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Math as Text, Rhetoric as Reason: Can the Humanities Save Math Education?

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Abstract

As a student I had always struggled hopelessly with math. I noticed many of my classmates and associates outside of school shared similar experiences with this subject. However, a unique convergence of fortuitous circumstances shed some much needed light on my difficulties with math. Using a creative and communicative approach, I was able to analyze my experience from a rhetorical perspective, which allowed me to see more clearly, not just the problem I was having with math, but the overall problems many seem to have with math education. My findings were astonishing and became the subject of my research for my honors college capstone thesis.

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Introduction

As one of the suffering multitudes who can cite traumatic experiences in the math classroom as significant factors in life path and education, an analysis of the subject of math education practices and outcomes has proved not only illuminating, but personally validating. Conversations on this topic play out with an almost startling consistency, as the experience of so many students taking math seem to point to a wide-spread issues within the professional and practical culture of math, math education, and the associated disciplines of science and engineering.

This thesis is a forensic autoethnography, a first-person post-mortem investigation of an extremely challenging educational experience with the subject of math, and an extraordinary first-hand discovery that elicited astonishing results. That discovery was based on an approach to mathematics from a rhetorical perspective, a communicative litmus that, to my knowledge, has never been attempted before. I found that by enlisting the principles of effective communication, I was able to deconstruct the math operations, and, as a result could use communication principles to reframe how it could be more effectively taught. Throughout the process, I was able to draw from a unique set of skills and experience in other disciplines such as music instruction to recognize parallels in causality and clarification.

The project was grounded in a multimodal space, initially composed in four parts, with each phase posted to a designated blog space as an online work environment from which my research director could give feedback and offer suggestions during the process. This repository served as a digital record of my compositions, illustrations and other media, which, as the print document took shape, was a valuable outline of the narrative thread as it emerged.

- Chapter one is intended to situate my experiences within the context of the analysis, and to establish ethos as a professional within the comparative discipline of music and music instruction. This parallel offers a crucial triangulation point in understanding the similar processes and practices shared by both music and math education.

- Chapter two is the introduction to how my experiences with music and math converged to illuminate the cultural dynamics at work. A fortuitous meeting with a math education professional and reformist confirmed these observations, and served to break down the cultural barriers that were obscuring a clear view to possible solutions. This empowerment, while absolutely the most important moment in the process, was not a stand-alone solution to my problems with math.

- Chapter three I elucidate on the application of some of the creative and rhetorical skills that eventually led me to design a new math education methodology for myself. In this chapter, the principles of rhetoric and effective communication upon which the application of these skills relied are outlined and discussed.

- Chapter four discusses the cultural collisions and power structures I have observed throughout my experience, and I share a real-life example of the rhetorical process of my method in its infancy.

It is my intention to convey in the most pragmatic terms a retrospective autoethnographical analysis of what was for me a life-changing discovery that could be of use beyond the scope of my experience alone.

This thesis is viewable in digital multimodal form at: www.mathastext.com

A note on how to read this document

In reading this document, it is presumed that the well-documented issues in math education are understood by the reader. It is also presumed that the reader possesses a basic understanding of the Greek classical foundations of the academic model and the interdisciplinary structure of the trivium (grammar, logic and rhetoric) and quadrivium (geometry, music, arithmetic and astronomy) which make up the seven original liberal arts. It should be understood that this model is based on the intersection of these disciplines.

It is also presumed that the reader is familiar with the basic arc of history in math and science and understands the salient points within the chronology of that history. The identity of math as the practice of measurement and the relationship between math and science are implicit as these practices are inextricably linked. The reader should also have a basic understanding of language and the basic functions of language and communication. There should also be at least a cursory understanding of Aristotelian and Platonic philosophy and definitions which provided the foundational architecture of modern thought.

Understanding the terms and the value systems at work

The author will make several points that illustrate the implied diametric relationship between math (numbers and science) and creativity (art and language) with the latter including a focus on rhetoric, communication, and linguistics as practices within the humanities.

Representative terminology for math and science may include: number, numeracy, measurement, operation, computation, engineering, metrics, materialism, physical, empirical, scientific method, quantity, positivist and natural sciences. The central principles associated with these disciplines may be expressed as observations of the physical world confined to what can be measured, and the empirical constraints of the observable world as the boundary for consideration by math and science. These disciplines are generally concerned with measuring what is observable in the physical world.

Representative terminology for the rhetoric and the humanities may include: arts, communication, rhetoric, creativity, literature, aesthetics, quality, language/linguistics and social sciences. The central principles associated with these disciplines may be expressed as the ability to use language to inform, educate, discuss and reason in context; building, decontextualizing and abstracting definitions and meanings to develop creative and innovative lines of thinking related to the relevance of empirical data within a contextual scheme. The non-exclusive consideration of all data, including what is or may not be observable, is essential to this process of understanding. These disciplines are often concerned with contemplating what is possible.

Logic will be discussed as a nodal point between its classical definition within the trivium, and the modern appropriated definition within mathematics.

The focus of the paper is to define these diametric concepts in order to illustrate the value of the intersections between them. Of particular interest is the author’s bias toward the arts and the virtues of the trivium – grammar, logic and rhetoric, and the diagnostic role of rhetoric in the discovery and development of a new methodology for teaching and learning math. The secondary effects on the practices and education of science and engineering are discussed here as a matter by proxy. The author speaks with inexorable candor on her own struggles with mathematics, and discusses with sobering frankness the findings of her research and related premises, and the culture and causalities that appear to be related to the difficulties so many students encounter in math classrooms.

In the interest of efficiency, where necessary, definitions of terms are included within the text.

Chapter One

The Student Who Teaches: Experience and Perspectives in Education and Learning

I have been a professional musician for most of my adult life, performing, writing, recording and managing a music career spanning more than 20 years. I have been playing guitar since the age of five, and I've garnered a good following based on my ability to do so with exceptional proficiency.

I am, by definition, self-taught, which is to say, outside of seven or eight private lessons scattered over many years, I received no real formal training or education in music. I learned to read traditional music notation in the fourth grade playing trumpet for a short time in the school band. But, being already proficient on another instrument, I found the music reading process clunky and counter-intuitive for actually making the kind of music I was interested in. I learned much faster by ear, and under my father's informal tutelage I became immersed in a variety of 20th century American music and well-versed in the techniques of the instrument and the philosophies of thoughtful musicianship.

Figure 1. Georgia Music Hall of Fame feature article and Liz Melendez CD and video releases, a graphic collage by Liz Melendez.

The result was I became a notable musician, and I'm very proud of my accomplishments as a guitarist, vocalist, songwriter, producer and bandleader. For nearly a decade of my career I supported myself almost exclusively as a musician. Living modestly, my creativity paid my rent and then my mortgage during that time. Once the recession made it clear that my years of supporting myself as an artist were over, I had to entertain other options like teaching music.

The Teaching Path

I found that teaching music came very naturally to me, and in many ways I enjoyed it more than performing. The opportunity to pass on what was so richly given to me in order to help students foster their own relationships and experiences with music has led to some of the most rewarding experiences of my life.

Almost immediately, I found that demystifying the music material and empowering the student revealed a new artistic path to them. Many people I’ve spoken to on this subject are under the misapprehension that music requires formal training and is exclusively a product of reading and reciting music notation. My experience and the experience of countless other professional musicians I’ve worked with over the past two decades certainly contradicts this myth. Yet, scores of people are systematically dissuaded from ever learning to play an instrument. They are frightened away by the cryptic and confusing notation taught by instructors, most of whom were taught the same way, hammering home the mythos that music is an exclusive experience reserved for the a select few who read music. As a musician, and as an artist, I have always found this myth utterly elitist, and I take every opportunity to debunk it.

Resetting Possibilities and Empowering Students

As a music instructor, much of my work often involves eradicating, as much as possible, the past damage in potential students caused by their previous experiences with instructors. In my studio, students are relieved to learn, that reading music is absolutely not a requirement, nor is it a “gate” through which one must pass before being permitted to learn to play an instrument. I use books for some exercises and I teach students the basics of note reading so they never have to fear encountering it. I then assure them it is not likely they ever will encounter it, often referring to traditional music notation as the “algebra of music.” It is merely one written form of music language. As a written language it is limited, cryptic and unnecessarily confusing. In this way, music notation can be compared to the confusing math notation found in algebra. Like math notation, traditional music notation is not written in the language of the people – a mechanism which seems designed to keep the aspiring beholden to the music papacy for access.

Like algebra, note reading has its uses. It is necessary in certain settings such as but not limited to:

- *academia* – if you're going to teach music in an institution, you have to know how to read traditional notation
- *playing piano* – nearly all piano music is written in traditional notation
- *playing in a symphony* – classical music is written in and requires reading of traditional notation
- *performing with a jazz group* – jazz and jazz standards are nearly always written in traditional notation
- *professional/studio work* – if you plan to be a musician-for-hire or hope to work in a recording studio, the work you will be given will often require you to read traditional notation

Traditional music notation is almost never encountered in any useable way outside of these situations. I find that most people who want to learn to play an instrument have much more informal aspirations. A few have more serious aims, and, in those cases, we set goals appropriate for that musical path. But most, nearly all, just want to play for their own creativity or enjoyment, or they want to participate in their community groups, churches or with friends or family who play together. And they have been given great anxiety about taking up an instrument by elitist myths and past experiences. I assure these students that in 20 years of performing, touring and recording, I have achieved master-level proficiency and, although I am musically literate, I have never found reading traditional music notation necessary. Most of them are so thrilled to learn this that they approach the instrument with a fresh sense of freedom, confidence and optimism. Obviously, most will not become the next Jimi Hendrix or Eric Clapton. Not all will be willing to invest the necessary time to learn and grow. But whatever course a student chooses, they are free learn without some oppressive or spirit-crushing mythology unnecessarily placed on them. If they do not become the next Hendrix or Clapton, it should be on their terms, based on how much they commit to practicing and learning. A student should never be blocked by the myth that reading music notation is the only pathway to the music experience.

When debating this issue I often ask people who they feel was the most influential music outfit of the 20th century. Nearly all of them give the same answer: The Beatles. And I agree. A more influential contemporary music group one cannot find. The most iconic, prolific and inventive musical geniuses of the last century, who shaped our culture in ways that transcend music and art, universally recognized as musicians and artists of the highest order – did not read music.

Figure 2. Paul McCartney interview, Source: https://youtu.be/ca_GCvApODg

Universality in Holistic Teaching Philosophies

Someone recently mentioned the Suzuki Method of music instruction to me so I looked it up. According to the suzukiassociation.com (2016) website:

> More than fifty years ago, Japanese violinist Shinichi Suzuki realized the implications of the fact that children the world over learn to speak their native language with ease. He began to apply the basic principles of language acquisition to the learning of music, and called his method the mother-tongue approach (About the Suzuki Method, 2016).

Suzuki correlates the linguistic effectiveness of children learning to speak before learning to read, with building some basic mechanical facility to produce tones (speaking) on the instrument before learning to read music notation:

> Children learn to read after their ability to talk has been well established. In the same way, children should develop basic technical competence on their instruments before being taught to read music (About the Suzuki Method, 2016).

The Suzuki Method, sometimes criticized by those who are invested in the rigors of the music myth, remains a highly regarded and widely instituted method for teaching music and many who have learned by this method report very positive and effective results (About the Suzuki Method, 2016).

The similarity between the holistic model of my teaching method and a method founded decades earlier and half a world away points to the universality of this organic taxonomical structure for teaching language-based concepts. The kinesthetic experience of producing relatable tones and phrases often inspires and promotes the desire to continue on the instrument. A student discovers music within the development of the mechanics and the residual experience of producing relatable tones and phrases, not by mindless direction to read and recite notation. In discussing the possible correlations between command of spoken language and written language, Harvard cognitive scientist and linguist Steven Pinker (1997) says in his foreword to Diane McGuiness's book *Why Our Children Can't Read and What We Can Do About It: A Scientific Revolution in Reading*, "Children are wired for sound, but print is an optional accessory that must be painstakingly bolted on" (Pinker, as cited in McGuiness, ix). This idea could point to a linguistic, cognitive and scientific foundation that may be at the heart of these successful approaches to teaching music.

The Myth of the Performer

Nearly all of my students with previous experience on another instrument, violin for example, can read music notation but have no idea what any of the notation actually means beyond "this symbol means I put my finger here." When I asked one of them if any of the music theory we talk about in my studio was ever taught to her previously on the first instrument, she looked puzzled and a little nervous, saying, "Not really." I have had similar conversations with other students. They are taught to recite and to memorize movements. They are taught nothing about how music actually works or the aesthetics behind why we choose the notes and chords we do on our instrument as a part of a musical language in concert with other instruments. They are taught nothing about the art of music. In my teaching studio I often note the difference between a phonetic understanding of a language, similar to those found in travel booklets people use to sound out basic phrases when visiting a foreign country, and true fluency of a language. Travel books teach the user to sound out sentences without any understanding whatsoever about what the sounds represent, the relationship to the written form of the language or how meanings are attached to the sounds they are making.

Using the phonetic example, it could be asserted that recitation of notes on a page without the associated linguistic comprehension is not actual music any more than the sounding out of syllables from a travel book is actual Italian. This would likely be a heretical statement in some elitist musical circles within which such limited demonstrations have been overly accredited. But, in reality, recitation of notes on a page is nothing more than a technical demonstration of the ability to read notes and recite them on an instrument. Performances based on reading notation are called “recitals.” People who take the traditional path to learning an instrument, are often *only* able to play notes if they are written on a page. They are never instilled with the linguistic features that make music fluency possible. For them, the music lives only in the written form, or in the memorization of what is written. One can imagine this is tantamount to not being able to speak unless what you want to say is written on a sheet in front of you. My professional experience with this as a musician and a band leader has been unfortunate, as the limitations of a recitation-dependent performer renders them unemployable in any situation where genuine musical fluency is required. It is my expert opinion that one can only really call himself a musician if he is able to compose, that is, to construct, deconstruct and reconstruct musical pieces, ideally in an extemporaneous or improvisational context. Ideally, a musician should be fluent enough in the language of music to speak, adapt, compose, and transpose, in real-time, the way one uses words. Anything less is to relegate oneself to the role of rote technician, which is unfortunately the litmus used by many in the music community.

For many of us with an informal background, music becomes a form of speaking. Playing an instrument is an expression, using technical ability to communicate musically with an audience and with your peers presenting the music with you. We learn about keys and chords and scales and harmony and melody and tempo from the examples of these concepts in our favorite music. The immersion of hearing and learning builds a holistic and narrative understanding of musical structure. The affection for songs and artists we love drives a passion to understand the language they are speaking – the language of music. We recognize that, like speaking, there is a lexicon to each genre and many genres share forms and phrases on common. These syllogistic connections facilitate the recursive heuristics of our experience which builds our fluency quickly and intuitively. Much in the way Suzuki (2016) describes the way humans learn to speak fluently before learning to read, through immersion and imitation, associating inflections and contexts with meanings, we develop the musical equivalent (About the Suzuki Method, 2016). In that scheme, traditional notation becomes merely a basic and, many times, limited documentation of a piece of music.

This is Not a Pipe

Semanticist Alfred Korzybski (2010) famously states in his seminal work *Science and Sanity*, which has mercifully been condensed into the volume *Selections from Science and Sanity*, "The map is not the territory," which quite literally frames the idea that a representation of something is distinct from that which is being represented (Korzybski, 2010, p.80). For example, in René Magritte's painting, "The Treachery of Images," the words Ceci n'est pas une pipe, "This is not a pipe," provoke the consideration of Korzybski's assertion. This is not a pipe, this is a painting of a pipe, which is distinct from the actual object and its experiential relevance. More accurately in this representation, this is an imprint on paper of a digital image, of a painting of a pipe. Understanding the sophisticated layers of such medial abstractions gives intellectual depth and dimension to information, symbols, meanings and objects.

Figure 3. "The Treachery of Images" by René Magritte. Source: Wikipedia

As Alfred Korzybski (2010), and Shinichi Suzuki (2016), could attest, music as it is expressed on the instrument is as distinct from the representation of music in written notation as the object of the pipe is from the painting of the pipe or as speaking is from the notation of the written word. These concepts can and do exist independently, and one should not be mistaken for the other (Korzybski, 2010, p.80)(About the Suzuki Method, 2016). So the myth of the performer isn't so much about how well but what he or she is actually demonstrating. Often a good performance can include a demonstration of reading and reciting. This may be rewarded in any number of ways, and it should be. It is difficult and can take years of practice to master. But for the hierarchies within the music world that set standards and definitions, traditional music notation and the reading of it have also come to appropriate the identity of the musical art form. They have made the map the territory, and the reading of the map has supplanted the physical reality and experience of the territory itself. Consequently, a great deal of myth and confusion has formed about what music actually is. As an accomplished professional in this field, I define music as an artistic expression of the tonally spoken language called music, which is distinct from and only conditionally associated with the technical ability to read traditional music notation.

The Argument for Reading and Recitation

“Reading and writing in language is important” is the argument often presented in this debate. It is only, however, when what will or can be written becomes infused with meaning, allowing the reader (and writer) to develop a fluent comprehension of the language, that reading becomes useful and relevant. In this context, the notation of a language makes sense for what it is: documentation. Conversely, the argument that “a student can get by in life without learning to read and write, but it limits their possibilities in life” appears to be where the literacy metaphor and the music metaphor diverge. As a matter of necessity and function for a human being, it is absolutely essential to the success and survival of the individual to master spoken and written language. In this regard, music is more like sports. Jordan Ellenberg (2014) makes an interestingly similar comparison between sports and mathematics in his book *How to Never be Wrong: The Power of Mathematical Thinking:*

> If you want to play soccer for a living, or even make the varsity team, you’re going to be spending lots of boring weekends on the practice field. There’s no other way. But here’s the good news. If the drills are too much for you, you can still play for fun, with friends. You can enjoy the thrill of making a slick pass between defenders or scoring from a distance just as much as a pro athlete does (Ellenberg, 2014, p. 5).

Most people who pick up an instrument are not trying to make it to the “varsity team”. Unfortunately, however, whether it is for self-fulfillment or some higher goal, all students are beat up with the rigors of an elitist “one true path” mantra that dictates note reading as the skill required for entrée into the sacred and mysterious realm of music. Some of them, like myself, may learn to read traditional notation, but find it highly impractical for applications outside of specific areas, like academia or symphony orchestra. Even if at some point a student would like to take their musical pursuit more seriously, one would be hard pressed to find a pedagogical justification for employing an unnecessarily dispiriting model for teaching music. I believe everyone who becomes great at something makes their beginning by establishing a relationship of true affection with the pursuit, and then has that affection nurtured, refined and directed not by mindless and arbitrary rigor, but by a conscious and discerning cultivation based on bolstering that individual's strengths and addressing their weaknesses. Helping people achieve their goals in a manner commensurate with the requirements related to those goals serves a better purpose than beating all students down with the same antiquated and draconian standards that will apply to almost none of them and does nothing to evolve the art form.

The Math Issue: A Parallel Experience for a New Future

Around the time I began teaching music, I made the decision to go back to school. My past struggles with math would come back to life and I would eventually register and either fail, switch instructors or withdraw from college algebra five times. As I will talk about more in a future chapter, I discovered the cause of my troubles with math and developed my own method for learning the subject, finally passing it with confidence on my sixth attempt with a B.

In the post mortem, as I am analyzing the process I used to conquer math and researching how math is taught and the measures educators are taking to improve it, I recognize a very significant parallel between the musical experience and the math experience. In each I see opposing perspectives, elitism, and hegemonic wrangling, and I believe that has had everything to do with my ability to recognize the problems that arise for so many in the math education experience. Some key parallel factors I have observed are:

- Overemphasis on notation and rigorous notation-oriented exercises which are not contextualized in any way
- Dogmatic adherence to the belief that notation is music/math and reciting notation off the page is the only path to musical/mathematical experience
- The myth of the performer
- My own holistic mastery of the instrument and success with math *outside the bounds* of these widely accepted fallacies

The development of my own musical abilities is my first proof that traditional misconceptions of what a subject is and how it must be taught can be completely false, and that those misconceptions can lead to unnecessary confusion for a student.

Mathematician Paul Lockhart (2009) addresses similar misconceptions in his well-known book *A Mathematician's Lament*. "Technique in mathematics, as in any art, should be learned in context" (p. 41). Much the way Suzuki advocates mechanical interaction with the instrument to build tonal facility before notation is introduced, Lockhart (2009) advocates students' mathematical forays of invention and creativity prior to engaging in the notation and operational language (Lockhart, 2009). Throughout *Lament* Lockhart (2009) emphasizes the unimportance of memorizing notation and formulas in learning of true mathematics (Lockhart, 2009). His scathing analysis illuminates what he refers to as the "soul-crushing" effects of overemphasis on notation and technical performance on the imagination and creativity involved in true mathematics (Lockhart, 2009, p. 21).

What I call the myth of the performer in music is represented in *A Mathematician's Lament* as Lockhart (2009) condemns the erroneous intellectual hierarchies created by the myth of the performer in the math educational system:

> Those who have become adept [at math] derive a great deal of self-esteem from their success. The last thing they want to hear is that math is really about raw creativity and aesthetic sensitivity. Many a graduate student has come to grief when they discover, after a decade of being told they were "good at math," that in fact they have no real mathematical talent and are just very good at following directions (Lockhart, 2009, p. 31).

Forty years of musical learning and experience in a number of other fields are the wells from which the fundamental wisdom of my discovery in math education has sprung. The perspective of one as a syllogistic parallel to the other is actually a concept that, if necessary, could probably be expressed mathematically in a future thesis. However, the math and math education communities are not the target audience for the methodology that will result from this work. The message associated with my project is directed at people, like me, who have suffered unnecessarily with the subject of mathematics, and, for whom, this message will be validation for the intelligence and reasoning at the heart of their effectively non-mathematical ways of knowing and learning.

Going forward, this parallel between music and math education would prove very illuminating, as math was about to become a very important part of my creative and academic life.

Chapter Two

Conversion vs. Convergence: Dogmatic Limitations in Math Education

I spent the last 30 years believing I was bad at math. I was good at almost everything else I've ever tried to do, but struggled hopelessly with this subject. If memory serves I failed high school algebra at least twice, finally passing it in an after-school program. Ultimately, I dumped my college track and asked my counselor to give me a schedule that would get me through high school without having to take any more math. I have heard similar stories from people who have also had negative, life-changing experiences with this subject.

After the recession in 2008 made it much too difficult to remain strictly an artist, I took the opportunity to finish my education. I reentered school, now decades after my previous math traumas, but I knew the key master, algebra, would be there waiting for me. I would have to pass college algebra if I wanted my degree. But before they would even let me near a college algebra class I had to take two remedial pre-algebra courses. I had my share of trauma with these and ultimately ended up with a D in college algebra. Twice. I was completely resigned to the fact that the problem must dwell within me somehow. I could tell the material was not difficult. I understood very complex mathematical concepts and could discuss them in a variety of contexts, but I couldn't perform well in math classes. After countless tutors, videos and visits to the school's math lab it seemed that nothing worked.

