they expressed their need to take mathematics. Whether they needed or wanted to study mathematics or not, they felt the obligation take mathematics to fulfill an academic requirement. Third, they realized that mathematics was different to learn than other subjects. Although some of the women could not articulate what made math different to learn, they all recognized a difference and, finally, they participated in negative self talk about mathematics. Their negative self talk contributed to a lessening of their confidence to learn mathematics. All of these themes echoed obstacles that I enumerated in chapter two. In addition of these common themes, all four women also shared a similar time when mathematics had become a problem, early adolescence.

I hope this dissertation will contribute to a better understanding of what the women themselves perceive as their problems with mathematics. By giving the students a voice, I have pointed out areas that educators can target in working with female students. Earlier in this chapter, I related practices I use in my classroom to make mathematics easier to learn and more interesting to learn: the learning environment, making mathematics more relational, and learning to learn mathematics.

Despite its accomplishments, this dissertation has it weaknesses. The nature of the data, i.e., interviewing only four women, limited the scope of the findings. Using more interviews would add another layer of interpretation. Also, journals could be used for a longitudal study. However, more interviews and/or more types of data gathering techniques would also greatly increase the time frame for completing an already time consuming analysis of the data.

To ask well is to know much. Arab proverb

Finally, from my investigations further questions are generated that present many opportunities for future research. In addition to mathematics teachers, are mathematic counselors needed to help students navigate the labyrinth of students' mathematics requirements? Should metacognitive skills be incorporated in teacher education programs? Could the history or philosophy of mathematics become a mathematics course in the standard secondary school curriculum?

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