Figure 4. Math as Text introduction, My Story, a video by Liz Melendez. This is s screenshot for a modal video piece I produced to introduce the subject of my research.
https://www.youtube.com/watch?v=Ugs9embHXG4

It was particularly disconcerting that I was basically a straight-A student, on the Dean's List, but just could not get past the math part of my course requirement. It was as if there were some invisible veil between me and the material that obscured the information and the disconnected numbers and symbols, swirling the operations into convoluted spirals of confusion. I'm a smart person, but for some reason this subject as it was presented just didn't make sense to me.

A Chance Meeting

In the summer of 2014 I had the good fortune to meet Dr. Dottie Whitlow when she and her husband Ed appeared in my teaching studio for ukulele lessons. When, during the introductions, Dr. Whitlow said she was a retired math teacher, my face could not hide my disdain for the subject. She revealed that nearly everyone one she talks to has the same story I have. Then she said the five words that would change my life: “It’s not you. It’s them” (personal communication, August 4, 2014).

It turned out, intentionally or not, the game was rigged. The failure did not reside within the students, but within a fundamental dysfunction and misunderstanding of how to best teach mathematics. Dr. Whitlow shared countless stories of her work as a professional educator, reformist and teacher trainer who had dedicated most of her career to meeting this problem head-on. She explained that the problem is systemic. It is prolific. And, according to her, efforts to remediate the problem are met with resistance and outright hostility within the math education community (personal communication, August 4, 2014).

No wonder this subject seems difficult to so many! So what now, I thought to myself.

I was studying rhetoric at Southern Polytechnic State University at the time. As an English and Professional Communication major I was able to view the educational process I was experiencing from a communicative and rhetorical perspective. This illuminated the entire problem as a rhetorical failure: a fundamental failure in communication and a widespread misunderstanding of the subject itself which had propagated a breakdown in math education. Once the problem had been located and identified, I realized I happened to have the unique blend of life skills and experience to know how to deal with it.

This rhetorical diagnostic experience would eventually become the topic of this honors capstone thesis. It will be discussed in more detail in future chapters, but rhetoric and the rules and principles of effective communication played a key role in this process. The focus of this chapter will be the illuminations and elucidations on the dynamics at work in the area of math education and the people who struggle with the subject like I did. I want to debunk the myths and expose the underpinnings of the problem from the perspective of someone who has solved it, for myself, and potentially for others too. This will set the stage for understanding, at least partly, how I did it.

The Myth of Absolutism in Logic and Reasoning

In the previous chapter, I discussed the myths associated with music and music education. I drew some parallels between music education culture and math education culture. Now I will expound on how the myth of absolutism appears in math culture as a rigid appropriation of the concept of logic by the mathematics community. I will briefly discuss the history of this appropriation and the possible impact it has had on math education.

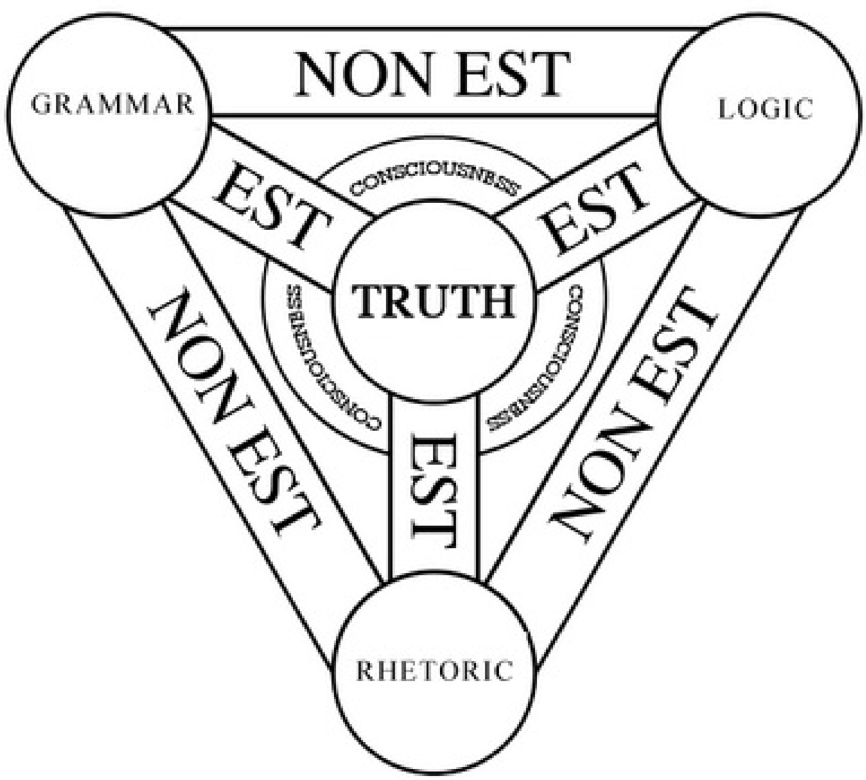


Figure 5. Shield of the Trinity representation of the trivium. Source: Wikipedia

The figure above is an illustration representing the trivium branch of the original academic model for the liberal arts which included logic, grammar (language), and rhetoric.

In his essay *What Logic did to Rhetoric,* philosopher Ian Hacking (2013) recognizes logic in its classical form, reminding readers that logic originally involved linguistic and rhetorical devices and employed various forms of reasoning such as inquiry, discussion, investigation, argument, proof and conjecture to elicit some empirical truth (Hacking, 2013). He discusses the point at which the mathematics community appropriated not only the terminology, but the concept of logic as a singular and synonymous term for mathematical theory:

> Mathematics and Logic had almost nothing to do with each other until the middle of the nineteenth century. By the end of that century there arose the logicist thesis, that mathematics is logic, pioneered above all by Gottlob Frege (1848-1925) towards the end of the nineteenth century (Hacking, 2013, p. 428).

Hacking (2013) continues to discuss the contrarian positioning of mathematics with rhetoric from the co-opting of some fundamental principles of Aristotelian rhetorical proof, to the inklings of a movement seeking to eliminate non-numeric forms of reasoning like rhetoric:

> When I speak of logic driving out rhetoric, I mean logic as driving out the conception of reasoning that is manifest not only in Rhetoric but also in Topics…. This is often regarded as contempt for induction, but in my opinion, and that of Arthos (2003), argument from example is something else, which is still undervalued in modern discourse (Hacking, 2013, p. 420).

The myth here lies in the divergence between math and the humanities imposed by this appropriation of logic. The implication being that math and science alone are the legitimate empirical forms of reasoning and everything else, art, language, the humanities, are discarded in the slough as dalliances that are interesting to consider, but ultimately deemed valueless to the function of reasoning.

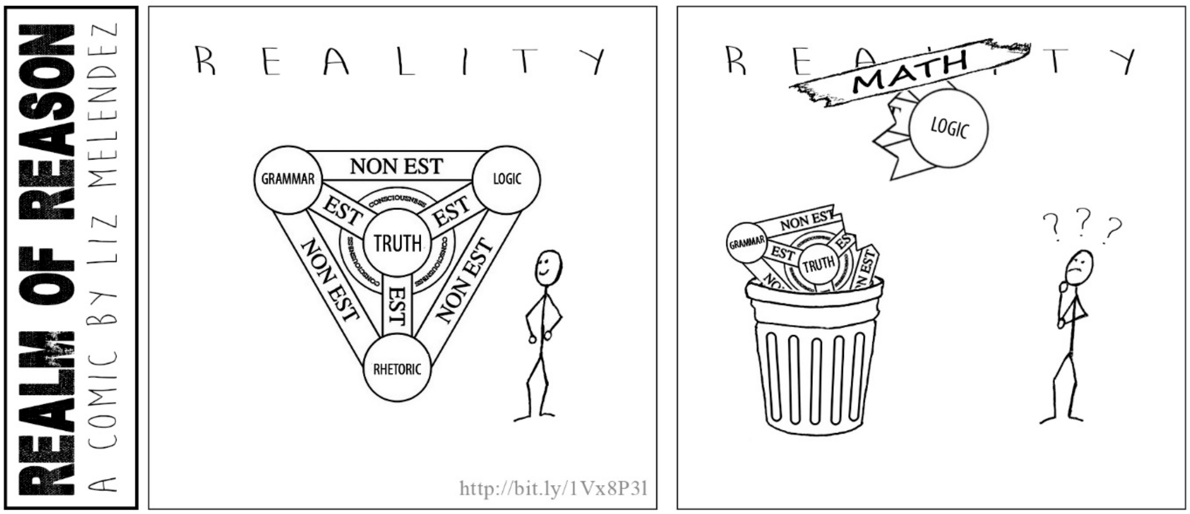


Figure 6. Realm of Reason, a composite illustration by Liz Melendez.

Induction, in the rhetorical sense, is the dialectic process by which an investigation of facts may be introduced, discussed, argued, validated or challenged. However, concurrent with the appropriation of logic as a synonym for mathematics described here by Hacking, the process of induction from rhetoric becomes re-introduced as mathematical induction, or the absolutist positioning of metric evaluation in reasoning and investigation. This re-definition dispenses completely not only with rhetoric but with the rhetorical structures which, particularly in the modern sense, can provide the foundational inductive context for the material relevance (logos) of mathematical data.

Qualitative and Quantitative Collisions

In his seminal work, *Number: The Language of Science*, written in 1930, famed mathematician Tobias Dantzig (2007) extrapolates at length the virtues of metric superiority as a demarcation in the evolution of reason moving in a decidedly mathematical direction. Classical Greek investitures in mathematical schools of thought are acknowledged by Dantzig, but stridently diminished. In acknowledging the classical aspects of reasoning, Dantzig (2007) squarely comes down on the side of materialist constructs of symbolism essential in mathematics. “Greek algebra before Diophantus was essentially rhetorical. Various explanations were offered as to why the Greeks were so inept at creating symbolism” (Dantzig, 2007, p.82).

Dantzig (2007) goes on to celebrate the Greek mathematician Diophantus for successfully developing an “abstract” form of representational reasoning, and seems in my estimation to reverse the values of what is “concrete” and “abstract” perhaps for the purposes of exalting purely metric forms of analysis. “Greek thought was essentially non-algebraic, because it was so concrete. The abstract operations of algebra, which deal with objects that have purposely been stripped of their physical content, could not occur to minds which were so intensely interested in the objects themselves” (Dantzig, 2007, p.83). It seems strangely converse, that number and measurement, which are very basic symbols of the metric attributes of some physical object or relationship, would be considered the abstract, while the arguably unquantifiable rhetorical aspects of discussing the relevance of the same physical object or relationship are considered the concrete.

Dantzig preens that the abstract virtues of mathematics strip objects of their physicality. However, mathematics as the language of science empirically requires strict adherence to the realm of what is physically observable. This peculiar intersection is of particular interest when considering how the boundaries of scientific study and mathematical rigor are defined. Where those boundaries are unclear, it seems exceptions are arbitrarily biased and fall inside the boundaries of empirical scientific method. So, it appears there is room for interpretation in how the investigative usefulness of mathematics can be applied and abstracted, but that interpretation has been partitioned to exclude logical arguments and rhetorical examination that might impart relevance and context.

This early 20th century attitude might explain the parochial tenor of so many books written afterward about understanding math. In John Allen Paulos' book *Innumeracy*, the posture of mathematical dominance is evident as an overriding theme. Paulos (2001) attributes the sway of media scares, pandemics, susceptibility to stock scams, belief in miracles and astrology, to an affliction he calls innumeracy: the inability to "think mathematically" (Paulos, 2001). If mathematics is the gold standard for all logic, and numbers are the exclusive standard for investigative process and reasoning, it follows for Paulos (2001), and perhaps others, that without the sovereign power of math and numbers we are mere cavemen, susceptible to myriad forms of deception and hysteria (Paulos, 2001). So persistent is this notion of fatal dualism nearly every book on the problem with mathematics education in my research seems charged with it. The gospel of number theory as told by Paulos and many others among this emergent numerati maligns so-called innumerate people as intellectually deficient, lost mathematical souls who simply do not understand the supreme importance of measurement and need to be saved. In other words, they need to be taught how to "think mathematically," if they want to be considered intelligent enough to engage in any kind of logic or reasoning. Such absolute logic and reasoning is persistently termed "mathematical thinking".

The Artistic Mind

From time to time, basic and elementary concepts counted as "discoveries" by the mathematical world are deemed to be mysterious or unique. But for artists and creative thinkers with more circumspective reasoning sensibilities, such discoveries can often seem quite concrete, not mysterious or unique at all. For example, the recent discovery of the turbulence model found in Van Gogh's *The Starry Night* had the science world baffled (Geisler, 2015). How could an artist with little or no mathematical training have envisioned the graphic representation for turbulence that had evaded the world's best physicists for centuries? Is it possible that the artist's vision of the universe is not merely a dalliance, but a valuable insight that can offer direction and relevance to mathematics and science?

Figure 7. The Starry Night, Van Gogh. Source: npr.org

What Van Gogh offers is a graphic representation. It is elegant. And although it contains representations of mathematically sound rational correlations, artistic representations in general would likely be considered by many in the math and science communities to be too mathematically imprecise to be of use. The attribution of Van Gogh's artistic madness notwithstanding, such alternative expressions of abstract physical reality can communicate mathematically relevant concepts which might then be erroneously dismissed as imperfect in application. The usefulness of such broad and aggregate conceptualizations may not to occur to mathematical minds which seem so prone to recede into metric fastidiousness. Is it possible that an impetuous attendance to the precision which is so essential to mathematical practice could be a hindrance to the propagation of discourse that could lead to new ideas and discoveries?

In an article titled *Mathematics, the Common Core, and Language: Recommendations for Mathematics Instruction for ELs Aligned with the Common Core*, linguistics and precision in mathematics education for English language learners (ELL) is addressed. In the article, Professor Judit Moschkovich, Ph.D. (2012) suggests that some communicative malleability can be helpful in the math education process. "Although students' use of imperfect language is likely to interact with teachers' own multiple interpretations of precision, we should not confuse the two. In particular, we should remember that precise claims can be expressed in imperfect language and that attending to precision at the individual word meaning level will get in the way of students' expressing their emerging mathematical ideas" (Moschovich, 2012, p.22). For the sake of communicability, Moschovich makes an important appeal here for more lucid considerations in the math education paradigm, and her observations seem relevant to any application of effective communication in math classrooms and texts.

There is a fallacious temptation to presume that this criticism of mathematical absolutism is a dismissal or misunderstanding of the importance of mathematics. I do not deny the crucial role of mathematics in the development of human history and science. I challenge and condemn the dismissal of the crucial role of the arts and humanities in the interdependent scheme of higher reasoning. I decry the elitist positioning of mathematics as the exclusive meta-structural process of valid thought and analysis, and believe this positioning is one of the driving forces in a toxic math education culture.

The Church of Math

The math and science communities may have come by this attitude of intellectual separatism quite honestly. For centuries, between the classical Greek period and the 17th century publication of Newton's *Principia*, the practice of mathematics and science was often a pursuit that flew in the face of papal authority. Investigations into these subjects were considered a challenge to the paradigms and conventions of those who had established a deeply entrenched sovereignty over the evaluation of the world around us. Today we recognize the perils of Ptolemiac stasis, and we celebrate the brave and strident souls who throughout history have risked life and limb to make the case for more evolved forms of reasoning and exploration. We recognize now that belief in a flat world or crystalline spheres, which were accepted as scientific fact for centuries, were theories better served by evolving forms of examination.

Copernicus, fearing persecution, concealed until late in life his theory that the Earth revolves around the sun. Galileo Galilei is later condemned for heresy for endorsing the Copernican heliocentric theory we accept as scientific fact today. At that time the challenges represented by mathematical and scientific study were not celebrated as advances but viewed as a threat to the power of the church. New discoveries in math and science were crushed and those engaging in such studies were punished with imprisonment or death.

It took hundreds of years for the maths and sciences to finally establish and keep a legitimate place among the disciplines. And humanity is better for it. The Reformation prompted by Martin Luther unseats the absolute power of the Catholic Church, creating a turning point that breaks the bounds of dogma and ignorance. This displacement of the church’s absolutist order would open the door for the studies that would lead to the great mathematical and scientific discoveries, ushering in a new age of intellectual enlightenment. It bears noting, that many celebrated moments in the history of math and science occurred during the neoclassical period, a time in which the world’s intellectuals were revisiting the virtues of classical schools of art and thought.

Today, it seems a new church has arisen, with engendered paradigms and similarly absolutist biases, quashing the original spirit of imagination and wonder that gave root to some of the greatest scientific and mathematical discoveries in the history of mankind. Some scientists might wonder if the math and science communities have stagnated into some sort of empirical dogma. Rupert Sheldrake (2013), for example, has been systematically attacked for his challenges to the science community’s dogmatic myopia. He is maligned as a pseudo-scientist, and, while many of his theories are certainly unconventional, even radical, he is in fact a Cambridge-educated scientist with a Ph.D. in biochemistry. Hardly a pseudo-scientist, Sheldrake’s most grievous transgression appears to be challenging the science community to live up to its own standards of stale and oppressive empiricism (Sheldrake, 2013). Much in the way Benoit Mandelbrot (2016) was maligned for proposing an intersection between nature and mathematics in his theory of roughness, it seems the suggestion of any naturalistic or humanistic intersection between math and nature is met with hostility (Benoit Mandelbrot, 2016). Today Mandelbrot’s insights into fractals have influenced nearly every aspect of digital life including CGI video effect techniques and communication designs for wireless technology (Benoit Mandelbrot, 2016).

Many problems we see in our world today could be directly attributed to a tragic degeneration in intellectual curiosity. Empirical studies now sublimate limited physical views over broad and inquisitive examinations of our world that include and appreciate the creative sensibilities found in the humanities. To participate in mathematical or scientific investigation requires conversion to the faith and strict adherence to the liturgical limitations of measurement and number theory. In this church, salvation and indulgences can only be granted by the papal math and science hierarchy, and, as students in math classrooms the world over find, the texts are not written in the language of the people.

The Myth of Intellectual Conversion

Shortly after I met Dr. Whitlow, she put me in touch with a colleague, a retired math teacher, who agreed to tutor me. My new tutor was a good teacher and very helpful. However, in retrospect, I now recognize she did not subscribe to the same outlier belief system as Dr. Whitlow, but was fully indoctrinated into the same church of math and “mathematical thinking” belief system described by Dantzig and Paulos. Working from her traditional math education perspective, our sessions seemed successful but did not result in any comprehension, retention or ability for me to perform on tests. After weeks of working together, I failed my college algebra midterm exam.

I was taking a rhetoric class at the time, and in that moment of midterm crisis and insight, I recognized the situation I was in with math as a rhetorical failure in, among other things, how the math information was delivered. I discussed my insights with my tutor to help her understand the experience I was having. I drew diagrams of the rhetorical situation and other communication diagrams to illustrate it. The more I drew, the more irritated she became. She finally announced tensely, “No, it isn’t any of that. You just don’t have a mathematical foundation,” which was the stock answer I had become used to hearing over the years. That session ended awkwardly.

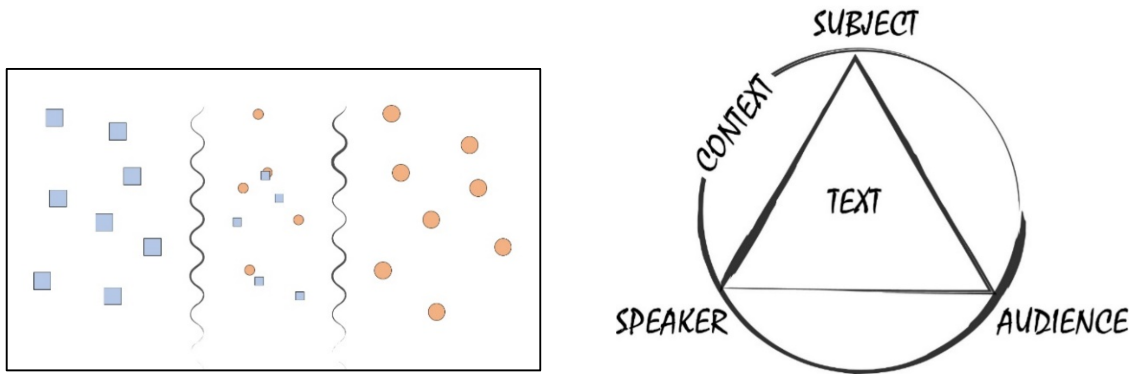


Figure 8. Example of shared semantics bypassing model and rhetorical triangle drawings, digital illustrations by Liz Melendez. To view animated modals right click here.

Over the course of the next 24 hours or so I had the inspiration for a completely different approach to teaching and learning mathematics. If Dr. Whitlow was right, and it was the math instructors who were failing, and if I was right that it was a rhetorical failure, a breakdown in communicative principles, then I knew I had the tools and life experience to confront the problem. In our very next meeting, I asked my tutor if she would be open to a completely new approach. I asked her to turn the sessions over to me, allowing me to ask questions and drive the conversation which allowed me to maintain the rhetorical integrity of the situation. I asked her to trust me. She was ambivalent, but agreed, probably sure that it was a huge waste of time and perhaps confident that the failure of it would put me back in my place. We resumed our sessions, as a discussion-based (dialectic) process, and I assumed agency in my math education with the math as the text and rhetoric as the rule.

However, it wasn't without difficulty. For my tutor this was a very uncomfortable disruption of roles, power and discourse. She was often impatient and irritated by this approach which abandoned the rote memory operations she was used to, and set creativity, cognition, iteration and communication as the standards. The rules for the operations remained mathematical, but the rules for the teaching and engagement of the text were now rhetorical. For my tutor there was much resistance to this upheaval, and much gnashing of teeth as she hammered away at these dialogic buttons:

If I spent too long pondering what she perceived as insignificant questions:

"This is not important!"

If I took the time to write down or draw anything she didn't understand:

"Don't write that down, why are you writing that down? That has nothing to do with anything!"

If I tried to engage in any conceptual discussion about math and reasoning:

"Math is about precision."

If I used analogies, art, mnemonic devices or anything she construed as a "trick":

"That is not 'real' math."

While she thrashed about, my results were immediate and undeniable. This seemed to confound her and pique her curiosity in turns. I began my new approach on November 3rd 2014 with my tutor in a new role of answering questions and assisting me in translating the math operations into what I called "human language." Occasionally we worked with another of my classmates which presented another level of intelligent dialectic reasoning and immersion as I shared with my classmate what I was learning, as I was learning it. It was only by rearranging the structure of this rhetorical situation that clear communication of the subject was possible.

Later, when I did research into the process after the fact, I found that my experience was validated by Paulo Freire's model of the dialectic student-teacher/teacher-student teaching environment from *Pedagogy of the Oppressed* (2000) in which the traditional roles in the classroom are subverted and the teaching is discussion-based (Freire, 2000, p.93).

As I progressed in learning the math material using the new process I was developing, my tutor would congratulate me on my conversion to becoming a more "mathematical thinker." I found this wholly reductive and insulting, as the process I was using to conquer math had nothing to do with mathematical thinking. I was using a creative process which I simplified to one base and concrete level of reasoning (numbers) and limited to one very narrow perspective (math). It was the intellectual equivalent of placing a keyhole over my thinking to understand mathematical operations, which made it possible to frame the product of my thinking to fit into the constraints of this keyhole. This limitation of my thinking enabled me to more often give the answers my math instructor was asking of me on homework and tests. My response to her congratulations was the retort that I would never hope to reduce my intelligence to mathematical thinking. This baffled her, and although she acknowledged my success, she never really could fully accept the devices at work in my process.

After reading many books on math education and coming to recognize the value system of rote memory operations in mathematics and math education culture, I can understand why such a response baffled her. What I was doing and what I was saying was, to her, probably tantamount to heresy. Many mathematicians and math educators seem to be indoctrinated into the sacred myth that mathematics is the solitary gold standard for all logic or some elite hierarchical tier of intellect. And, from what I've heard, read and experienced, many of them seem at the ready to attempt to delegitimize any argument or solution that disrupts the supremacy of this belief.

The Myth that Math is Difficult

This rhetorically rich and functioning environment of my new process set the stage for one of the biggest revelations in the process: That math is not at all difficult. The subject is at times clunky and cognitively unwieldy, and the language and semiotics are, like traditional music notation, unnecessarily perplexing and dysfunctional. This leads to the misconception that the subject is difficult, which leads to unnecessary confusion and anxiety for students. But the concepts in true math are actually very simple. Stripping away the ineffective communication, clunky language and confounding symbols, and employing a rhetorical structure to re-assemble the subject, text and message, exposed a system of very concrete essentials in thought and understanding propped up to seem more mysterious than they actually are. Not only is math not difficult, I found the confines of metrics (numbers) very rudimentary and limited in scope as investigative or reasoning devices. In terms of truly abstract concepts, numbers and measurement offer only a basic understanding and very little insight.

From this new vantage point, I was able to demystify the subject and dispatch the problems I was having with math quite handily. The title of my thesis could be, *Flipping the Script: How Creativity and Rhetoric Crushed 30 Years of Math Struggle in Under 6 Weeks*.

Reward and Expert Power: the Myth of Mathematical Infallibility

As a part of my degree program, I studied the effects of power dynamics on communication within groups. In the math classroom this would be most likely categorized as a combination of “expert” and “reward” power, which is, the implied power of an instructor based on a presumption of expert facility in mathematics combined with the ability of the instructor to reward students’ efforts. There also seems to be an implied social hierarchy among educators with the instructors of math and science at the top of the educational food chain, teachers of other subjects below them and students at the bottom. Within such a local or global social group dynamic, this hierarchical relationship seems to have a tremendous effect on how mathematicians, scientists, and educators in these disciplines are perceived by students and society.

To an appreciable degree, much of the imbued power in this arrangement might be an associative byproduct of the presumed objectivity of number theory and mathematical practice. The perception of the infallibility of number and empirical reliability bleeds into the presumptions of how mathematicians or math educators might use their expert and reward power. But, it is prudent to consider how much the reliability of empirical data depends completely on how it is situated within rhetorical contexts and the intentions of speaker/receiver interactions.

In his book *Proofiness, The Dark Arts of Mathematical Deception*, Charles Seife (2010) illustrates numerous examples of how “bad math” exploits the presumption of mathematical empiricism by manipulating associations with numbers, facts and implications (Seife, 2010). Based on such manipulations, information backed by numbers and mathematical data on everything from government policies, to advertising, to economics, to education is corrupted by abuse of the implicit faith the public seems to have in mathematical reality. As Seife (2010) points out, “Making up scientific-sounding measurements is a grand old tradition” used by advertisers to bolster claims such as the benefits of cigarette smoke, using “phony measurements…” and tricks “like actors dressed up in lab coats” (Seife, 2010, Chapter 1, para. 20).

Such forms of deception are possible because there is a presumption of authority in expert and reward power that seems to go unquestioned where mathematics and science are concerned. The noted behavioral experiment conducted by Yale psychologist Stanley Milgram in which subjects were instructed to deliver electrical shocks to an unseen participant exemplifies the implicit expert and reward power of roles when the experimenter is presumed to be a scientist. The unseen participant is an actor and no one is harmed, but Milgram’s results showed that in the face of humanistic and ethical crisis, a subject will continue a line of action, an electrical shock, to arguably unconscionable ends resulting in the presumed injury to the unseen participant, simply because a man in a lab coat instructs him to continue. In other words, the average person will defer to the judgement of a scientist, in spite of his own best judgment, indications of harm to others or the absence of any reasonable rationale (Davidson, 2015). This was an experiment in the effects of implied expert power on the ability of individuals to make value judgements in their own behavior. Milgram’s findings are interesting to consider while doing research into the possible power dynamic at work between a dominant culture (mathematicians and math educators), and a population that is almost completely dependent upon the wisdom and integrity of that dominant culture (math students).

It seems the numbers and data of “good math” hold up in the best interest of the common good not when the number operations are understood but when contexts and meanings of their application are understood. Without context we might presume that because we feel can rely on the pure objectivity of numbers that we can rely on the veracity and pure objectivity of those who are using them. For example, in the math classroom, trust in the instructor could be said to be implicit. When the student is having difficulty, it then seems a foregone conclusion then that the problem must be with the student. Perhaps the propensity for being deceived described by Paulos isn't so much a product of innumeracy, but of the mythos surrounding mathematics and numbers which lulls the public into a false state of intellectual complacency, and, on many levels, consciously and unconsciously exploits their trust.

The Myth of Causation: Manufacturing Math Difficulty

In *Innumeracy*, John Allen Paulos (2001) attributes difficulties with mathematics to "…anxiety or to romantic misconceptions about the nature and importance of mathematics," continuing his attribution by pointing to his conclusion that a "…consequence of innumeracy is its link with belief in pseudoscience" (Paulos, 2001, p.5). Pseudoscience being one of the blanket terms used to marginalize any idea that threatens the absolutism of mathematics in logic. Paulos continues his polemic by claiming that a population who does not understand math "….still believes in Tarot cards, channeling mediums and crystal power" (Paulos, 2001, p.5). Overall Paulos' tone and his word choices: "inadequacies," "lack," "exaggerated appreciation," "inability to recognize" denote his overtly absolutist condescension, at once demoralizing and self-aggrandizing within the framework of claiming to want to educate (Paulos, 2001, pp.5-6). This tone is prevalent in similar books on this topic. Paulos (2001) himself points to his awareness of this tone as he claims assuredly, "I hope I've avoided the overly earnest and scolding tone common in many such [books]" (Paulos, 2001, p.6).

From my autoethnographic experience and the research and reading I've done, an important factor effecting the breakdown in math education reform appears to be in the unwavering presumption that the problem resides within the student. Articles and presentations are always directed at the student with themes like "How to Make Students More" this and "New Techniques for Getting Students to Be More or Do More" of that. According to Dottie Whitlow, one teacher training module she has been asked to evaluate mentions rhetoric, in terms of how to make *students* understand rhetoric (personal communication, December 15, 2014). Almost none of the articles I researched present even the possibility that it may be the teachers who need to be "Made More" this or to "Be More or Do More" of that outside the context of changing the student. There are many well-intentioned educational reformists in the math world who do effective work but seem to simply have their sights set on the wrong target.

Stanford mathematics professor Jo Boaler (2015) is probably the most notable among contemporary math reformists. She offers the most comprehensive and intelligent insights into the problems in the math and math education community. In *Mathematical Mindsets: Unleashing Students' Potential through Creative Math, Inspiring Messages and Innovative Teaching* she exposes attitudes of intellectual separatism, "…too often [math] is taught as a performance subject, the role of which, for many, is to separate students into those with the math gene and those without" (Boaler, 2015,p.93). Like Dr. Whitlow, Jo Boaler (2015) is an outlier within the math community as she is one of the few to readily concede the illusion of exceptionalism in math difficulty as a subject, pointing directly to obfuscating teaching practices as one of the driving causes of that illusion. "…the reason so many people think math is the most difficult is the inaccessible way it is often taught" (Boaler, 2015, p.96). She also expresses appreciation for the arts by situating mathematics among the disciplines, "Mathematics is not more difficult than other subjects— I would challenge people who think so to produce a powerful poem or work of art" (Boaler, 2015, p.95).

In a particularly disturbing exposition Boaler states:

> One high school teacher I met gave 70% of his students an F in every math class he taught, every year. He did not see the students' failure as a reflection on his teaching; he saw it as a reflection on the students who he did not believe had the "gift." In discussions with this teacher, I realized that he feels justified in failing so many students, even though he is ending students' academic futures and stopping them from graduating high school, because he believes he is the guardian of math success and his job is to make sure only the "stars" move on to higher levels (Boaler, 2015, p.95).

Later in that paragraph, I found this passage that was of unique interest to me:

> Some university math departments give students a lower grade if they attend office hours and seek help. They do this because the admirable approach of working harder, which should be encouraged, is a sign to them that students don't have the gift (Boaler, 2015, p.95).

David Pimm also mentions what could be viewed as the othering effects of language used by math educators. In his book *Speaking Mathematically: Communication in Mathematics Classrooms*, Pimm (1987) states that the use of the word "we" by an instructor to describe himself as a part of an "in-group" who can do math correctly, implied that students who are having difficulty in the class belong to another, or, more accurately, an *other* group (Pimm, 1987, p. 70).

Boaler’s candor, which made her a target of abuse and derision within the math and math education communities, is refreshing and so necessary in dismantling the corrosive myths that prevent teachers and learners from recognizing the causes of their problems with math and where to look for solutions. While I have the utmost respect for Dr. Boaler’s efforts, her position, like so many others, often only lacks the provenance of understanding the problem from the student perspective. Although it is empathetic in exposing the ills and attitudes in the math culture, it still seems based on attending to the issue from the student deficiency perspective. Efforts that do not engage to an appreciable degree the first-person perspective of the student, miss the opportunity to take the problem out by the root, and, as such, may remain largely palliative.

The myth that math is difficult seems to feed so directly into the myth that the problem is a deficiency within the student, that in turn feeds into the myth that the solution is based on finding a remedy for that deficiency. Consequently, the overriding message in nearly all reform approaches is that the student “lacks” foundation or talent or intelligence or ability. From my perspective as a once-suffering math student, this is like holding a man underwater and then saying he lacks oxygen without considering the actual root cause of his situation. Unfortunately, this misconception of deficiency is accepted readily by students which leads to demoralizing and fruitless efforts toward fixing a problem that does not exist within them.

Part of my honors program has presented me with the opportunity to volunteer my time as a math teaching assistant helping people who have returned to school to earn a GED. In my duties as a volunteer teaching classes, I noticed that, with the exception of a few situations, when mathematical concepts are explained to a student thoughtfully in linguistic terms they can understand and within an effective rhetorical and dialectic framework, they are shocked, pleased and perhaps even sometimes annoyed to learn that, except for the clunky and confusing written language, math is very simple. It is frustrating to realize that most if not all of the difficulty they have experienced – difficulty which has persistently been framed as a deficiency within them which sets them apart from their classmates and deterred their progress in school and in life – actually amounted to nothing more than pointless rigor, confusing language and poor communication.

Educational blogger Yatit Thakker (2015) offers his opinions for "*Why Calculus is so Difficult*." The three reasons Thakker lists: "1) Things start moving. 2) There are word problems. 3) It's like real life" (Thakker, 2015). As an artist, I find his insights very interesting, particularly because I do not find the reasons he has listed to be points of difficulty. "Things moving" or the effects of change over time are aspects of narrative situated-ness and context which are not difficult for me as a designer and writer to conceptualize. The "problem" with word problems is almost never the words, but the poor rhetorical practices causing breakdowns in the connections between agents, meanings and operations. And finally, the observations of "real life" is what art is all about. I point out Thakker's blog as an example of mindset, because as I am beginning to teach myself the basic concepts of calculus and speaking to others who have taken it, the only real "difficultly" I can find and that many others can report is in the enormous amount of formulaic memorization involved. It may be that, for an artist, as in the Van Gogh example, the ideation of a natural phenomenon or of a value changing over time is actually quite natural to consider. In calculus this involves language and operational facility to compute and express in mathematical language, which ultimately just involves a commitment of time and technical discipline. This leaves only the memorization of confusing and bulky language and notation to cause difficulty, a dynamic that fosters a culture of mathematical performers who are adept and memorizing and reciting but understand little or nothing about the concepts at work. Referring back to the music world using confusing notation to unnecessarily overwhelm and dissuade students, I find the use of these mechanisms to manufacture "difficulty" where almost none exists an egregious disservice to students, education and practice.

Dr. Whitlow has shared many stories about math teachers attending her training workshops being brought to tears with grief over the revelation that the problem, as Dr. Whitlow proclaims, "is them." They cry, she says, because not only do they realize the great disservice they have done to their students, but because they themselves are products, and victims, of the same perpetuating dysfunction in the math classroom (personal communication, October 15, 2014).

The Myth of "Real Math"

I spent many hours being chided by my tutor about my evolving rhetorical and creative process not being "real math." I had to proceed in spite of this persistent derogation of my approach. However, a deeper study into what "real math" is reveals some surprising facts.

One important revelation is the difference between training and teaching, pointing out that most of what is happening in the classrooms and the text books is not teaching but training. In the book *Mathematics: the Birth of Numbers* by Jan Gullberg (1997), Professor Peter Hilton in the foreword makes the point that "…the first serious error we often meet in considering the role of mathematics is the confusion of education with training" (Hilton, as cited in Gullberg, 1997, p. xvii). Training, then, is defined as "…the acquisition of set skills that will prove useful… so the skills must be learned… committed to memory, and no real understanding need occur" (Hilton, as cited in Gullberg, 1997, p. xvii). It is this apparent disregard for real understanding and fluency, combined with the perpetuation of rote, mindless computation and formulaic recitation that seems to be at the heart of this downfall in math education. If no real understanding need occur, then no communication is necessary and no rhetorical process is utilized or even considered. Indeed David Pimm (1987) echoes this observation in *Speaking Mathematically: Communication in Mathematics Classrooms.* “Many teachers do not see the value or even possibility of discussion in mathematics as a consequence of the view of mathematics which they hold” (Pimm, 1987, p.70).

However, to real mathematicians math is much more than the rote operations and disconnected computations being taught in the classroom. Yet this institutional misrepresentation of the subject is perpetuated by those tasked with teaching it and those making value judgements on academic performance. Mathematician Paul Lockhart (2009) expounds on this in his book, *A Mathematician’s Lament*. “The cultural problem is a self-perpetuating monster: students learn about math from their teachers, and teachers learn about it from their teachers, so this lack of understanding and appreciation for mathematics in our culture replicates itself indefinitely” (Lockhart, 2009, p.30). He continues, “Worse, the perpetuation of this ‘pseudo- mathematics,’ this emphasis on accurate yet mindless manipulation of symbols, creates its own culture and its own set of values” (Lockhart, 2009, p. 30).

Within a week of working with my tutor using the new process I was designing to learn math, I was asking questions she could not answer and making observations she could not conceive. This is not to say she was not capable of teaching and explaining the operations. But, at this point she was demonstrating the math culture described by Lockhart and others and I was experiencing it firsthand. As she was contentiously making the case for “real math” to assail my process, it turns out what I was doing was, in fact, real math. But she was incapable of recognizing it.

For example, as we were studying functions and logarithms, I noticed some relationship between a 1/x function and a logarithm. It was apparent by the graph there was similarity in how these functions seemed to behave, so I wondered if they were related.

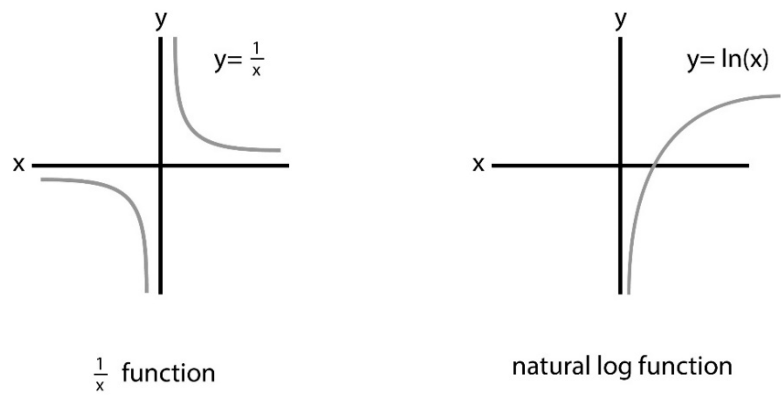
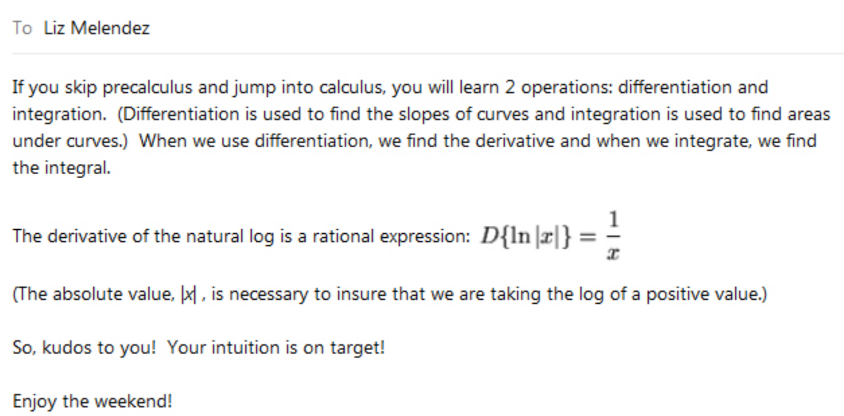


Figure 9. Diagram of a 1/x function and natural log function, graphic illustrations by Liz Melendez.

"They are not related," she stated flatly. "They are two different things and have nothing to do with each other." I was not convinced, as I've never found "just because" a very compelling argument. "They are related," I said. "I'm willing to bet on it."

The next morning I received the following message in my email from my tutor:



To Liz Melendez

If you skip precalculus and jump into calculus, you will learn 2 operations: differentiation and integration. (Differentiation is used to find the slopes of curves and integration is used to find areas under curves.) When we use differentiation, we find the derivative and when we integrate, we find the integral.

The derivative of the natural log is a rational expression: $D\{\ln|x|\} = \frac{1}{x}$

(The absolute value, $|x|$, is necessary to insure that we are taking the log of a positive value.)

So, kudos to you! Your intuition is on target!

Enjoy the weekend!

Figure 10. Email screenshot by Liz Melendez.

There is a very clear explanation of this from Khan Academy, which uses the formulaic approach to demonstrate what I saw in the graphic without numbers or formulas or rules, just conceptual and visual reasoning followed by inquiry and induction. I noticed something, and I asked a question. My tutor gave an answer and sought out information to support her argument, which led to the truth that would makes sense of the computation and cultivate fluency. This is an early example of how I learned math by re-framing it into a working rhetorical situation, but it took an enormous amount of persistence, resolve and emotional strength to accomplish in the face of resistance and intellectual culture clashing.

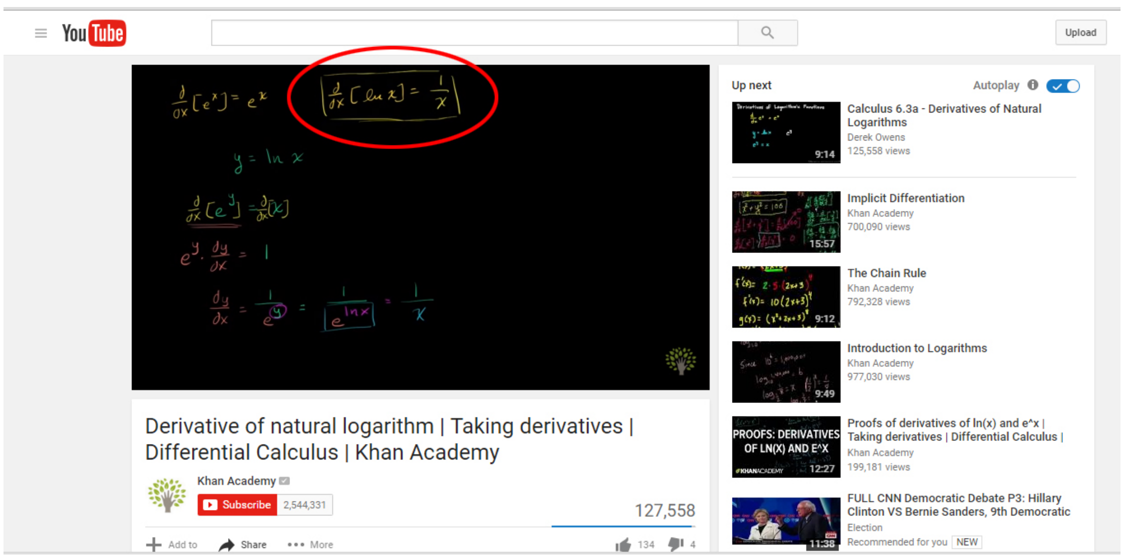


Figure 11. Screen shot of Khan Academy video. Source: https://youtu.be/765X_PAxhAw

My experience has been that creativity, inquiry and investigation are usually not welcome in the math classroom. Dr. Whitlow said I should not be afraid to ask questions, in the classroom or anywhere else (personal communication, August 4, 2014). I've asked questions, or made creative observations with my instructors and my tutor and it is usually met with irritation and hostility. I used to think this was because I was asking the wrong questions or because the instructor just didn't want to be bothered. But in my retrospective research on this project I've come to realize that it is more likely because they do not know the answer. In "Julian's Story" from Concepcion Molina's *The Problem with Math is English* (2012), a young math teacher is gripped with fear: "'What if someone asks why something to the zero power is 1?' Julian worries. He has no idea of the answer. As a student he blindly accepted and memorized the various rules and procedures presented to him – just as his teachers told him to do… Shaken and dejected, Julian realizes he does not know mathematics at the level needed to teach it well" (Molina, 2012, p.xix).

Dr. Molina then confesses, this is his own story. I would wager it is the story of many math educators who answer questions and precocious observations with irritation and hostility. They, like "Julian," may be terrified to be found out. How ironic that the rhetorical and creative induction process I used to conquer mathematics, and the same creativity and artistic curiosity at the heart of the most impassioned mathematicians' testimonials like Paul Lockhart, turned out to be more "real math" than my tutor's "real math" after all.

Convergence, not Conversion

My hope is that this chapter illuminates some new perspectives, and that my real-life experience with converging rhetoric, creativity and inquiry to conquer mathematics will demystify and demythologize the subject. By reclaiming my agency in my own educational experience I was able to throw off the shackles of mathematical absolutism. In doing so, I set mathematics free to work interdependently with all forms of pure logic and reasoning at my disposal, finally making it useful and relevant.

I want readers to know that much, probably most, of what students endure in the math education experience is not real math at all but is actually mindless training in operations (Hilton, as cited in Gullberg, 1997, p. xvii). According to mathematicians like Paul Lockhart (2009), what is presented in schools does not represent true mathematics at all (Lockhart, 2009). By his standard, creativity has a significant place in the pursuit of mathematical reasoning. So, according to Lockhart (2009), the math curriculum in public schools not only alienates and harms students, it isn’t even based on legitimate practice (Lockhart, 2009).

After taking this long and honest look at the math and math education mindset, it would do to have some insight into the rhetorical process and how effective communication plays an important role in how mathematics is taught. There is much to learn about the intellectual space in which these discourse communities converge.

Chapter Three

A Collision of Cultures

It has been mentioned many times in the previous chapters that the language choices found in books, websites and videos on math education seem consistently skewed against the best interest of the student. This is not to say this tone is deliberate. In fact, I would imagine the entire discourse on this subject may be quite unconscious.

After my first few conversations with Dr. Whitlow, as I began working with a new professional math tutor but continued to struggle, I reached a point that allowed, or perhaps forced, me to adopt a detached view of the situation. This new detached perspective of my math experience allowed me to see it as a rhetorical situation – a failed rhetorical situation.

What is Rhetoric?

That was the number one question I was asked during my poster presentation on the subject of rhetoric and math education at the Kennesaw State University Symposium of Student Scholars. Most people associate the term rhetoric with either politics or with the term "rhetorical question," neither of which adequately represent this art form. My challenge, then, was to explain, or at least try to explain, what rhetoric actually is.

Many definitions of rhetoric can be found in texts and sources ranging from classical distinctions to more modern interpretations. Most often the contemporary definition identifies rhetoric as a method of effective communication. Andrea Lunsford, professor of English and writing at Stanford University and author of *Essays on Classical Rhetoric and Modern Discourse* is cited in the *Dictionary of Rhetorical Terms* as defining rhetoric as, "…the art, practice, and study of human communication" (Lunsford as cited by Howard, 2010, p.172).

The director of this thesis, Dr. Kim Haimes-Korn has described rhetoric succinctly as the intellectual space "where thought meets language" (personal communication, March 2016). I. A. Richards, rhetorician and author of *Philosophy of Rhetoric* is also cited in the *Dictionary of Rhetorical Terms* as defining rhetoric as, "the study of misunderstandings and their remedies" (Richards as cited by Howard, 2010, p.172). This was certainly true when I took a fresh look at the subject of mathematics and broke it down into parts as a rhetorical process. In the context of my math situation, I would say the study and examination of communication and language of math in the rhetorical context definitely served as a problem-identifying and problem-solving mechanism.

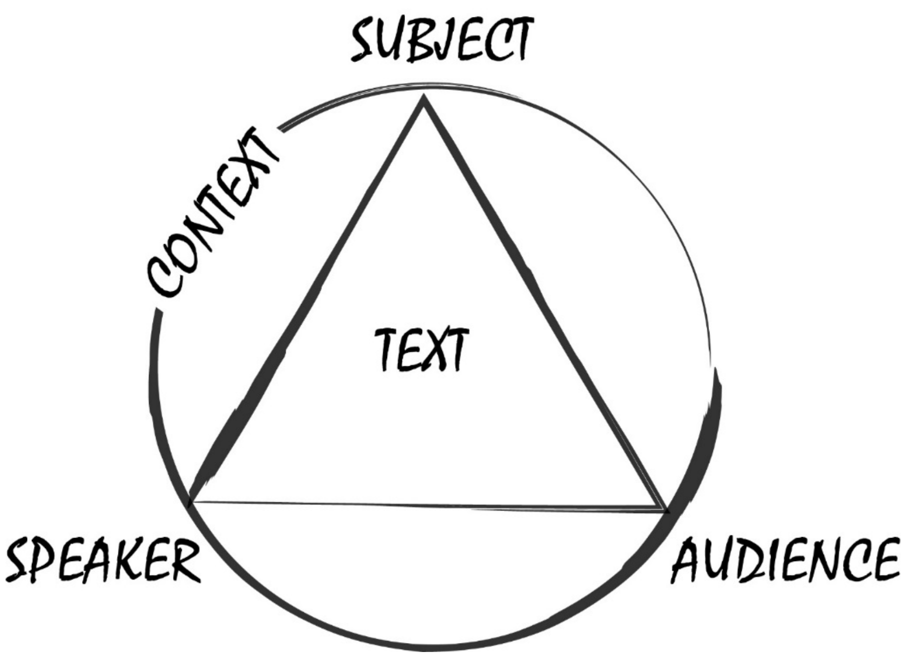


Figure 12. Rhetorical Triangle, a graphic illustration created by Liz Melendez.

As we see in the above illustration of the rhetorical triangle, loosely based on Aristotle's model of the rhetorical situation, there is a speaker and an audience. These may also be classified as writer and reader, or sender and receiver. There is a subject about which the speaker will be speaking, with the intent of informing, educating or persuading the audience. Ideally, the speaker has considered his audience fully in order that he or she may most effectively communicate the intended message. The speaker must establish credibility (ethos) with the audience as a knowledgeable source of the information on the subject about which he or she will be speaking. In considering the audience, sensitivity to the emotionality involved (pathos) can help the speaker consider the best tone and style for the delivery of his or her message. The speaker may incorporate logical examples (logos) to illustrate the facts and data associated with his or her message. Visual rhetoric in the form of graphs, media or illustrations could incorporate a branch of rhetorical communication that delivers messages on many levels to make a presentation more effective. The text is the environment and language in which the subject is engaged, and all of this is framed within a context, a cohesive cognitive arrangement of interdependent communicative structures that give the entire situation relevance and meaning.

Every human interaction is a rhetorical situation on some level, and examining what works best in communicating a message very often affects the success of every endeavor from relationships, to business, to athletics, to politics. So why not education? And why not mathematics education? Although classical examples of rhetorical mathematical engagements can be found, early use of rhetoric in mathematics does not adequately reflect the modern use of rhetorical structure upon which this thesis is based. A modern understanding of rhetoric is imperative to understanding the effectiveness of rhetorical structure and the application of rhetorical principles to a modern math educational situation.

The Reference of My Experience

The primary source I could reference in my rhetorical examination was my own experience in the many math classrooms in which I found myself. From earlier high school years, to college most recently, the experience had remained disturbingly consistent.

I failed both algebra and geometry, finally scraping by in both subjects to graduate from high school. My original college track back then included another algebra class. I knew I could not bear trying to pass a higher-level algebra course when I understood absolutely nothing about the subject having barely passed on my last attempt, most likely by the merciful graces of the P.E. teacher assigned to teach after-school algebra. I visited my school counselor/advisor and asked for the track that would get me though high school without any more math, which meant college would not be in my future.

When I finally got to college many years later, I knew math would be there waiting for me. But I was older now, and had the confidence of a grown and experienced adult. Surely, I could revisit this subject with a fresh perspective to earn a passing grade and, hopefully, leave math behind me forever.

Many of my peers in college, of all ages, share a common experience in their own stories of struggle and trauma with math. In my first math course, a remedial pre-algebra class I was required to take before being allowed to take college algebra, I was literally brought to tears sitting in my chair. An impossible-to-understand instructor showed black and white text PowerPoint slides, pointing with a stick at a math problem, then pointing to the solution and saying, "Yes?" He had to turn the lights off to get the projector to work so we were unable to take notes. The room seemed to be frozen with a palpable fear. It was as if a worst-case-scenario was playing out for all of us who were clearly sitting in a remedial pre-algebra course because we had trouble with math. When a student finally got up the courage to ask a question the instructor became irritated chiding, “This is review! Yes?” My eyes welled up as I truly believed my college experience was over almost as soon as it began.

I eventually did drop that class and found a better instructor. I passed the prerequisite math courses, but did so having retained no real understanding of what was covered. By the time I made it to college algebra, I was treading academic water, laboring furiously like a man running the wrong way up an escalator, making bits of progress but moving backward in comprehending the material. The concepts were easy to understand in and of themselves, but framing them into problems in the math language to which I was expected to work out a solution seemed impossible. My roommate at the time would tease me as I disappeared under a mountain of scratch paper with problems worked out on every inch of every sheet. It was a desperate effort with absolutely no sense of progress in comprehension. It felt a lot like the *I Love Lucy* candy factory scene, a frantic attempt at performing some task with no conceivable idea of how to go about it, with an expectation looming large and fear of failing plaguing every thought. Every visit to a tutor and every website blared the same corrosive sentiment had heard since high school, that the problem was I lacked a “foundation.” As a matter of sociological self-ideation, I was resigned to believe what I was told, that the problem must be a deficiency that existed within me, so I would just have to work harder.

Finally, a Diagnosis

As discussed in a previous chapter, I met Dr. Dottie Whitlow on August 4, 2014 when she and her husband Ed came into my studio for ukulele lessons. It was Dr. Whitlow, widely respected math educator and reformist, who was the first person to say, out loud, that my problem with math did not lie within me as some deficiency, but was a scourge brought about by the failings of math educators and of the educational system itself.

This shift in the dialogue was a complete upheaval of the power structures that convince students like me who struggle with math that the problem lies within them as a deficiency. Students come to accept the misconception that they possess an intellectual short fall that sets them apart from their classmates and from society. Dr. Whitlow's refreshing and irreverent honesty unlocked the shackles of cultural propriety that blinded me from seeing this situation for what it actually was – an institutional and systemic rhetorical failure.

What is Missing?

Looking back on my history with the subject of math, and using the rhetorical situation as a new diagnostic device, I could inventory the communicative elements found, or not found, in math classrooms, textbooks, materials, and, most recently, in books and videos intended to remediate and reform math education. By taking a closer look I recognized some glaringly obvious deficiencies, not in students, but in the entire communicative approach to the subject.

As a rhetorician, with a wealth of life experience in education and communication in several fields, I stopped looking at math as some horror with which I had been cursed to endure, and examined it as a rhetorical breakdown. I looked at it as a communication problem that needed to be solved.

Viewing it as if it were any other scenario, these are the observations I could make based on the litmus of the rhetorical situation:

Speaker: Math educators, in my experience, are rarely good communicators. They often either cannot or will not engage the audience (students) beyond a dry recitation of the data (Pimm, 1987, p. 70). Lectures are usually a demonstration of the instructor's ability to perform operations, with some definitions and formulas written down. Questions from the audience are most often received with hostility and irritation, sometimes dismissed as insignificant.

Audience: It is impossible to detect any consideration for the audience in the lectures, texts and other materials. David Pimm (1987) acknowledges in *Speaking Mathematically, Communication in the Math Classroom* that "mathematics is predominantly passive… listening to a teacher going on" about the material (Pimm, 1987, p. 43). This objectification of the receiver has an alienating effect on the audience. As a result students shut down, and disengage – resigning themselves to the passive role of data receptacle described by Freire (2000) in the banking model of education described in *Pedagogy of the Oppressed* (Freire, 2000, p. 93).

Subject: According to Paul Lockhart (2009) in his book *A Mathematician's Lament*, the actual subject of mathematics is completely absent in the math curricula, texts and classrooms. The material covered is nothing more than an arbitrary set of disconnected operations that have nothing to do with actual mathematics, but are rather selected based on how easily they can be turned into operational work and written into tests (Lockhart, 2009, p.57).

Text: Whereas mathematics is the subject, math as the text is the metric language that includes the operations, formulas, expressions, theories and math exercises in the form of classroom lectures, literal texts and examinations. Math as the text in this case remains lifeless in today's math classrooms. As Lockhart (2009) states, it is being replaced instead with "…mindless manipulation of symbols" which "…creates its own culture and its own set of values" that are inconsistent with the subject. See the "ladder myth" described below (Lockhart, 2009, p.30).

Context: Where mathematics education is concerned, there seems to be no space made for this, probably the most important element of the rhetorical situation. In the math classroom, textbooks and materials, context is virtually non-existent. Operations, concepts, theorems, formulas and definitions are disseminated, arbitrarily and completely un-contextualized in what Lockhart (2009) calls the "…confused heap of destructive disinformation known as 'the mathematics curriculum'" (Lockhart, 2009, p.55). The poor arrangement of the information and concepts is an artifact of what Lockhart (2009) refers to as the "ladder myth," which is information presented with "…no historical perspective or thematic coherence, a fragmented collection of assorted topics and techniques united only by the ease with which they can be reduced to step-by-step procedures…" continuing, "…we have teachers and textbooks presenting the 'negative exponent rule' as a fait accompli with no mention of the aesthetics behind this choice" (Lockhart, 2009, p.57).

There is no flow, no substantive exchange on the subject, and from my experience, no intelligent discussion welcome in the math classroom. According to David Pimm (1987), where discussion in math classrooms is concerned there seems to be, for teachers of math, "confusion bordering on incomprehension concerning how to talk mathematics" (Pimm, 1987, p.46). In the few classrooms where instructors are trying to initiate dialogue, they find students are frozen by the conditioning of the math education culture that discourages active discourse (Pimm, 1987, p.70). Students enter the math classroom as though they were filing into a funeral, filled with dread and anxiety, many harboring fears that are often realized in the form of confusion, misunderstanding and failing grades. Textbooks are awkwardly written in the disconnected style described by

Lockhart, and students systematically find the descriptions and instructions within them of little or no help. Often the textbook compounds the confusion of the material. In the illustration below, we see a model of communication in math education. The variation in color indicates that the onus or urgency for the success of the communication is most intense for the student, the participant in the model who knows the least about the subject.

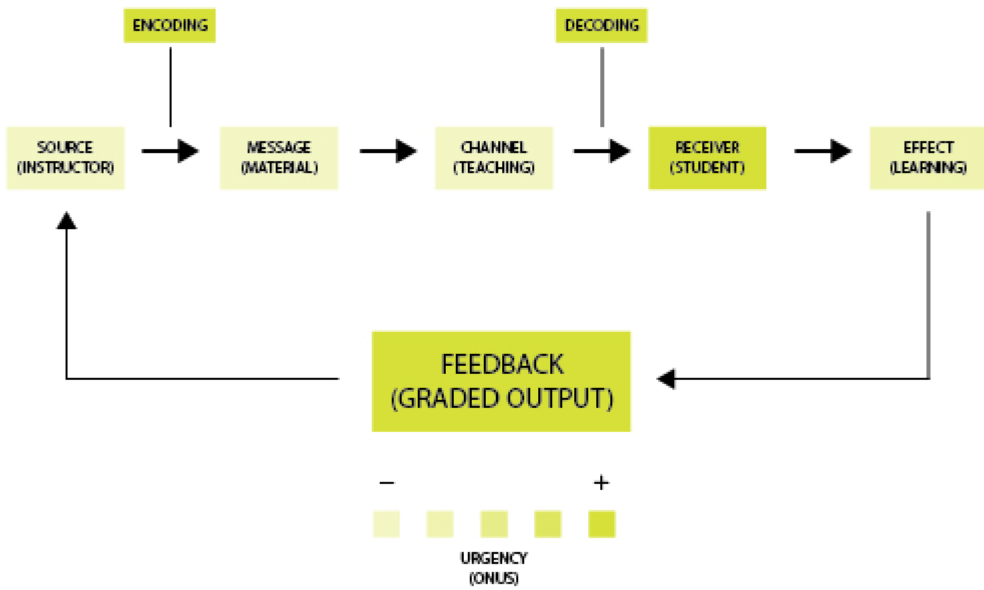


Figure 13. Communication model graphic created by Liz Melendez.

Encoding, Decoding and Language Registers

In the diagram above, “encoding” and “decoding” refers to the process of creating a message based on shared or understood terms (encoding), ideally with a consideration for the audience receiving the message in doing so. The audience then receives and interprets the message based on shared or understood terms (decoding). Communicators study this process to achieve the best possible outcome: a successful conveyance of an idea.

Linguistic registers dictate the level of formality in discourse: frozen, formal, professional/academic, casual, and intimate. Jargon and specialty terms distinguish the codes, the shared or understood terms, among discourse communities. When discussing the formal register found in the math classroom, David Pimm (2009) in *Speaking Mathematically: Communication in Mathematics Classrooms* discusses the rigidity of the spoken math language, similar to that I've found in nearly all books on the subject. Such coded language seems intended to be misunderstood. Consequently, the encoding occurring does not involve shared or understood terms and meanings and therefore alienates all in the audience for whom the terms have not been properly or clearly defined (Pimm, 2009, p.78).

Currently, the burden of understanding messages in math classrooms and texts involves a decoding process that is unsupported by shared meanings. For me, the remedy for this was to encode the original idea with more naturally understood language and meanings, which enabled me to decode the message in other applications and contexts. This process of playing both sender and receiver to properly encode and decode the messages was a long and arduous method, and involved a great deal of creativity, investigation and induction.

The Illumination

The night after I first attempted to convey the experience I was having to my tutor, I pondered the sketches of the rhetorical situation and communication models I had drawn for her. I couldn't shake the idea of this collision between these two concepts: math and the rhetorical situation. It occurred to me that if the math education environment represented a rhetorical failure, that it could be examined as such and that the solution, then, would be illuminated by looking at the problem rhetorically. It was as if I stood in front of a wall covered in cryptic symbols and images, holding a missing piece of some ancient puzzle in my hand, the rhetorical triangle, and, seeing a place for it, plugged it in and the entire wall lit up. I could see the whole situation, I could identify the problems. And I knew I had the life and professional experience to actually do something about it, for myself, and, perhaps, one day, for others too.

I spent the next several days decoding, encoding and then decoding again, the mathematical path immediately in front of me. It came slowly for some parts and quickly for others, but the results, overall, were immediate. My email correspondence with my tutor serves as a basic timeline of this extraordinary process. Using a variety of creative tools, rejecting every convention of traditional math education practice, I turned 30 years of math struggle completely around in under six weeks, and for the first time in my life, I felt, academically and professionally, completely free.

A Matter of Adjusting Tone

If we examine how the current tone of math education affects the communication of the material, we can see that there appears to be a territorial constraint on the tone and semantics of the subject. The diagram below illustrates the current tone I've encountered in the classroom, materials and reference books in my research. With the "mathematical" and "creative" reasoning styles set to diametric poles, I have plotted, roughly, the position of some key figures in my experience and research based on the tone of their rhetoric.

Notice that the space between the wavy lines indicates the field within which the math education discourse is limited, illustrating the skewed influence of mathematical absolutism in the tone of that dialogue. When language and discussion are considered by math educators, there is an almost pathological misconception that engaging in almost any discourse axiomatically compromises mathematical precision (Pimm, 1987).

Those on the outside of that semantic field of discourse may struggle to conform to the narrow semantic and intellectual limitations set by these parameters.

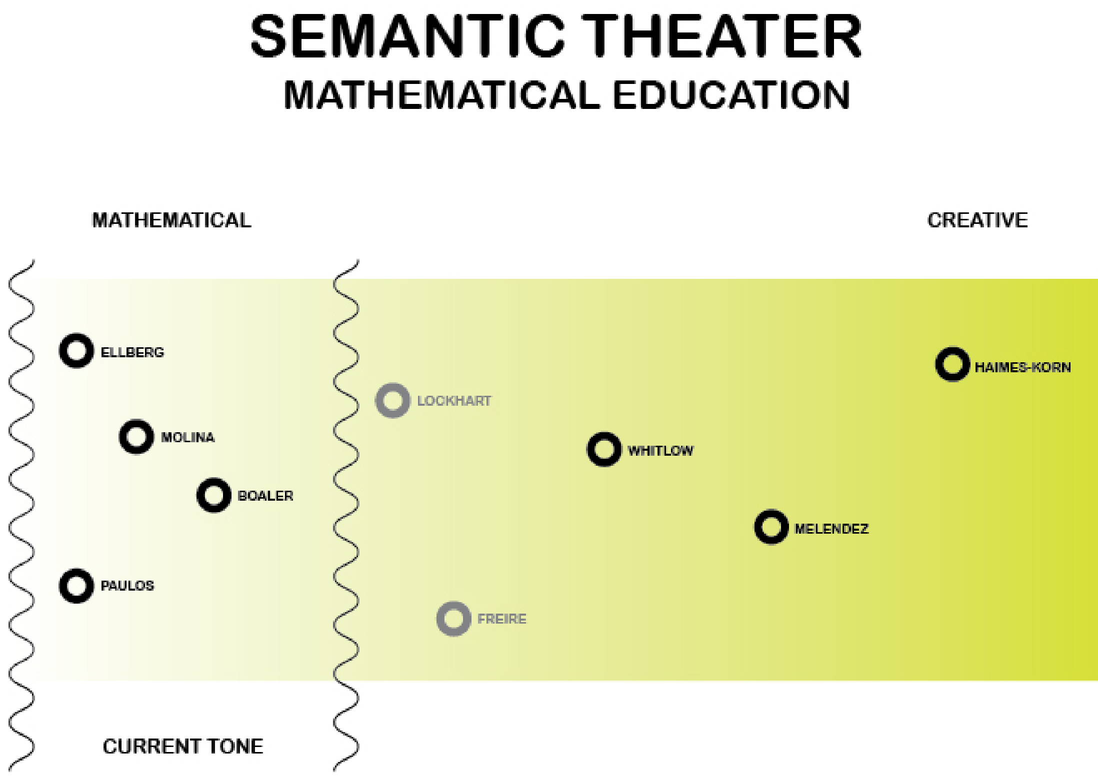


Figure 14. Semantic theater, current tone, a graphic created by Liz Melendez.

Below is an illustration of the adjustment I made to the semantic field in my approach. By incorporating a more creative spectrum of investigative tools, a more balanced and effective rhetorical situation could be constructed for this subject. I was able to shift the semantic field to include the more creative elements of reasoning I later read about in Paul Lockhart's *Lament*, which exposed the simplicity and relevance of true mathematics apart from the confusing notation and language.

Notice the figures plotted on the spectrum now found inside the semantic field of the adjusted tone, and those close or closer to it. This illustrates the postulate accessibility of mathematics to those who are more creatively intelligent.

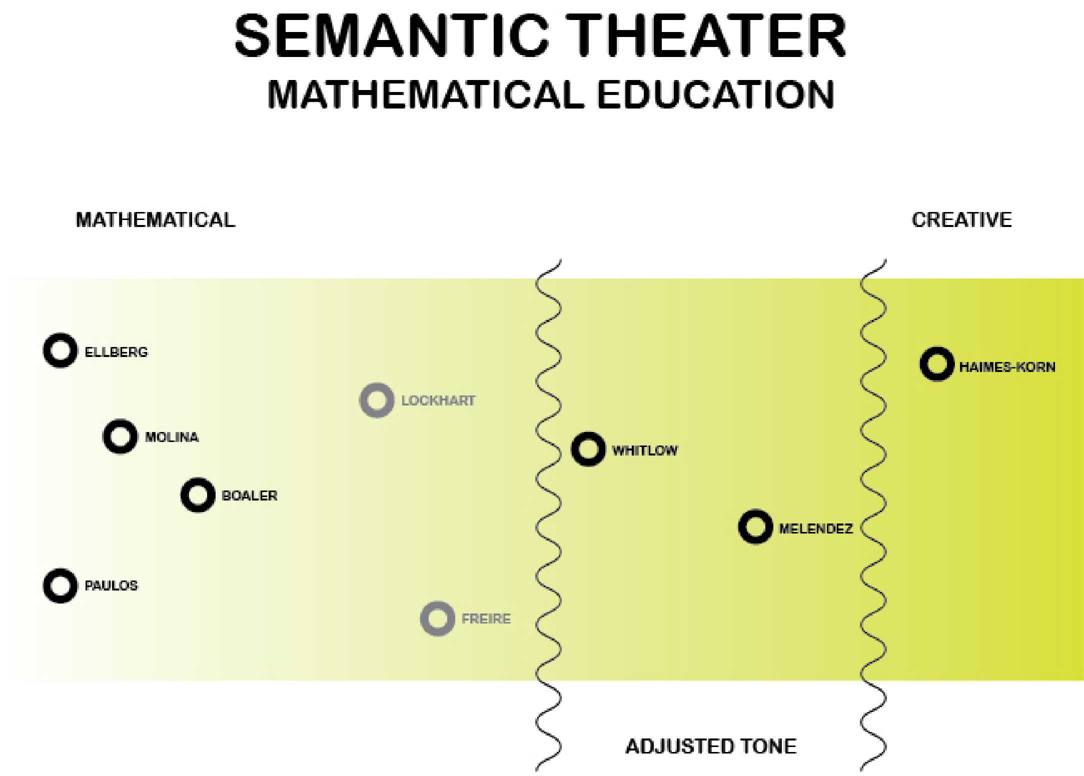


Figure 15. Semantic theater, adjusted tone, a graphic created by Liz Melendez.

By making this adjustment, I changed the rules of how I was allowed to interact with the subject of mathematics. While this did not fundamentally change the math text, it forced a new rhetorical set of rules by which a successful discussion of the subject abides. This shift allowed me to dispatch the subject quickly, right-sizing mathematics as an aspect of logos within a much larger and more sophisticated rhetorical scheme of investigation and reasoning.

Dr. Dottie Whitlow unlocked the restraints, rhetoric set the rules, and my unique set of skills and experience illuminated and actualized the possibilities of this new semantic domain. I do not expect this shift to be a welcome adjustment for some, perhaps many, in the math education community. As I've seen in my experiences with my tutor, and the reactions in casual discussions about changing the tone of how math is taught, many people have a very rooted sense of position and self-image in the current tone. Many are performers who have been petted as "stars" or good "mathematical thinkers." They have been rewarded with knowing other-ness based on their ability to effectively memorize, recite and perform math operations. The shift shown in the illustrations is not for them. My research is not intended to change how performers and reciters experience math education. It is intended to break the unnecessary constraints of exclusion that limit the effectiveness of math education in the spirit of intellectual justice, truly intelligent investigation, and thoughtful scientific discovery.

For open minded math educators who are eager to engage more sophisticated and creative techniques for teaching mathematics, it is essential to understand rhetorical structure and effective communication. Breaking down the barriers between these discourse communities is key, so it might be helpful for senders and receivers to consider the math language teachers are speaking and students are trying to understand.

Chapter Four

The Math Language, Disruption and Rebuilding Trust

Defining what mathematics is, played an enormous role in helping me understanding how it could best be taught. The idea that math is a language seems widely rejected. Perhaps that definition resembles too closely the humanist sensibilities found in language arts and the humanities. In my research it appears that math and science would like to remain as distinct from the humanities as possible. These suppositions notwithstanding, the solution I found lies squarely in the fundamental realization that mathematics bears all of the hallmarks of a language, with semiotics, narrative structures, meanings and contingent associations that culminate in a representative expression of an idea. The only distinction in mathematics, is the imperious adherence to precision often necessary for the development and discovery of reliable data. But while this distinction of math from the humanities does not, in itself, divorce mathematics from its inherently rhetorical foundation, it does seem to have unnecessarily severed the essential congruencies necessary for connecting meaning with the mathematical text. Just as musical notes are not dead symbols that live only on the page to be recited by rote in some experiential void, mathematical concepts are also not dead operations but are rather very much alive, with rhetorical and linguistic relevance, narrative arcs, meanings and relationships that can drive substantive discussion and exploration. This is Lockhart's (2009) math. Math as an art (Lockhart, 2009).

But, it seems the educational community as a whole has been ambivalent on this point. Linguist Michael Stubbs, professor of English Linguistics at the University of Trier, Germany, in his editor's preface to David Pimm's book *Speaking Mathematically, Communication in*

Mathematics Classrooms, discusses the educational community's slowly evolving view on the role of language and discourse in education going back to the 1960s. Pimm's book discusses continued attempts made by linguists to validate the importance of language in learning. It would seem the idea has not progressed much over the past half century. According to Stubbs (1987), "Language plays a central part in education. This is probably generally agreed, but there is considerable debate and confusion about the exact relationship between language and learning" (Stubbs as cited by Pimm, 1987, p.ix). Speaking to the research on this topic at the time and the responsibility of educators and administrators to make informed policy decisions Stubbs says, "Any action that we take – or, of course, avoidance of action – has moral, social and political consequences" (Stubbs as cited by Pimm, 1987, p.x).

Michael Stubbs (1987) also challenges the dismissal of linguistics by "non-specialists" who see this and subjects like psychology, sociology as "fascinating, but of no relevance to educational and social practice" (Stubbs as cited by Pimm, 1987, p.x). He continues, "It is bad theory to make statements about language in use which cannot be related to educational and social reality" (Stubbs as cited by Pimm, 1987, p.x).

There persists an apparent fear that any correlation with language will infect mathematics with subjectivity. Confusion over what language is and how it functions may be at the core of that fear.

Where David Pimm describes attitudes regarding math as a language in the last quarter of the last century, renowned mathematician Keith Devlin (2000) literally writes the book on the math language at the dawn of the new millennium. In *The Language of Mathematics, Making the Invisible Visible* Devlin goes to great pains to define the parameters and functions of the math language. In doing so, Devlin demonstrates the very breakdown that seems to be at the heart of the entire matter (Devlin, 2000). Here, the incomprehension of the math community in how to “speak math” described by Pimm (1987) a decade earlier, emerges as the same register of formal, closed-loop, confusing jargon found in math lectures, textbooks and classrooms (Pimm, 1987).

For example, here is an excerpt from *The Language of Mathematics, Making the Invisible Visible* in which Devlin references mathematician George Boole’s algebraic approach to Aristotle’s syllogisms:

> Boole’s algebraic logic provides an elegant way to study Aristotle’s syllogisms. In Boole’s system, the four kinds of subject-predicate propositions considered by Aristotle can be expressed like this:

SaP: $s(1-p) = 0$

SeP: $sp = 0$

SiP: $sp \neq 0$

Sop: $s(1-p) \neq 0$

(Devlin, 2000, p.61).

Figure 16. Mathematical Syllogisms, a graphic illustration by Liz Melendez based on a diagram from page 61 of *The Language of Mathematics, Making the Invisible Visible* by Keith Devlin.

For those looking to Devlin’s book to gain a better understanding of math, there are only more layers of the same rigid and perplexing language. Devlin is, literally, preaching to the choir as those who understand the jargon and tone in his book are already native to the math language. This points to a very important audience-consideration aspect of this math and rhetoric discovery: the types of people best suited to effectively address and remediate the issue of ineffective communication in math education, are, often, the very people who are alienated by the math subject. It is unlikely that many in the humanities could muster the desire to revisit what for them was probably a traumatic educational experience of marginalization and futility. So, mathematicians and math educators have little choice but to keep begrudgingly repackaging the same ineffective language with the same results, often, with seemingly little if any desire or inclination to go much further.

In this treatise I submit the premises of the relationship between mathematics and linguistic rhetorical principles and have delivered an account of my application of these premises with extraordinary results. Fundamentally, this seems an issue of conflicting worldviews. However, allowing for discussion and critical analysis of mathematics in application can inspire interest in the subject, bring life to the math text and build a bridge to intellectual relevance that can ignite genuine engagement and inclusion in mathematics and science. While mathematicians and math educators seem to fear the corruption of mathematical objectivity, I submit a firm and confident faith in the empirical integrity of mathematical practice. My assertion is that mathematical operations and computations, while remaining supremely objective, must be discussed under the auspices of rhetoric. And it is my contention that mathematics cannot only exquisitely endure being included among interdisciplinary reasoning methods, but will likely thrive within and because of them.

The *Science of the Reading Brain*

The development of written language has its origins in basic mathematics, as the need for symbols was a direct result of the need for keeping track of property, crops and livestock in trade. However, the act of reading, that is, the recognition of symbols upon which one may derive a meaning, is an unnatural function for which the human brain has adapted. In *Proust and the Squid*, *The Story and Science of the Reading Brain*, Tufts University professor Maryanne Wolf (2007) explains that there is no genetic foundation in the human brain for reading, but through evolution the brain has developed fully interdependent cognitive systems that make literacy and numeracy possible. Wolf defines the complex brain processes involved in recognizing and attaching the meanings to symbols necessary in reading. She describes the complexity of this process in which such symbols and meanings are shaped and understood based on a number of factors such as previous knowledge, syntax and context with other symbols. The brain has evolved to adapt its basic object recognition circuitry to recognize letters and then groups of letters which form unique meanings in words. The meaning of words changes as they are situated with other words within sentences, and sentences within paragraphs, paragraphs within narratives, and so forth (Wolf, 2007, pp.9-12). “Because of this design feature in our visual system, called retinotopic organization, every line, diagonal, circle, or arc seen by the retina in the eye activates a specific, specialized location in the occipital lobes in a split second” (Wolf, 2007, p.13). She makes an example of a reading from Marcel Proust to convey how this highly sensitive visual cognition is ultimately constructed by contexts of what the brain has previously experienced. Which is to say, the brain of the reader is not a static repository for input, but the evolution of complex cognitive processes that shape understanding and object recognition by association with previous experience (Wolf, 2007, p.15).

Stanford mathematics professor Jo Boaler (2015) also addresses the extraordinary plasticity of the brain in her book *Mathematical Mindsets: Unleashing Students' Potential through Creative Math, Inspiring Messages and Innovative Teaching*. She tells the story of an unusual medical procedure in which the entire left hemisphere of the brain in a 9- year-old girl was removed to stop uncontrollable seizures. After the surgery, the girl was paralyzed as the left hemisphere controls motor function. “But as weeks and months passed, she stunned doctors by recovering function and movement that could only mean one thing – the right side of her brain was developing the connections it needed to perform functions of the left side of the brain” (Boaler, 2015, p.3). Boaler continues, “The new findings that brains can grow, adapt, and change shocked the scientific world and spawned new studies of the brain and learning…” (Boaler, 2015, p.3). This example of brain plasticity demonstrates how little we understand about the brain and how it learns.

Understanding how the brain processes symbolic representations to build meaning is essential in recognizing how to best convey these representations. In the math classroom, the symbols enter this cognitive process but are divorced from the aesthetics and context of previous knowledge involved in constructing meaning as described by Wolf. It seems as though mathematics has abandoned such aesthetics in favor of an insular and superficial value system limiting the meanings of symbols to nothing more than mindless directives telling students “When you see this symbol, do this action.”

In *Mathematical Mindsets: Unleashing Students' Potential through Creative Math, Inspiring Messages and Innovative Teaching* Jo Boaler (2015) describes the role of language and dialogue in how the brain learns:

> If you learn something deeply, the synaptic activity will create lasting connections in your brain, forming structural pathways, but if you visit an idea only once or in a superficial way, the synaptic connections can "wash away" like pathways made in the sand. Synapses fire when learning happens, but learning does not happen only in classrooms or when reading books; synapses fire when we have conversations, play games, or build with toys, and in the course of many, many other experiences" (Boaler, 2015, p.1).

Like water leaking from a sieve, remembering math language and operations always had this fleeting characteristic that prevented deeper understanding for me. However, rhetorical sensitivity, which is the essence of effective communication, employs principles that appear to innately facilitate effective recognition, interpretation and use of symbols. This seems to correspond naturally with the way the human brain processes and retains information.

Semiotics, Math Symbols

Semiotics defines a symbol as a sign that represents something based on a learned and shared understanding of the representation. For example, a letter or music note is understood based on the language and culture within which it is used. As opposed to an icon which is a sign that looks like what it represents, such as a spark shape for electricity. An index is a sign that implies a relationship that points to what it represents such as smoke indicating fire. This cursory explanation may help to understand some of the confusion around written language symbols found in math notation.

Considering how the brain erupts with activity at the sight of written symbols, it would seem natural to consider how we build meanings, particularly shared meanings, between individuals, cultures and discourse communities. When we use similar symbols for different meanings and present them without context, we may be forcing the brain into a superficial default of transient rote memory operations. For example, the letter “x” is introduced early as an operational symbol for multiplication. Later, it is reintroduced, usually with little or no explanation, as a symbol for an unknown value, a variable. Around this same time, operational symbols for multiplication become a splayed group of disparate symbols: a dot (•) between numbers, parentheses around numbers, or no symbol at all with a number (a coefficient) and a variable positioned together. Parentheses are then also presented as grouping symbols with a variety of rules and juxtapositions that affect their use. Such confusingly arbitrary definitions of symbols would require a well-structured sense of cultural meanings and linguistic associations to be effective. However, in the absence of such structure, when presented without any context outside of the local application, for instance the operation between numbers in a particular problem, there is no opportunity for internalized and recursive experiential learning.

Theoretical physicist Richard Feynman (2010) found traditional math notation so untenably inefficient, that he developed his own form of notation. Within his own work, he found his notation much more intuitive. However, he discovers the problem will be in doing work with others (Feynman, 2010, p.24). The lack of shared meanings prevented Feynman from being able to use his form of notation on an on-going basis, but the story bears noting. Not because a new notation should be developed, but for the reason stated earlier, that the notation as it stands requires a well-structured sense of cultural meanings and linguistic associations. Math teacher Bill Shillito (2015), in his presentation on notation to the Georgia Council of the Teachers of Mathematics said "math is not about notation, it's about ideas" (Shillito, 2015). During his presentation he discussed how traditional math notation impedes learning, with students wasting most of their energy dealing with the cryptographic aspects of assignments rather than on intellectual engagement with mathematical concepts.

Rhetorical Choices in the Math Classroom, an Example of a Successful Process

In one of my early attempts at taking college algebra, I sat in a lecture on the union and intersection of number sets. The basic concept is about the numbers two sets have, or don't have, in common. The numbers two sets have in common are called intervals. The professor, in a dry monotone blew through the topic and quickly drew the following diagrams to illustrate it:

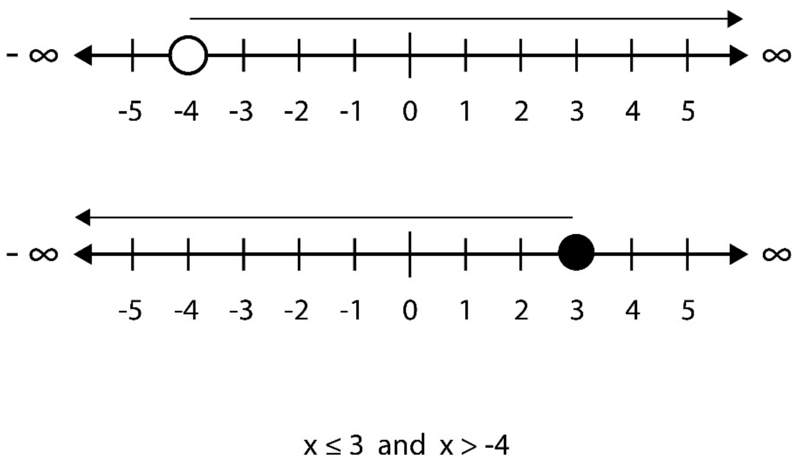


Figure 17. Illustrations of professor, a digital graphic by Liz Melendez.

The representations on separate number lines made it difficult to see the relationships between the number sets. With trepidation, several students asked questions. Judging by the tension in the room it seemed the class was having difficulty understanding. Having taken the class several times before, I was familiar with intervals, unions and intersections. It was something I did understand because in a previous experience with a different instructor, the illustrations done on the board were much clearer. I asked the professor if he could please redraw the two representations with both number sets on a single line. He did not understand my request so I called out the illustration step-by-step and he redrew them on the board. With every step he seemed to get more irritated, angrily scratching each mark with degenerating detail.

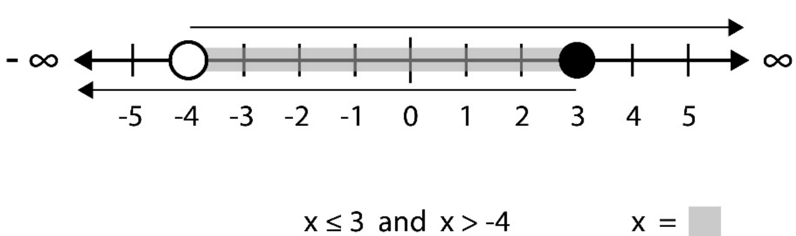


Figure 18. Illustration that worked, a digital graphic by Liz Melendez.

When he was finished, the entire room shuffled back in their chairs, and a collective “Oh!” sighed from a smattering of relieved voices.

This is an early and very rudimentary example of the type of process I would eventually use in a macro scale to conquer the entire subject rhetorically. However, it is not as simple as a change in a diagram. A communicator is trained and skilled in every nuance of every rhetorical choice. Each decision is part of a thoughtful and crafted endeavor and should not be taken too much for granted as the simple implementation of graphics and word choices. Years later, when I was trying to explain rhetoric, particularly visual rhetoric, to my tutor, she directed me to a website where she found a graphic of functions represented using different colors. Because I had mentioned the importance of color choices she felt that this website was proof that what I was saying was nothing new. Her comment was something like “See there, that color thing you were talking about is already being done.” However, she was not aware of the affect a barrage of primary colors, indiscriminately chosen, has on the eye. Nor was she aware of what an assault on the senses that can be when one is trying to communicate a message.

As an example, I can’t just pick up an instrument I’ve never played and start banging on it, and, in hearing a sound say to a practiced and skilled musician, “See there, I’m doing the thing you’re doing and making sounds. I’m a musician.” Rhetoric is an art, and the communications involved in the practice of this art are guided by principles understood by those who are proficient in high levels of effective and thoughtful discourse. Anyone can learn to use rhetoric. But it takes a conscious practice and study of how language functions to become fluent in the craft.

The ineffectiveness of the professor’s visual rhetorical choice from the example, was compounded by his additional rhetorical choices: a harsh response to my request for an additional graphic example, an irritated vocal tone, using abrupt body language as he drew the new diagram, the hasty and degenerating quality of the drawing. However, this rhetorical breakdown, which I had become accustomed to experiencing in the math classroom, was remedied by my request to create another common visual representation that was clearer. His rhetoric in turn conveyed a message about what a student might expect if they asked questions. But my pressing forward, largely attributable to the fact that I am an adult and more inclined to assert myself where an 18-year-old student might not, forced the instructor to engage in a new and more effective rhetorical situation. And, like my tutor would demonstrate years later, it seemed clear that he did not welcome this kind of communication in his classroom. The exchange with this instructor was arduous and this one small example of successful rhetoric took a considerable amount of energy for me to implement. Hopefully, this gives some indication of how much work it took for me to implement this process continuously across the entire subject over the course of several weeks to develop a new and working model of math education for myself. Which is why the adaptation of it, for me, is so crucial in making it useful on a larger scale. I have done all the heavy lifting. My focus now is on further research and developing a fully-functioning and accessible methodology.

Techne, Linguistics and Math Education

In Aristotelian logic, *techne* involves the technical skill or craft of a practice. In mathematics, this would be the ability to thoughtfully perform operations and computations. On a musical instrument, this is the ability to produce the correct tones effectively with the correct timing.

Linguist Noam Chomsky (2007), who has published notable works on mathematical intersections in linguistics, advises in his book *On Language* that one should mind the overlap of contingencies in engaging topics of the humanities and social sciences versus topics such as mathematics, where some technically specific computational fluency (techne) is integral to sound practice (Chomsky, 2007, pp.124-126). It appears, then, that it is important to consider how much precision and computation is actually required to discuss and gain understanding about mathematical ideas and to understand the distinction between the discussion of those ideas and the technical engagement of mathematical text. According to Lockhart (2009), the non-numeric, non-computational space is where pure mathematics begins – with ideas and abstract creativity that can lead to more substantive engagement with the techne – the operations and symbols of the language (Lockhart, 2009). By sensing where the creative and the technical overlaps occur, one can determine the role of technical aptitude and then apply it only when it is integral to the process. More importantly, however, one can also recognize how learning is undermined when the technical contingencies are misplaced and unnecessarily imposed upon the humanistic features of the practice.

Invariably, engaging in a pure mathematical text, while benefitting greatly by the virtues of Lockhart's creative inspiration, will eventually require a degree of technical aptitude at the operational and computational level. But teaching math concepts is the delivery of information to human students, which requires humanistic fluency distinct from the technical aptitude found in the mathematical text itself. Similarly, music, which benefits greatly by a genuine artistic fluency of the musical language, will involve the practical and effective application of mechanical aptitude on an instrument. Just as technical recitations on an instrument do not demonstrate musical fluency, simply being inspired to play beautifully isn't enough, practicing and mastering the mechanics of musical technique is essential.

Reversing the Flow

Chomsky's work on the mathematical features in linguistics has established him as a respected authority in the mathematics community on the formulaic nature of how languages are formed. In David Pimm's (1987) *Speaking Mathematically: Communication in Mathematics Classrooms,* the interdisciplinary question also seems to only flow one way, as Pimm suggests that teachers of English could benefit greatly in what they could learn from teachers of math (Pimm, 1987). While he mentions a possibility of some reciprocity, the notion is immediately marginalized by the author's admitted inability to see how language could engage mathematics except for the possible use of metaphor in descriptions (Pimm, 1987, p.7). In *Developing a Mathematical Vision, Mathematics as a Discursive and Embodied Practice,* chapter two of the research volume *Language and Mathematics Education: Multiple Perspectives and Directions for Research*, a citation attributed to Pimm (2010) concedes to the idea of linguistic attributes in mathematics "as a language register that carries 'a set of meanings that is appropriate to a particular function of language" but, again, the terms seem very measured and provisional (Pimm as cited by Gutierrez, Sengupta-Irving, Dieckmann, 2010, p.38). This is consistent with the tone of many works related to language and mathematics I found in my research.

It is common to find references to the influence and value of "mathematical logic" on the critical thinking that occurs in the liberal arts disciplines. It is as if the concession that the relationship exists between the disciplines is only in the value flowing from science and math to the liberal arts and humanities for the latter's benefit. However there are articles to be found from the math perspective that espouse the virtues of the humanities and the arts in math, science and engineering education. One such article from December 2014, titled "*Full STEAM Ahead: A Manifesto for Integrating Arts Pedagogics into STEM Education*," (2014) cites the inability of the engineering world to recognize the value of the arts and humanities as the "disciplinary egocentrism of [engineering educators]… a failure to see connections between a given discipline and an interdisciplinary subject or problem, which limits the ability to incorporate new ideas and practices." (Connor, Karmokar, et al., 2014, p.7) Connor, Karmokar, et al., cite this as a possible factor in the breakdown of interdisciplinary applications. The title, "A Manifesto…" seems to imply the outlier positioning of this topic, and the date indicates that professionals are still talking about the concept of the application of the arts and humanities into science and mathematics in terms of theory to be argued. While some schools may be adopting the STEAM (science, technology, engineering, arts, mathematics) moniker as a replacement of the former STEM, which excluded the arts, it appears that the traditional STEM fields are having difficulty adapting to this evolving pedagogy. Jo Boaler (2015) found in her extensive research that "math was the STEM subject whose professors were found to hold the most fixed ideas about who could learn" (Boaler, 2015, p.95).

Several articles can also be found acknowledging the possible need for a revolutionary change in science and math education, however the language is still very measured. The term "interdisciplinarity" appears to be a salve for the irritation caused by being forced to consider the arts and humanities in the study of science and math. And while the door is cracked open, there is no mention of modern rhetorical practice in any of the articles I've found on the subject. There is only very broad reference to the possibility of taking more seriously the data that has shown positive results for interdisciplinarity in educational practices. Of the studies and articles that do exist, almost none of them seem to come from the United States where, according to an article by Robert DeHaan (2005), the demand in science and engineering fields is "growing at the rate of almost 5% while the rest of the labor force is growing at just over 1%," as our failure rates in math and science continue to escalate (DeHaan, 2005, p.254) (NSB, 2004).

It was by reversing the flow that my discovery was made. The original description of the experience I shared with Dr. Haimes-Korn was that I felt as though I was crawling backward through the failed rhetorical model and doing everything in reverse. My taxonomical process was basically upside down. I had nothing to guide me through the development of this method except my experience, my creativity, my communication skills, my intuition and my absolute unwillingness to give up. Dr. Whitlow said she and her contemporaries in the math education field had never heard of anyone who had tried as long and as hard as I had to succeed at math. In finally working out a solution I was not encumbered by the ideological constraints of math or math education culture that brings fear to the math community and brought anxiety to my tutor. Once the blinders of the student experience with mathematics were removed by my original conversation with Dr. Whitlow, it cleared the way for an unobscured view of the issue. Such a perspective was perhaps unique to someone like me at that time. Someone with the skills and willingness to make the best use of this revelation. Someone who would not hesitate to reverse the flow. Someone who had the emotional maturity and persistence to push the investigation forward, and someone with the mentorship of a respected agent from the opposite discourse community with a like mind for seeking real solutions to the math education problem.

Aims in Discourse: “Doing” math vs. “teaching” math

If one considers the differences between the aims of discourse in mathematical practice and mathematics education, it may be easier to view the intersection of these with clarity. To do this, it is important to consider how language is used as it relates to the intended purpose, or aim of the discourse. James Kinneavy (1969) offers a very useful definition of language distinctions by Aristotle, who called science “language directed to things” and rhetoric “language directed to persons” (Aristotle as cited by Kinneavy, 1969, p.301). While it is my proposition that the principles of rhetoric can be applied to the relationships of affect between things, ideas and people, it is important to recognize that, as a commonplace, even the classical definitions set rhetoric apart from the material practices of science, and, by proxy, mathematics. We are, therefore conditioned to accept the difference between how language functions in mathematical practice as operations between numbers and how language functions in rhetoric as communication between people. This distinction gives us an important clue to possible solutions to the math education problem.

One of my first personal discoveries during this math education and rhetoric experience was the realization that math teachers are rarely, if ever, mathematicians. Learning this came as a shock to me, and it bears similarities, once again, to the music world. Many music teachers have no actual musical experience beyond a number of demonstrations of rote recitation. So, the deviations between mathematics and mathematics education could perhaps be directly attributable to the projection of technical expectations onto teachers trained in rote memory operations as if they were mathematicians possessing genuine mathematical fluency. These expectations are then unjustifiably projected onto students.

These differences point to a breakdown between two discourse communities, mathematicians and math educators, with each possessing unique linguistic codes and registers, and who actually share very little in common. The mathematics world has its own rhetorical and narrative structures and aims. However, the math education world is really more accurately characterized as a communicative endeavor, and thus rooted in the rhetorical realm of the social sciences and in the classical traditions of academia. If we follow the classical Aristotelian definitions, then mathematics is a dialogue with things (science), and mathematics education is a dialogue with people (rhetoric) about things (science) and this distinction demands its own unique set of methods and expectations (Kinneavy, 1969, p.301).

Taxonomical Considerations

In order for me to make best use of Dr. Whitlow's insights, I had to dispose of all previously accepted models for learning math. The parallel between mathematics education and music education was apparent, and while I could not model my musical experience completely by going back in time to be reared by a mathematician like Paul Lockhart who could teach me the intrinsic value of pure mathematical theory the way my father taught me about music, I could at least be free of all that had been flatly ineffective in the traditional math education process. For this, I actually rearranged a taxonomical model that worked in an extemporaneous and organic sense of order for the unusual situation in which I found myself. Which is to say, I did what made most sense for the most immediate task and followed that sequence to a successful end.

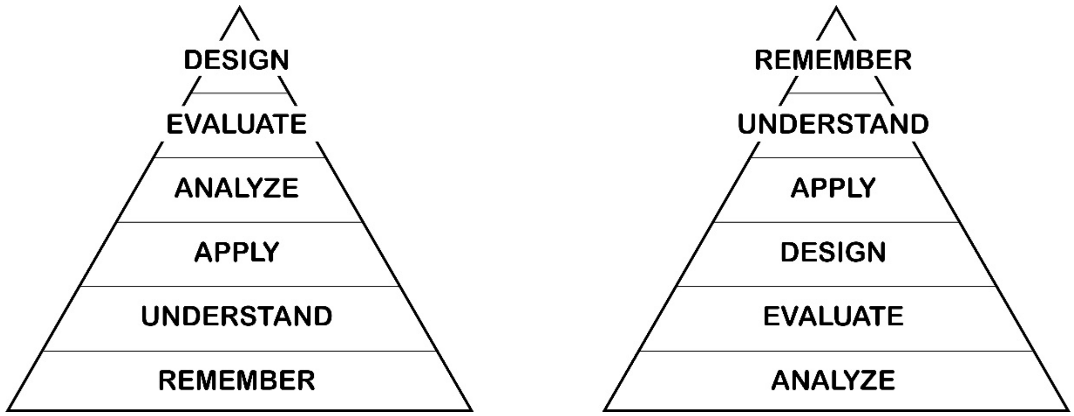


Figure 19. Taxonomy comparison, left, Bloom's taxonomy, right, my taxonomy, graphic illustrations by Liz Melendez.

This new taxonomical order evolved loosely in the following sequence:

Analyze: In the arrangement up to that time, the math material and text had been disconnected, irrelevant, and highly resistant to useful analysis beyond transient application. In my taxonomical model, I used the adjusted perspective gained from Dr. Whitlow's affirmation to analyze the rhetorical situation, the material and the text and contrast it against previous experience.

Evaluate: Through an evaluation and rhetorical examination I determined, among other things, that the material lacked context and was not founded in the rhetorical framework necessary for it to be effectively conveyed to a student audience. In this case I was the audience, but I considered the rhetorical situation for an ideal audience – students who struggle in the math classroom. By realigning the entire subject based on effective rhetorical principles, I was able to extract the actual mathematical content from the tangled mess created by what I later determined was a failed or non-existent communication model typically used in teaching math. I was able to separate what was supposed to be communicated from the "confused heap of destructive disinformation" that was actually being delivered (Lockhart, 2009, p.55). This compartmentalization allowed me to interact directly with the text, the math, and begin to interact with the concepts in terms of the semiotics, narratives and contexts. With this separation I could now look at the math and then begin to decipher what needed to be communicated. From there I was able to build a recursive cognitive structure upon which I could finally, truly depend.

Design: During this process, the interactions with the texts compelled me to create (design) an entirely new communication environment, a new, working rhetorical situation into which I could feed the mathematical text, and, by playing both the part of the speaker and the audience, I could insure the rhetorical integrity of the process. This was the point at which my tutor seemed to experience the most anxiety, as her role in this new model had shifted from that of the "knowing other" to that of a translator. It made her visibly uncomfortable to have to try and demonstrate knowledge beyond the rote operational understanding. Although my method was incomprehensible to her, she was helpful with the operations and with checking my answers which at this point was all I needed.

The design process then became a literal endeavor, as I began to use my graphic design skills to create my own materials for documentation and study. This highly kinesthetic interaction with the text was also important to how I was able to effectively internalize the material so quickly. At times it was infuriating to discover how simple a concept actually was after reviewing the convoluted representation of it as it had been taught to me previously.

Apply: By using my communication and graphics skills to design new and effective material for myself based on the math concepts, I was able to apply the concepts effectively and demonstrate a higher measure of fluency than ever before in the mathematics classroom, on homework and on tests.

Understand: Engaging in a rhetorical dialogue with my tutor and fellow students, designing materials, working on problems and homework examples, brought about fluency in application. My exam results reflected this shift, and I entered into each math exam with a growing confidence I had never experienced before. I truly understood the material for the first time, and was, from that time forward, finally free to engage the subject of mathematics to any degree I wished.

Remember: For years previous the small droplets of understanding I could divine by working with tutors, doing myriad practice problems or looking at videos resulted only in transient moments of comprehension. These droplets quickly evaporated without the context of interdependent rhetorical concepts that could have created meaning and helped with retention. While some memorization techniques worked for limited comprehension in the short-term, I could never retain the information long enough to perform on exams. However, with this new model, I could catch the droplets, or knowledge, in a bucket of my own construction and could comprehend and retain that knowledge within a contextualized taxonomical structure using a rhetorical process. I could then deposit these into whatever type of application I needed: homework, tests and dialogue. Since I was no longer dependent on a teacher or tutor to deliver the material one hard-fought drop at a time, I was free to refill my bucket with a pure understanding of the subject which facilitated further taxonomical development. Fluency became the font from which I would at last be able to draw any mathematical knowledge I needed. I would never have to be struck with the fear described by Julian in Dr. Molina's book, a fear borne of the insecurity in the limitations of what one actually understands versus the rote performance and parroting of formulas and operations. I could use contextualized memorization techniques and remember the mathematical concepts, because they were animated and kept alive in the logos (data) of a working rhetorical framework that demands communicative efficacy. I supplanted the entire math education model with one of my own invention, based on the classical model of education and reason, and built with modern skills to effectively communicate mathematical text.

Presentation for the GCTM

After the success of my project, I was invited to share my story with the Georgia Council on the Teachers of Mathematics (GCTM) at their annual conference in October 2015. Dr. Whitlow and organizers of the conference felt it was important to feature a story like mine, an experience from the student perspective, and as an effective communicator, I was uniquely equipped to deliver this message.

I prepared a presentation for the conference – a retrospective of my process based on my thesis, for the purposes of providing a brief description of my experience. Dr. Whitlow suggested the use of some interactive elements that could engage the audience and leave the educators with some useful take away concepts. I created a thoughtful and compelling visual presentation and designed a companion booklet the audience could use to make notes and take with them.

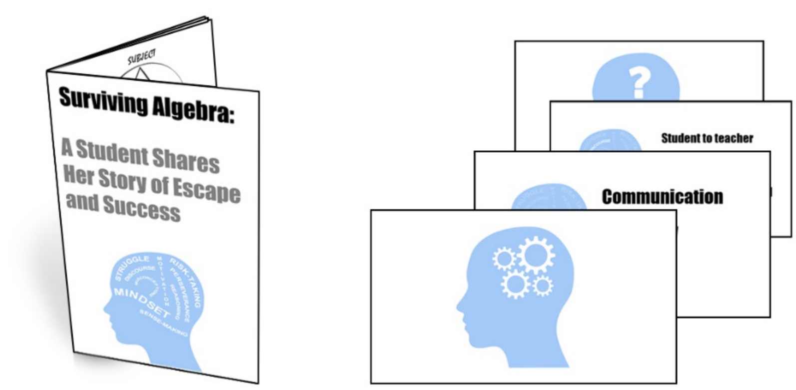


Figure 20. GCTM presentation materials, graphics by Liz Melendez.

My ethos (credibility) was established by Dr. Whitlow's introduction of me as her music instructor, the momentum of which I used to propel the beginning of my presentation. I discussed the parallels between music and mathematics and the fallacies that drive the confusion of both in the educational setting. Using succinct examples and visual elements, I introduced a small but engaged crowd of about 15 math educators to the principles of rhetoric and illustrated the role it played in my success. I found this group curious and they readily participated in the dialectic style of my demonstrations. It was important to me, that, while educating this audience, I effectively demonstrate in my presentation the principles of rhetoric in education described in this thesis. This made the GCTM presentation itself a real-time, real-life exhibition of my theories.

At the close of my presentation, my tutor, who was in the audience offered a message of advice to her fellow educators. Having come through this process and witnessing it first-hand she urged others not to make the mistake of disregarding the variety of ways in which students learn.

Math Education Culture

Exposure to this population of math educators at the GCTM, in addition to my many classroom experiences, has been very informative. From a rhetorical perspective, an analysis of the speakers is essential to understanding, at least in part, how the breakdown in communication occurs in the classroom. I learned that there are many educators and administrators who recognize a problem and would like very much to find and implement a solution. Some are hindered by the misapprehension of where the deficiencies lie, but seem earnest and amenable to learning about how to be more effective.

My understanding of reformist efforts in math education is that such overtures are hindered by deeply entrenched systemic resistance. The desire of math educators to improve math education appears to be almost a hushed and tempered movement against ineffective and draconian inflexibility. The culture, according to David Pimm (1969) seems to suffer from a resistance to communication for fear of "…involving, and hence, exposing the self," in the interest of preserving the impersonal objectivity of mathematical practice (Pimm, 1987, p.70). This resistance to communication was certainly evident in observing the behavior of my instructors and the reactions of my tutor. However, as Dr. Concepcion Molina's shares in the story of Julian as himself, the instructors may in many ways be aware of their limitations and, consequently, may be terrified of feeling exposed.

Because of this fear, math reformists seem to operate informally, in small, quiet factions of like-minded instructors and administrators. For some, Jo Boaler's experience with Drs. James Milgram and Wayne Bishop at Stanford, which I will discuss in the next section, may serve as a cautionary tale, discouraging math teachers from pursuing an outright censure of their professional community. In *Mathematical Mindsets: Unleashing Students' Potential through Creative Math, Inspiring Messages and Innovative Teaching* Boaler (2015) mentions a culture of math teachers who "…think they are superior to teachers of other subjects in their schools, and who think their job is to find the few math students who are special like they are" (Boaler, 2015 p.95). Dr. Whitlow has shared numerous accounts of resistance from peers who resented the effectiveness of her unconventional teaching methods (personal communication, August 4, 2014). Such effectiveness is likely a threat to those whose entire identity is tied to the erroneous hierarchies of their profession. Meanwhile, the corrosive status quo of attitudes and curriculums as described by Paul Lockhart are an oppressive force bearing down on conscientious educators and hopeful students alike.

It is difficult to broach the topic of inefficacy in math education without the inference that such redress is simply blaming math teachers for the problem. This is a difficult and complex intellectual conversation that needs to happen if a real solution to the math education problem is to be found. Math reform as it is discussed here is not an issue of blaming math teachers, but rather an indictment of the culture within which they are cultivated and must operate. It is the presentation of a premise based on an autoethnographical account which demands a thoughtful examination of the intellectual pedigree of our math and science communities and the effects of it on the math education community. Albert Einstein famously postulated that “you cannot solve a problem using the same thinking that created it”. So, there is likely a worthwhile analysis to be found in tracing the steps of my discovery backward to determine why my method was so immediately and innately effective in the face of enormously ineffective teaching practices coming from within the cultures that appear to have produced the problem.

The Essential Art of Disruption in Change

Jo Boaler could probably be considered the preeminent authority on the difficulties of math education reform. In his essay, *Mathematics Educators and the “Math Wars”: Who Controls the Discourse?* David Stinson (2012) discusses the power play at the heart of Boaler’s well-documented story of professional and personal persecution. The abuses she experienced epitomize the oppressive climate experienced by math reformists at the hands of the traditionalist power structure of mathematicians who have positioned themselves as the arbiters of the practice and education (Stinson, 2012, p.2).

As Dr. Boaler conducted her research into more evolved approaches in math education, her fellow Stanford mathematics professors Drs. James Milgram (who should not be confused with Dr. Stanley Milgram mentioned in an earlier section) and Wayne Bishop endeavored from the very beginning to block her efforts. The two waged a vicious campaign of personal and professional harassment against Dr. Boaler, her associates and the subjects involved in her research (Boaler, 2012). The latter of these, perhaps the most insidious, as the anonymity of research participants was breached by Milgram and Bishop invoking their considerable academic power to exact the personal information of people who were involved in Boaler's studies. This information was then disseminated and used to harass the participants directly. Milgram also attempted to destroy Dr. Boaler's career with charges of scientific misconduct. Stanford determined the "allegations were unfounded and terminated the investigation" (Boaler, 2012). Dr. Boaler eventually left Stanford in 2006 under the pressures of Milgram's and Bishop's persistent efforts to harass and discredit her, returning home to England for a number of years. In 2010 she was invited back to Stanford with full apologies from the institution, however Milgram and Bishop offered no apology and continued to teach at Stanford after Dr. Boaler returned. But the story is public and available on Dr. Boaler's Stanford webpage for all to view (Boaler, 2012).

A change in mindset is certainly part of the solution, as Dr. Whitlow's exposition changed my mindset. The essential difference is in designation. "It's not you, it's them," was not only a revelation, it completely reset how I saw the problem which allowed me to dump the ballast of erroneous thinking. The resultant empowerment of this shift was essential to the positioning that made a non-mathematical solution visible to me. Without it, I may have made some progress, but would have likely been blocked from the intellectually liberating experience from which I gained the most insight.

Judging from the struggles Dr. Jo Boaler initially suffered in the so-called “math wars,” it may be that the level of disruption necessary for the most change should not come from within the oppressive mathematics community, but from well outside of it. Such free disruption is the luxury of those who do not bear contingent associations or professional affiliations that might hinder the process and obscure the view to a better path. Reformists may do well to form unlikely and powerful alliances as they may find that those who understand the math education problem best are those from other disciplines who have actually suffered from it.

The Right Wrong Way: When the Path is Not Always Obvious

Thirteenth century Portuguese sailors, wishing to expand their expeditions southward to the west coast of Africa, encountered extreme difficulty returning home upwind. “Forcing their way against the trade winds” they found was “a slow and perilous business” which dramatically limited the expansion of their enterprises (Bentley, Ziegler, 2011, p.469). Those who had succeeded continued this extremely difficult and labor-intensive upwind journey until the discovery of a return route that involved sailing in the opposite direction of their home port, heading into the open sea. The “volta do mar” (return through the sea) was a course that took sailors farther out into the Atlantic ocean where they discovered the prevailing westerly winds that sailed them easily back to their home port (Bentley, Ziegler 2011, p.469). It was counter-intuitive, but it led to a discovery that would ultimately make it possible for navigators like Christopher Columbus to sail to and return from the New World (Bentley, Ziegler, 2011, p.469).

Malcom Gladwell, in an interview with Jill Krasny says, "Successful disrupters are people who are capable of an active imagination". He continues, "They begin reimagining their world by reframing the problem in a way no one had framed it before" (Gladwell as cited by Krasny, 2012). Portuguese sailors made the discovery of the volta do mar by sailing in the opposite direction of their home port, into the unknown to discover the power of winds in a territory outside of their own, efficiently and effectively circumventing adverse and dangerous conditions instead of fighting against them (Bentley, Ziegler, 2011, p.469). As a result, incalculable possibilities were revealed, the history of mankind was forever changed and it set into motion the unfurling of boundless new frontiers that shaped our world. Having discovered a new and dramatically effective route myself, I can suggest with confidence that it may be time for the math education community to change course, and sail into unknown and uncomfortable territory.

The Case for Other Ways of Knowing and Learning

In her Ted Talk noted autism advocate Temple Grandin, Ph.D., (2013) discusses the paramount importance of instructors and institutions coming to recognize and acknowledge the variety of possible ways people know and learn. She states specifically that "…more kids need to skip algebra and go straight to geometry and trig," shedding the unnecessary rigor in order to make way for the higher-level reasoning at work, particularly in some people with autism (Grandin, 2013). Grandin goes on to suggest that Einstein, Mozart and Tesla would likely be diagnosed on the autistic spectrum today, and as "other" thinkers and learners, they would likely have been marginalized and the world would have been deprived of their collective and individual genius.

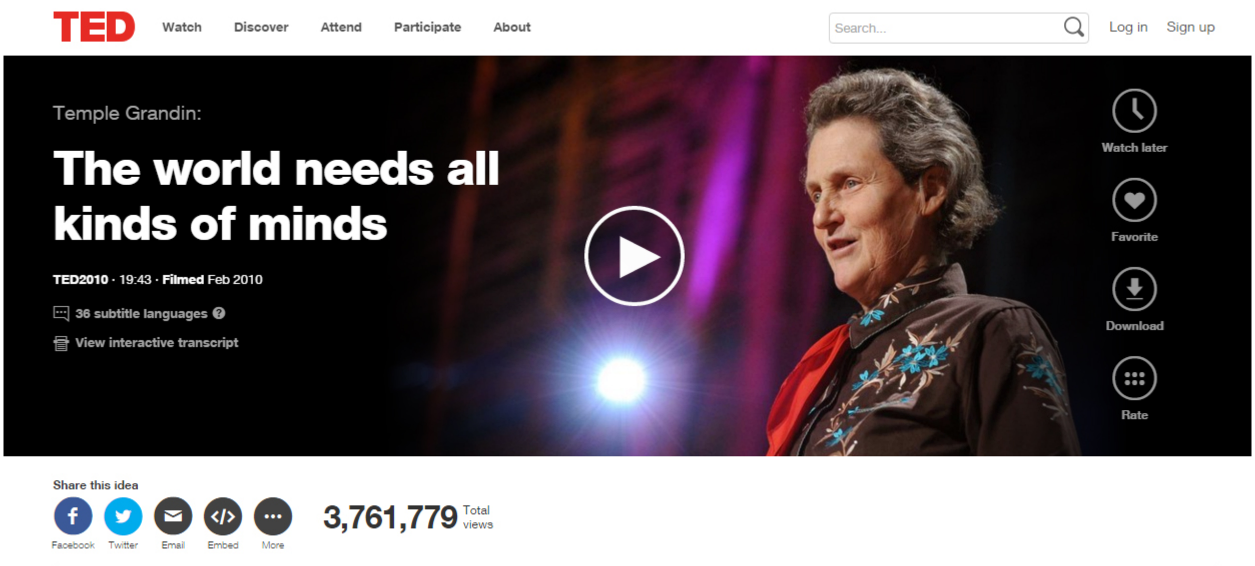


Figure 21. Temple Grandin Ted Talk screenshot. Source: Ted.com

How many Einsteins or Teslas are having their intellectual curiosity and confidence crushed every day in math classrooms all over the world? If math is set up as an erroneous gateway to higher education, how many unwitting victims are having their spirits unnecessarily broken, abandoning college or dropping out of high school? In *Speaking Mathematically: Communication in Mathematics Classrooms*, David Pimm (1987) cites the "increasing use of mathematics qualifications as a 'critical filter' for many jobs in our society, despite evidence that little of the content nature is actually required by many such positions" (Pimm, 1987, p.153). The sociological and cultural ramifications of this "filtering" seem apparent as Pimm (1987) notes some in the math and science education communities "…have feared for the exclusion of certain groups (ethnic minorities, girls) from the knowledge of 'high culture' (be it Shakespeare or Euclid) which gives access to power" (Pimm, 1987, p.155).

Research mathematician, educator and author Paul Lockhart (2009) comes as close as anyone I've read in my research to truly understanding the problem in math education, and he makes no bones about its destructive influence on humanity. “The mathematics curriculum doesn’t need to be reformed, it needs to be scrapped” (Lockhart, 2009, p.37). He writes beautifully and expressively, extolling the virtues of true mathematics as distinct from the monstrosity that has become the math curriculum. His belief is that what is taught and how it is presented is as far from true mathematics as anything could be. He goes on to say that pure math is “…wondering, playing, amusing yourself with your imagination” and that the subject is “…really about raw creativity and aesthetic sensitivity” (Lockhart, 2009, pp. 24, 30). He marvels at the possibilities of being creative and maintains that creativity is where math derives its real power. From my experience, math, as an art form among other art forms and methods of examination, inquiry and discussion would be far more interesting and infinitely more relevant in an evolving and changing intellectual world.

Educational Disaster and Recovery

The Dust Bowl of the late 1930s was a man-made environmental disaster brought about by misguided and over-zealous agricultural practices. And while the banks saw to their interests, it was ultimately the farmers and those who relied on the agricultural system who suffered. Today we find ourselves in an educational dust bowl of sorts. The current state of math education could be called a man-made intellectual disaster perhaps brought about by misguided and zealous educational practices in this subject. While it appears that some may be seeing to their interests, it may be the students and the teachers who want to be effective who are suffering.

Regardless of which side of this issue a reader finds himself, it is a mathematical certainty that to continue on a tack that strips a situation of substance while expecting substantive results is a fallacious path of ever-diminishing returns. It was the thoughtful re-seeding of the soil over time that brought our nation back from the brink of environmental annihilation. Similarly, it will require an equally thoughtful re-seeding of our intellectuality to bring us back from the brink of educational annihilation in the subject of math.

Our parting sentiments…

When I called my tutor at the end of that first successful semester to talk about my triumphant final exam grade and finally passing my required college algebra class, a peculiar conversation ensued. While she was pleased with the results, it seemed she could not get comfortable with accepting the process by which the success came about. She said she just couldn't believe how quickly I grasped the math concepts, to the point that in the early weeks she believed my difficulties had all been a lie. She said in those early weeks she felt that she had been duped, because it couldn't be possible that my non-mathematical approach was actually working. She said the answer had to be that I had to have been good at math all along and that my problems with math had been nothing but a ploy intended to fool her. I was astonished. When I reminded her that from the beginning I told her I understood advanced math concepts and that I only had difficulty with the language her response was, "Well, when you said that I thought 'Yeah, right, well then why can't you do the math?'"

Her comments were hurtful to hear and it has taken many months for me to truly grasp the nature of her response. Even today it is still very difficult for me to understand how far outside of all logic and reasonable judgement one would have to venture to believe that my life-long math struggle had all been nothing more than a 30-year ruse constructed to deceive a woman I had never met for the purposes of making her feel uncomfortable and foolish. It was incredible to me that it was easier for her to believe something so absurd rather than to accept that my method, a method based well outside of mathematics in the creative and rhetorical realm, was actually working. She admitted that she eventually realized this was not the case. But the fact that her apparent resistance to interdisciplinary approaches was so pronounced it would bring her to such a ludicrous conclusion rather than accepting the successful results of a creative method for learning math was both telling and disturbingly consistent with the narrow attitudes of power and absolutism I have found in my experience and in my research of many mathematicians and math educators.

As Dr. Jo Boaler (2015) described, my tutor may have long enjoyed a notion of intellectual superiority as a math “star,” as "…some teachers, have built their identity on the idea they could do well in math because they were special, genetically superior to others” (Boaler, 2015, pp.94-95). For my tutor, the myth of intellectual exceptionalism and math star superiority may have been quashed by the experience of witnessing my process which must have been uncomfortable for her. Perhaps this is how it was possible for her to become so irrational in her initial reaction, and perhaps why it might be reasonable to expect other math educators to react similarly to new and disruptively effective solutions to the math education problem.

We did work together some the following semester, meeting for few sessions before exams, using the same rhetorical process. I went on to pass precalculus handily on the first try with a B. My math requirement satisfied, we parted ways with new understanding and with some enduring tensions and residual frustrations left by the power struggles and conflicting worldviews. But I remain appreciative of her help and the role she played in assailing my methods early. Her challenges to my new approach throughout the process were important to the rhetorical structures of effective and demonstrable argumentation within which I was operating.

Rebuilding Trust

Educators may find that after years or even decades of suffering with the subject of math, students may not readily welcome new approaches. As Jo Boaler (2015) points out, “many people have been traumatized by math” (Boaler, 2015, p.x). Students may appreciate reforms, but will probably not come running to instructors with open arms. It may take a very long time to establish a level of trust upon which students feel they can depend long enough to engage new methodologies. In my experience teaching math to adult students who have a lot of trepidation about the subject, telling them my story seems to establish a level of trust only one who has struggled the way they have could probably enjoy. They may trust me because they know I am one of them and they do not sense that I am trying to trick them or crush their efforts. They seem to be encouraged by my testimony of success and may feel validated by my irreverent candor on the subject. Whatever the case, the students responded well and in the classes I taught and some students told me for the first time ever they found themselves actually looking forward to coming to math class.

Educators who are sensitive to this dynamic may find it helpful to engage honestly and take the time to consider the validity of how their students process and reason. For educators interested in new and effective methods for teaching math, it may be prudent to allow for some time to re-introduce the subject to students who are anxious and hesitant. Dr. Whitlow says, the most important thing she trains math teachers to say is “I don’t know” when a student asks a question for which they do not have an answer (personal communication, October 15, 2014). Rather than becoming irritated or threatened, instructors may find it much more valuable to give students an opportunity to engage and challenge what teachers and textbooks present with possibly fresh and illuminating perspectives so inherent in pure math practice.

Conclusion

What do we have as a civilization when creative thinkers engage in scientific exploration and challenge the scientific paradigms of their times? We have Isaac Newton. We have Albert Einstein. We have Galileo Galilei. The most invaluable scientific discoveries of humankind were not a result of the mindless mastication of paradigm thinking, but were instead the result of bold and creative ideas that stretched beyond the bounds of such paradigms. Often these advances occur in spite of harsh criticism and resistance by those whose investitures lie in the existing paradigms. Sometimes we find such agents cloaked disingenuously in the axioms of seeking to preserve the integrity of sound practice. But where would we be if we had allowed the great discoverers to be dismissed as “pseudo-scientists” based on the agents and paradigms of their times? Would it have been more scientifically sound to go on believing the world is flat, or that the atom is the smallest particle in the universe? For science to survive, we must push new ideas forward despite the opposition that threatens to move us into an intellectual dark age. Every advancement in human history occurred under these conditions of innovation and resistance. We stand at the precipice of a new age of investigation and discovery. Math would find a welcome place among the other disciplines, not as an erroneously overarching and dominant intellectual meta-structure, but as one of many investigative tools in reasoning. The humanities can provide the wide berth such investigation demands, where math is free to adhere to the rules and laws of measurement within the scheme of application, invention and ideas. Rather than cloistering the math subject with exclusivity in the cold and somber halls of the math world, mathematical concepts can and should be engaged as a dialectic thread that runs through the arts and humanities as one of the core disciplines. I am loathe to suggest imposing creative teaching techniques on math educators for which many might be profoundly ill-suited. Instead I will suggest that the talent for reforming mathematics education can likely be found in abundance, across the hall, in the minds and classrooms of the teachers of the humanities, language arts, communication, art and media. My future studies will be focused on establishing a new space to start a conversation about math and science that is intelligent, innovative, interdisciplinary and interactive. A space where all disciplines are welcome to participate, posit and query. A space where truly mathematical and scientific ideas can be expressed in a cooperative approach to investigation and study, unfettered by empirical demagoguery and acculturated intellectual paralysis.

There may be those in the math education establishment who would decry such innovative approaches, complaining that it will lower the standards of mathematical education and practice. On the contrary. I believe the standards for performance in mathematics should be raised commensurate with the implementation of interdisciplinary approaches and methodologies. The efficacies of these should then handily meet with such standards as a matter of course. Math as a text should remain sovereign to the empirical constraints of material investigation, while the entirety of the rhetorical context in which it is situated remains sovereign to the *possibilities* of investigation. Math provides the reliable data essential in the logos upon which other rhetorical principles can cooperatively rely. This relationship works brilliantly, and I have experienced the results of this first-hand. Using such an approach I was able to design such an interdisciplinary method that worked for me, and, with work, could be adapted to work for others. With it I crushed 30 years of math paralysis in less than six weeks. The focus of this forensic autoethnographical account is a qualitative introduction to my work going forward which I hope will not only yield a widely applicable approach and methodology for learning math, but may perhaps pave the way for quantitative studies in my graduate and post-graduate work to provide models and data which could substantiate further bases for my premises.

This thesis should initiate a new dialogue about mathematics education through a student-centric retrospective analysis of the circumstances in which I found myself with the subject. I have cited credible sources, pointed to compelling correlations and congruities and offered elucidations on a range of relevant possibilities. This qualitative study may not meet the empirical litmus some in the math and math education communities might demand. These educational communities are struggling, and it is an imperative that a solution to their problems be found. So, while I may not be able to quell such ambivalence, I can invite readers to follow my graduate and post-graduate studies which may offer the opportunity for quantitative assessment and modeling of the theories and hypotheses generated by this work. As of this writing, however, all I have to offer is my account, my analysis, and my successful results.

“Children need to hang around a teacher who is asking bigger questions of herself than she is asking of them.” Donald Graves.

Postscript

Dr. Dottie Whitlow is the Georgia representative to the National Council for the Teachers of Mathematics (NCTM). She recently returned from the NCTM's Annual Meeting and Exposition, a national conference held in San Francisco this April, and reports that the tone of this year's conference was particularly subversive. Presentations such as "The Status Quo is Unacceptable," and "Changing the Mathematics Culture of Your School," seem to indicate that reformation in the math education world may be imminent (personal communication, April 17, 2014).

Figure 22. Jo Boaler and Dottie Whitlow. Photo by Dottie Whitlow

If so, it would be, to a large degree, the result of many years of struggle by a small group of math reformers like Drs. Jo Boaler and Dottie Whitlow who were fighting this fight before it was fashionable or even safe to do so. Thanks to their efforts, the time may finally be right to start a real conversation about new paradigms in mathematics education.

Annotated Bibliography

About the Suzuki Method. (n.d.). Retrieved January 18, 2016, from https://suzukiassociation.org/about/suzuki-method/

The discovery of the Suzuki Method was very timely for this project. The holistic and intuitive nature of this method is relevant to establishing some of the foundations of my premise that rigid teaching methods are not the only path to a musical experience.

Benoit Mandelbrot. (n.d.). In *Wikipedia*. Retrieved January 18, 2016, from https://en.wikipedia.org/wiki/Benoit_Mandelbrot

Benoit Mandelbrot is one of the most notably disruptive agents from the science world. In interviews he describes the experience of being excommunicated from the math and science world for having the audacity to imply that there can be naturalistic considerations in mathematical practice. Science and mathematics did eventually realize the value of Mandelbrot's discovery, and his insights changed the world we live in.

Bentley, J. H., & Ziegler, H. F. (2011). *Traditions & encounters: a global perspective on the past*. McGraw-Hill.

This basic history textbook contained the adequate citable content for describing the volta do mar phenomenon I needed for this reference. It is simple yet relevant to illustrate the importance of the effect shifting paradigms have on a universal scale.

Boaler. J. (2012, October). Jo Boaler reveals attacks by Milgram and Bishop. Retrieved January 18, 2016, from http://www.stanford.edu/~joboaler/

This link to the first-person account by Jo Boaler on the Stanford.edu website was introduced to me by Dr. Dottie Whitlow soon after we first met. While I did not read any of her books until very late in the process of writing my thesis, I was very familiar with her story of persecution by Milgram and Bishop, and knew she was the preeminent authority on modern disruptive math reform.

Boaler, J. (2015). *Mathematical mindsets: unleashing students' potential through creative math, inspiring messages and innovative teaching*. John Wiley & Sons.

Jo Boaler is a prolific advocate for math reform, with hundreds of citable sources. I chose this particular book because it is the most recent and was most closely related to the direction of my thesis. Her candor throughout was exactly the type of content support I was seeking, and her ethos in this space is irrefutable. Some of her section headings were startling similar to the section headings I had composed for the original draft of this thesis over a year before reading her book, which seems to point, again, to the universality at the core of this issue. Jo Boaler is probably the foremost authority on what a math education reformist faces in the uphill battle for a paradigm shift in math teaching practice.

Chomsky, N. (2007). *On language*. The New Press.

Chomsky is one of the most respected and iconic intellectuals of this age. His elucidations on the features and functions of linguistics are essential to any text that would approach the subject of communication, and it was important to illustrate how the discourse has been situated between mathematics and linguistics for some time. On this particular facet of the subject, there is probably no better authority.

Connor, A. M., Karmokar, S., Whittington, C., & Walker, C. (2014). Full STEAM ahead a manifesto for integrating arts pedagogics into STEM education. *2014 IEEE International Conference On Teaching, Assessment & Learning For Engineering (TALE)*, 319. doi:10.1109/TALE.2014.7062556

This was one of the few articles I read that made a serious case for the arts in the pursuit of the maths and sciences. While audacious, it approaches the subject very consciously, which is the great obstacle it seems every educator must contend with when attempting to advance the idea of more evolved and interdisciplinary teaching practices in the STEM subjects.

Dantzig, T. (2007). *Number: the language of science*. Penguin.

Tobias Dantzig is a very respectable source on the subject of math. Of particular interest for the purposes of this thesis, is the citation on the evolution from its classical Greek foundation, to what one could consider the modern mindset for math. The posturing tone is so evident, and appears to bear the marks of the intellectual origins driving modern attitudes of math and science toward the humanities.

Davidson, M. S. (2015). Psychologist Stanley Milgram begins obedience-to-authority experiments. *Salem Press Encyclopedia*.

The Milgram study could almost be considered common knowledge, but I chose this article to include a source for my reference. Because the origins and outcomes of the Milgram study are so well known, the relevance to power in the section in which it is cited are apparent.

DeHaan, R. L. (2005). The impending revolution in undergraduate science education. *Journal of Science Education and Technology*, *14*(2), 253-269.

This article contained a good overview of the revolutionary rumblings in the science education ranks. It also included some statistical data to support the overall effects education problems in math and science have on various social groups and society in general.

Devlin, K. J. (2000). *The language of mathematics: making the invisible visible*. New York: W.H. Freeman, c2000.

Keith Devlin is a foremost authority on the subject of math and math education. However, his position and tone, while less exacting than Paulos, is basically situated on a diametric plane of math exceptionalism. His voice is valuable as an example of tone in the rhetoric of those who are doing research and publishing work on this subject.

Ellenberg, J. (2014). *How not to be wrong: the power of mathematical thinking*. Penguin.

Jordan Ellenberg's *How Not to Be Wrong* is yet another in a number of attempts to explain the presumed complexity of math to the masses. While the tone is similar to other books on this subject, Ellenberg's soccer analogy provided a very useful example for situating the misapplication of notation and rigor across a wider variety of potential goals.

Feynman, R. P. (2010). *"Surely you're joking, Mr. Feynman!": adventures of a curious character*. WW Norton & Company.

Because semiotics is an important aspect of my thesis topic, I knew it would be relevant and useful to include the story of Richard Feynman creating his own written math notation. His inability to continue using his notation because his peers could not decipher his work was also important, as the concept of shared meanings, in this case among experts in the field, is so crucial to understanding how to implement effective communication of math concepts.

Freire, P. (2000). *Pedagogy of the oppressed*. Bloomsbury Publishing.

Paulo Freire's legendary text, now in this 30th anniversary edition outlines the sociopolitical dynamics at the heart of many problems in public education. Freire makes no bones about his assertions of how social politics based on class have relegated education to an "instrument of oppression," leading to dehumanization in the relationships between student and teacher and pointing to these underpinnings as a causation behind how curricula are shaped and how the tone of the educational process is set. In Chapter 3 Freire emphasizes dialogic as "the essence of education as the practice of freedom."

Gleiser, M. (2015, April 1*).* Van Gogh's Turbulent Mind Captured Turbulence. Retrieved April 18, 2016, from http://www.npr.org/sections/13.7/2015/04/01/396637276/van-goghs-turbulent-mind-captured-turbulence

I searched out as many topical references as possible, and this NPR story about the Van Gogh turbulence story was an important illustration of the value an artistic mind has to offer the math and science world. The value of the artistic perspective has becomes so systematically dismissed, that this turbulence pattern in *The Starry Night* had gone unnoticed while physicists toiled over generating a graphic model to help them understand how turbulence patterns are formed. Most importantly, it is relevant to consider that Van Gogh was not trained in math or science, but employed his artistic talent and creative vision to produce an intrinsic work that had nothing to do with the pursuit of science.

Grandin, T. (2013, February 10). Temple Grandin: The world needs all kinds of minds [Streaming Video]. Retrieved from https://www.ted.com/talks/temple_grandin_the_world_needs_all_kinds_of_minds

Temple Grandin's story is a compelling example of why one should never dismiss the intelligences of different types of learners. The trend toward diagnosing and dismissing makes her story even more relevant as we look at addressing the problems in math education today.

Gullberg, J. (1997). *Mathematics: from the birth of numbers*. WW Norton & Company.

Mathematics: From the Birth of Numbers is a monstrous 1,039 page text that explains mathematics and provides a remediation to the institutionalized text and reference books which Gullberg, like Lockhart, believes are at the heart of the dysfunction in math education. This book serves as a reference for essential mathematical theories with a tone that denotes the significance of context and understanding.

Gutierrez, K., Sengupta-Irving T., & Dieckmann, J. (2010). Developing a mathematical vision: Mathematics as a discursive and embodied practice. In J. N. Moschkovich (Ed.), Language and mathematics education: Multiple perspectives and directions for research. Charlotte, NC: Information Age Publishing.

This additional citation of Pimm speaking on math as a language was another source of his comments on the linguistic registers at work in mathematics.

Hacking, I. (2013). What Logic Did to Rhetoric. *Journal of Cognition and Culture*, *13*(5), 419-436.

Ian Hacking's article contained a perfectly succinct citation about the origins of logic and the classical foundations that connect pure logic to the humanities by heritage and practice. The mention of Frege was especially useful to find together in one article with information supporting many important points associated with my premise. It offers the timeline I was looking for in determining when the concept of logic had been torn from its classical definition to become redefined as a synonym for mathematics.

Howard, G. T. (2010). *Dictionary of rhetorical terms*. Xlibris Corporation.

This article was a good source of the definitions I needed. It happened to include the quotes I wanted to use by the most significant rhetoricians all in one place.

Kinneavy, J. E. (1969). The Basic Aims of Discourse. *College composition and communication*, *20*(5), 297-304.

James Kinneavy's quote makes a very important distinction in the different aims at work between mathematical practice and mathematical education, with the former pertaining to language "directed to things" and the latter as "language directed to people." This sets up

the premise of math education in a communication sphere as it involves talking about "things" to "people."

Krasny, J. (2012, October). Malcolm Gladwell on What Really Makes People Disruptive. Retrieved January 18, 2016, from http://www.inc.com/jill-krasny/malcolm-gladwell-on-the-one-character-trait-that-makes-people-disruptive.html

Malcolm Gladwell is a very good source for citing discussions on disruptive ideas. The changes necessary in the math education world are disruptive to the status quo, and his mention of the reframing of ideas is an essential element of my thesis.

Korzybski, A. (2010). *Selections from science and sanity*. Fort Worth, Texas.: Institute of General Semantics.

Alfred Korzybski's quote, "The map is not the territory," was a perfect anchor point for setting up my premise on distinctions between notation in music (or math) and the fluency of practice. The ability to extricate the art from the notation can prove to be difficult, as is has become an entrenched set of values in both music and math education communities.

Lockhart, P. (2009). *A mathematician's lament*. New York: Bellevue literary press.

According to the foreword written by Stanford Mathematician Keith Devlin, Paul Lockhart "…brings to the thorny and much-debated issues of mathematics education a perspective that few others are able to draw upon. Paul… began as an accomplished research mathematician, teaching students in universities, and then realized his true calling was in K-12 teaching…"

Lockhart comes as close as anyone in the math world to truly understanding the problem with math education. He incorporates a pure dialogic example to illustrate his point, as an imaginary conversation between two characters, Simplico and Salviati.

Lockhart does hit spot on with his assertions regarding rote memory performance as patently invalid as a representation of math efficacy, pointing out that it gives performers a false sense of intellectual supremacy where no real mathematical talent actually exists. His insights as an educator on how the dysfunctions in math education are unnecessarily harming students were very useful for backing up my own personal experience with this harmful process.

National Science Board. (2004). *A Companion to Science and Engineering Indicators 2004*, NSB 04-07. Retrieved October 20, 2004 from www.nsf.gov/sbe/srs/nsb0407/start.htm.

This the source of statistical data used in part of the thesis. Although rising failure rates are a known phenomenon, it is useful to provide specific information to underscore a point or, perhaps, point to other underlying effects and causalities for the reader to consider. In this case, the data points to a dearth in qualified science and engineering candidates to fill positions in those growing fields. This can have localized effects the indicate availability in the job market. But it can also have far-reaching implications in our ability to compete in a global community where technology is constantly changing and affecting every industry.

Paulos, J. A. (2001). *Innumeracy : mathematical illiteracy and its consequences*. New York: Hill and Wang, 2001.

Upon reading Paulos, and hearing him speak in videos on this subject, it was clear that his tone and posture were excellent examples of the overriding tone one can expect when reading books or engaging the topic with math or science professionals. So persistent is the presumption of an intellectual hierarchy, of which Paulos and many others in the math and science fields feel they are at the top, that it seems to drive the phenomenon of expert power to which individuals and institutions defer. It seems most often to be an unconscious occurrence, but it is a disturbing norm of our society that makes it difficult to confront the issues at the heart of the math education problem.

McGuinness, D. (1997). *Why our children can't read, and what we can do about it: a scientific revolution in reading*. Simon and Schuster.

Understanding the evolving nature of how humans process information when reading symbols is so important when considering the role of notation in the education and practices of math. A conscious approach to solving the problems of communication in math textbooks and classrooms, it seems, would then have to somehow involve many of the principles and mechanisms already present in rhetoric and effective communication practices.

Molina, C. (2012). *The problem with math is English: a language-focused approach to helping all students develop a deeper understanding of mathematics*. John Wiley & Sons.

Concepcion Molina is a respected math educator, education development advocate and an associate with SEDL. His experience has led him to write this comprehensive study of the role English plays in the confusion of teaching and learning math. I appreciate Molina’s admission that inefficacy and rote memory performance are dysfunctions

passed on to students who become teachers and pass the same rote practices on to students.

Moschkovich, J. (2012). Mathematics, the Common Core, and language: Recommendations for mathematics instruction for ELs aligned with the Common Core. *Commissioned Papers on Language and Literacy Issues in the Common Core State Standards and Next Generation Science Standards*, *94*, 17.

Reading Moschovich's article on English learners (ELs) and math education revealed an interesting parallel to the math language thread of my premise. The consciousness of math educators in attempting to teach the subject to students for whom English is not a first language, and who have yet to master English to the level that facilitates the typical discourse found in math education, provided these educators with the opportunity to consider the clarity of their delivery. Of particular interest, were Moschovich's comments on the attendance to precision in the language-conscious process of teaching math. It is one of the few pieces of citable scholarly material I found which put forth the idea that mathematical ideas can be conveyed in spaces where precision is not the fundamental goal. This, perhaps more than any other material in my research, accurately described my experience, particularly in terms of trying to convey to math educators that I understood the math concepts, but had difficulty with the language and then having my position systematically and summarily dismissed. The unwillingness for many math educators to consider the possibility that students are engaging in the kind of high-level reasoning found in advanced mathematics without possessing the ability to engage the precision of math language, particularly the written and operational math language, speaks to the heart of this entire matter.

Pimm, D. (1987). *Speaking mathematically: Communication in mathematics classrooms*. Taylor & Francis.

This book was suggested by a math education professional as an example of how the math education community had been attempting to address the issues of communication in the math classroom. It is clear throughout that the author's intention is to investigate the subject. However, it appeared to me that there is a staunch resistance to giving up much territory in doing so. I find this to be the case in the messages of several well-meaning agents from within the math world who appear to be genuinely interested in discovering new approaches to more effectively teaching the subject. This is why I do not see an up-ending reinvention of the math education paradigm as the most fruitful path. Rather, creating new interdisciplinary spaces for discourse on the subject of math is likely a better use of time and energy.

Seife, C. (2010). *Proofiness : the dark arts of mathematical deception*. [Kindle Fire version]. Retrieved from Amazon.com

In addressing the significant role of expert and reward power where math and science are concerned, it seems relevant to make clear distinctions between the reliability of math practice, and the intentions of practitioners in the application of mathematical data. Because there is a tendency to see these as one in the same, it is too easy to become complacent and complicit in the erroneous establishment of social and educational hierarchies. It was important to me to make these distinctions in the course of identifying and debunking myths about numeracy and intellectual integrity.

Sheldrake, R. (2013, January 13). Rupert Sheldrake: The science delusion [Streaming Video]. Retrieved from https://www.youtube.com/watch?v=JKHUaNAxsTg

Rupert Sheldrake is an indisputably controversial figure. However, it appears he comes by this reputation honestly, as it seems to be based solely on his audacity to challenge the status quo with their own empirical litmus. Probably the highest crime an outlier can commit is being right, and Sheldrake may be an example of this axiomatic phenomenon. While readers do not have to subscribe to his beliefs and postulations, the severity of the science communities' response to Sheldrake is the story behind the story that has made him something of an underground cult figure among progressive intellectuals.

Stinson, D. W. (2012). Mathematics Educators and the "Math Wars": Who Controls the Discourse?. ScholarWorks @ Georgia State University.

Stinson's piece is an example of the evolving culture among math educators, bolstered by Jo Boaler's pioneering efforts at challenging the math education community from within. Her story appears to have outraged and inspired math educators who are truly interested in addressing the problems in their profession, and Stinson is a good example of this encouraging trend.

Shillito, B. (2015). A good notation is its own explanation!. Presentation, GCTM at Rock Eagle, Eatonton, Georgia.

Bill Shillito's quote, "Math is not about notation, it's about ideas," from his GCTM presentation stood out to me as an indicator that some math educators are of the Paul

Lockhart variety. Bill Shillito shared that he also was a fan of Paul Lockhart's *A Mathematician's Lament*.

Thakker, Yatit. (2015, January 5). 3 Reasons Why Calculus is so Hard [Web log post]. Retrieved from https://omninox.org/blog/3-reasons-why-calculus-is-so-hard-2

In a social media world, blog spaces have become a valuable resource for professionals to communicate trends and methods with a global audience. Yatit Thakker's blog about difficulty and calculus was actually perfect for illustrating the contrasts in how difficulty is defined and perceived in different discourse communities. The disparity of these perceptions is a key factor in the misdiagnosis of the problem and, in some cases, in how difficulty is manufactured.

Wolf, M. (2007). *Proust and the squid : the story and science of the reading brain*. New York: HarperCollins.

Maryanne Wolf, professor of Child Development at Tufts University and director of the Center for Reading and Language Research presents compelling insights into the reading brain. Many of the experiences I discuss in my thesis involve the semiotic dissonance I and so many experience in the math learning process. Wolf has encapsulated some interesting facts about how the human brain adapted the unnatural ability to recognize shapes in writing and to attach meaning to shapes as humans formed written language. She discusses how various parts of the brain evolved spontaneously to work together in developing symbolic meaning-making capability. Her insights into how the brain makes meaning are noteworthy in any project discussing communication and learning.

Appendix A

Modal Video Element

Figure A1. Math as Text introduction, My Story, a video by Liz Melendez, https://www.youtube.com/watch?v=Ugs9embHXG4

As part of my English and Professional Communication degree program, I created this short video introduction to my story, in which I give a brief visual and oral account accompanied by my own music.

Appendix B

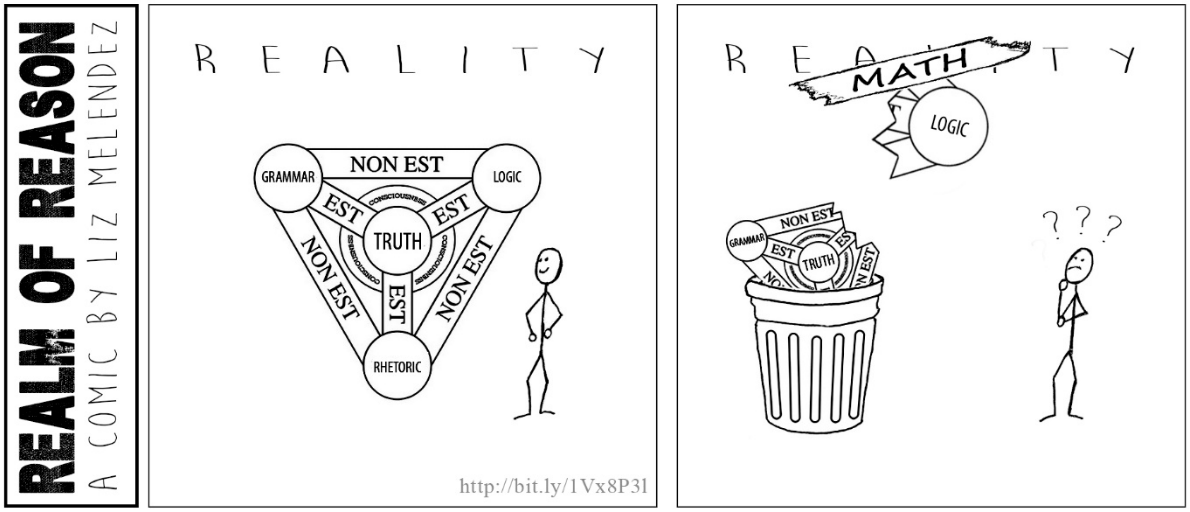


Figure B1. Realm of Reason, a composite illustration by Liz Melendez.

Creating visual narratives and graphic elements has been an important part of the media arts and design facet of my professional communication program. I found opportunity to use a variety of visual forms to illustrate concepts in this thesis, including this mixed media composite.

Appendix C

Bypassing Model and Rhetorical Triangle Graphics

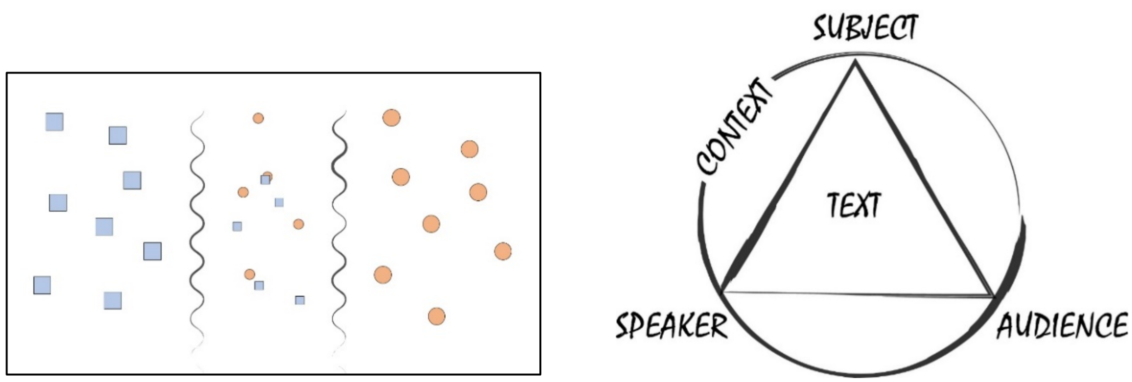


Figure C1. Example of shared semantics bypassing model and rhetorical triangle drawing, digital illustration by Liz Melendez.

A digital rendering of one of the two diagrams I drew to illustrate my experience for my tutor. I originally drew these on the back of a receipt which, had I known what was about to happen, I would have kept. Animated versions of these illustrations are available to view at www.mathastext.com .

Appendix D

Function Illustrations

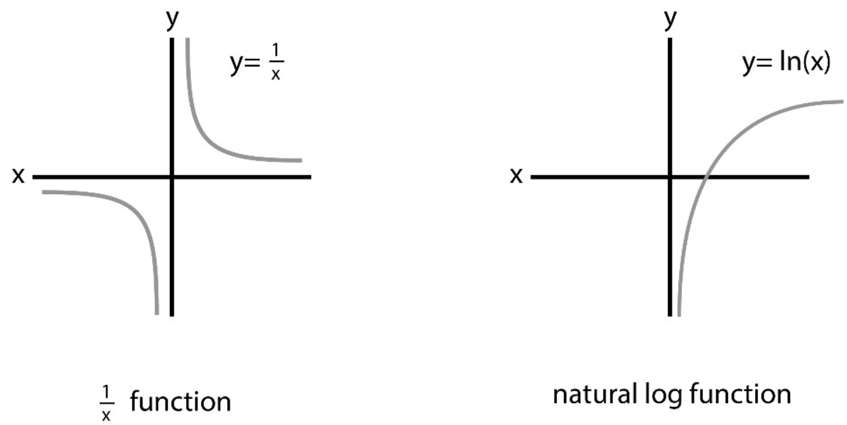


Figure D1. Diagram of a 1/x function and natural log function, a graphic illustration by Liz Melendez.

Appendix E

Communication Model Graphic

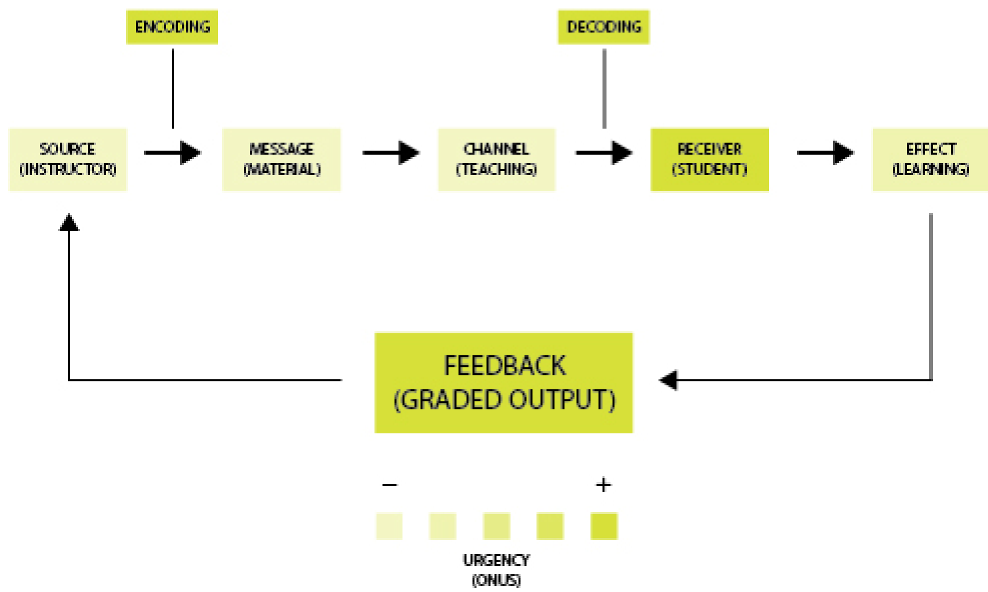


Figure E1. Communication model graphic created by Liz Melendez.

Based on a communication flow chart, I created this color graphic using the intensity of color, lighter or darker, and a metric legend to illustrate urgency within the math education communications I have experienced.

Appendix F

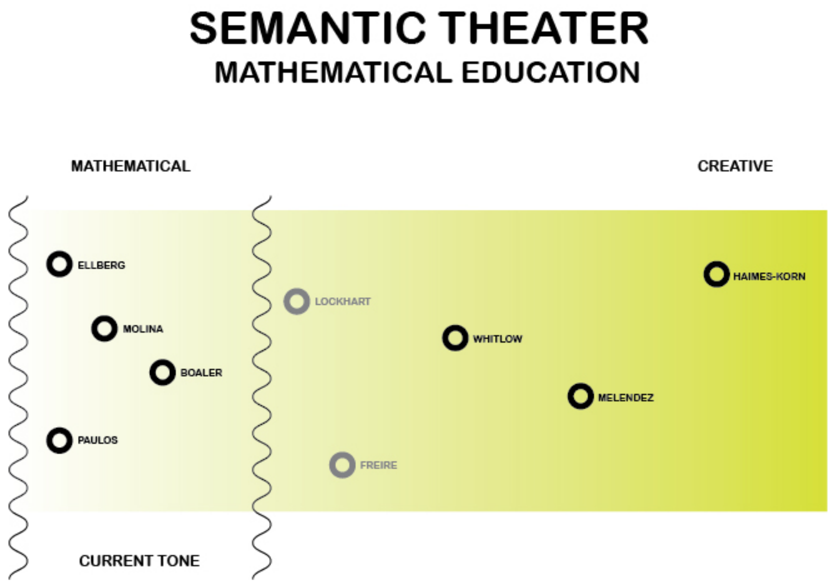


Figure F1. Semantic theater, current tone, a graphic created by Liz Melendez.

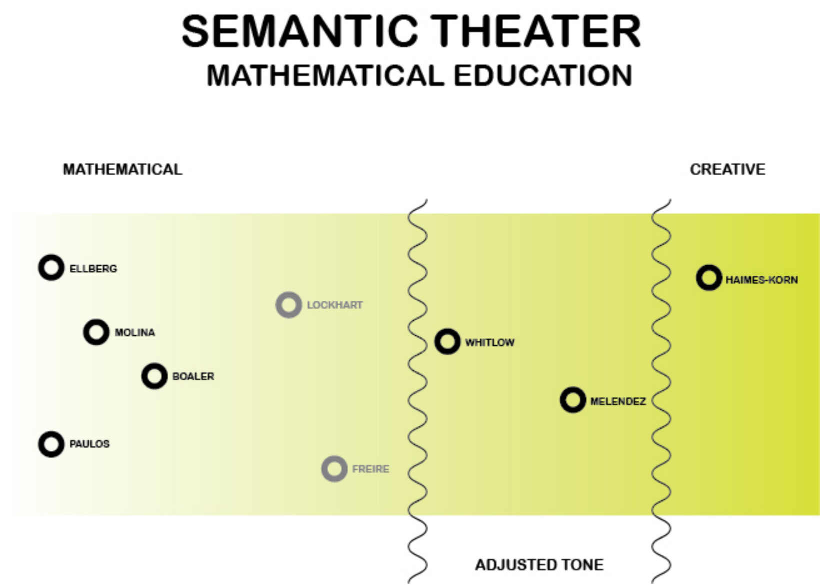


Figure F2. Semantic theater, adjusted tone, a graphic created by Liz Melendez.

Appendix G

Illustrations of Diagrams from Classroom Lecture

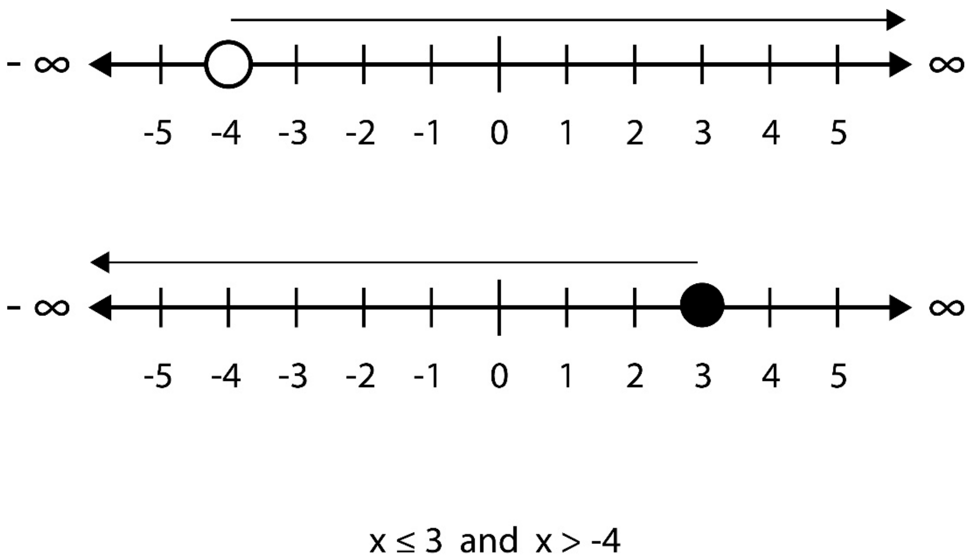


Figure G1. Illustrations of professor, a digital graphic by Liz Melendez.

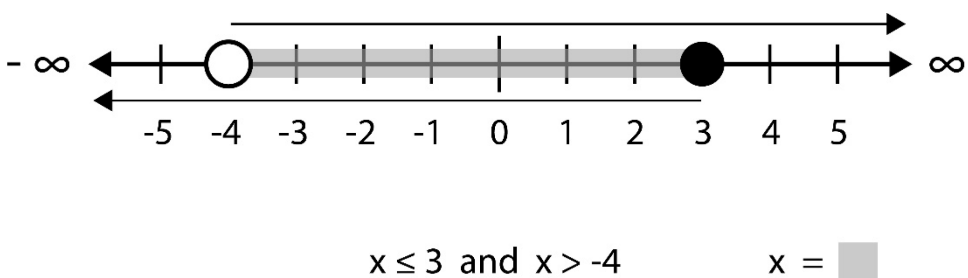


Figure G2. Illustration that worked, a digital graphic by Liz Melendez.

Appendix H

<u>Taxonomy Illustrations</u>

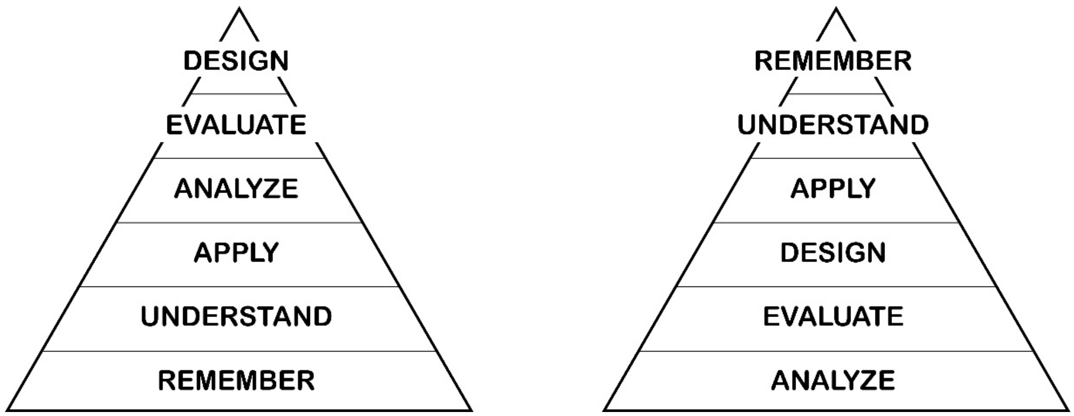


Figure H1. Taxonomy comparison, left, Bloom's taxonomy, right, my taxonomy, a graphic illustration by Liz Melendez.

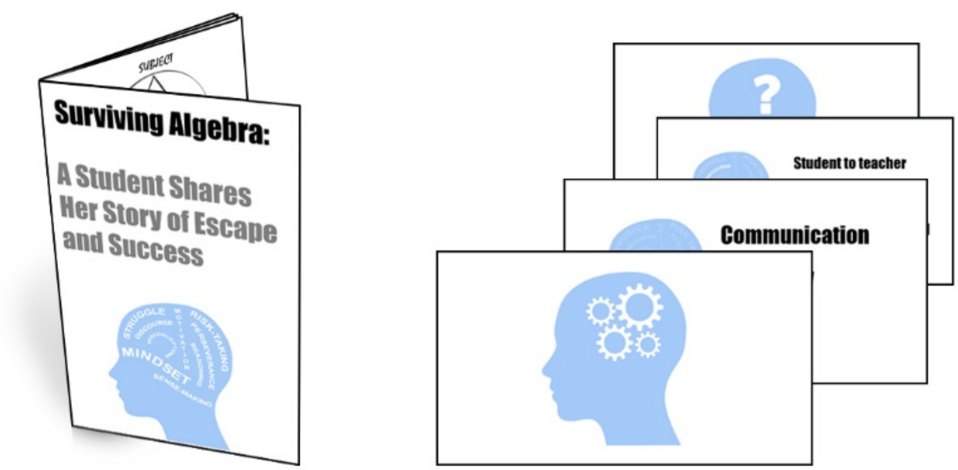


Figure H2. GCTM presentation materials, a graphic by Liz Melendez.