REAL FANTASIES IN MATHEMATICS EDUCATION: NUMERACY, QUANTITATIVE REASONERS, AND TRANSDISCIPLINARY WICKED PROBLEMS

By

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ABSTRACT

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This dissertation has seven chapters. In chapter one, I discuss through why I am doing this dissertation, my positionality, and how I learned from and with all of my committee members.

Chapter two is where I situate my dissertation study through developing a social theory of quantitative literacy by translating a social theory of literacy (Barton & Hamilton, 2000). I also describe my epistemological stance towards research as a creative act, my theoretical commitments to critical postmodernism, and summarize my methodologies and methods for each of the three articles.

Chapter three is my first article. In this article, I historicize the numeracy discourse by writing a genealogy that traces how statements about numeracy emerge in scholarship, with a focus on the United States. Scholars' statements about numeracy form a discourse that pressures mathematics education to reform. These pressures are sustained when scholars connect numeracy to historically powerful justifications for reform. I name these as three *promises* embedded in the discourse: (1) numeracy promises to reflect modern reality, (2) numeracy promises to empower, and (3) innumeracy promises to have social costs. I conclude with a discussion of the *literacy myth* and its implications for mathematics education.

Chapter four is my second article. In this article, I take the *quantitative reasoner* to be a persona embodying the goals mathematics educators describe for who our students should become. The quantitative reasoner has both cognitive and affective dimensions; they know and

feel particular things about mathematics and statistics. As a member of a curriculum design team, I invoked the value of students becoming quantitative reasoners to defend new courses existing. My students helped me see that the quantitative reasoner is an incomplete person who is a fantasy of mathematics educators, including myself. Together, we re-humanized the quantitative reasoner and each other.

Chapter five is my third article. This article describes findings from a study on students' projects during a mathematics course in quantitative literacy. The issues students chose to research turned out to be connected to a particular class of problems. Across places and disciplines, people are working on these *wicked problems* which are messy, global, connected, responsive, and unavoidable. Wicked problems are in contrast to curricula that may center tame problems. This apparent mismatch provided the impetus to consider education for wicked problems. After coding students' projects using the Rittel & Weber's (1973) ten characteristics of wicked problems, I found three themes: complexity, transdisciplinarity, and openness.

Chapter six is my conclusion. In the chapter I synthesize what I have done in my dissertation and revisit some of my theoretical work – most notably my social theory of quantitative literacy. I also use my dissertation to revisit mathematics education as a whole, including research, and try to make some new connections and trouble my conclusions.

Chapter seven is my parting thoughts. In it, I return to my positionality by discussing an aesthetic choice I have engaged during this dissertation. That aesthetic is the *metamodern* aesthetic and it involves the juxtaposition of incredible seriousness with playful detachment. I think about the metamodern aesthetic and my millennial identity in order to reframe doing education research.

To Lynette
Not all those who wander are lost

ACKNOWLEDGEMENTS

I think this dissertation is an expression of change. There are so many people and moments who have contributed to that change – thank you all.

To Beth: Thank you for your expertise, attention, kindness, and patience during these past two years of dissertation work. Thank you for letting me wonder and wander, joining me there, and pointing me new places, too. I also want to thank you for opening your home to graduate students, and bringing us all together there.

To my committee members: Higinio, Jack, and Vince, for your dedication and continued support over the past five years. Each of you has influenced not only my thinking, but my being. I am grateful to have worked with you all.

To Sharon Senk: for years of advice and guidance, I am glad that our careers overlapped, even for a short time.

To my cohort: Thank you for all of your insights and support as we walked these paths together.

To my family: For your unwavering support as we all continue to grow, and to all the moments yet to come.

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CHAPTER ONE:

INTRODUCTION

"Why are you studying quantitative literacy? Why are you writing this dissertation?"
-Dr. Beth Herbel-Eisenmann, Multiple Occasions

I struggled to title my dissertation. I think doing a three-article format contributed to this struggle, but also that my dissertation has emerged as significantly different from my proposal in several ways. Where I initially proposed to focus on affect, now affect is only part of one of my three articles; where I initially proposed to focus on transformative learning, now learning is less salient than curriculum; where I initially proposed to focus on follow-up interviews, those interviews are not present in this dissertation; where I initially proposed to complete archaeological methods regarding students' critical incidents, now I do genealogical method of a scholarly discourse; and where I initially proposed to focus on students, my focus is now the plural relationships between and among students, me as the teacher, me as the researcher, curriculum, and mathematics education.

In some ways, I love that my dissertation evolved so much. I think it reflects how seriously I take change, and how afraid I sometimes am of staying the same. My partner Lynette called herself a "deeply engaged dabbler," and she agrees that idea applies to me, too (I just asked her). My dissertation transformed because I have, but also for practical reasons. In this dissertation, I write about different aspects of two courses in quantitative literacy (QL), which I co-designed, piloted, and researched. My dissertation proposal, written mostly in winter 2016, was inspired by previous teaching experiences I had with these QL courses.

In my proposal, I planned to study transformative learning experiences that might begin in, or be continued by, these courses. I anticipated that students might experience intensely

affective moments like I felt I had witnessed in prior semesters, and which I thought might be considered opportunities for transformation. I summarized my proposed study:

> I propose that the unity of emotion and cognition from a poststructuralist perspective suggests that embracing, rather than suppressing, intense emotions in the classroom opens opportunities for transformative learning. I attempt to better understand, therefore, the emotive, cognitive, and active dimensions that are felt, thought, and done when we collectively attempt to read and write our world with mathematics and statistics. I want to understand the potential for mathematics and statistics to provide tools to transform our understanding of the world. (Craig, 2016)

Although transformation, affect, and this kind of learning were my foci during the proposal—and continued to be my foci during most of the data generation, the course itself, and my early analysis attempts—I struggled to make headway in analyzing and writing about what I had experienced. I remain convinced, in fact more so, that these QL courses do offer something radically different to a population of undergraduate students for whom the general mathematics requirement at this university had often previously loomed large. Many conversations with different students who commented on their gratefulness for these courses were enough to convince me. All of my in-class experiences have so significantly informed how I think about mathematics education that it is impossible for me to imagine myself without them. I had never witnessed the kinds of emotional moments that inspired my proposal before in a classroom – as a student, a teacher, or a researcher. I think these moments deserve serious attention, and my commitment to my students means I *will* pursue describing them in the future.

This dissertation is quite different than that proposal, however, because every time I began writing about the relationships and the learning that I experienced, I struggled to situate that learning and those relationships. I think the reason why I struggled so mightily is because I could not lean on common notions of the mathematics classroom. In a recent conference presentation, my co-presenter, Lynette, and I similarly struggled to contextualize the course from

which we were presenting experiences. Ultimately, I think the reason for this struggle can be summarized quite simply by stating: *these courses are not math courses*. And that is what makes studying them so worthwhile to me.

Positionality: A Story of Belonging and Leaving

"A reader lives a thousand lives before he dies. The man who never reads lives only one."

-George R. R. Martin, A Storm of Swords (Jojen Reed)

I love to read. I got Harry Potter and the Deathly Hallows at 12:01 a.m. the day it released, and went to sleep some eight and a half hours later, with the back cover facing up. That I love to read is, ironically, a challenge to becoming a scholar at a time when writing, not reading, is most clearly valued by the academy. Job performance metrics account directly for quantity and "impact" of writing and, at best, indirectly for reading. I have no doubt that writing is important (after all my love of reading relies on authors). At the same time, I cannot help but notice that what is expected of newly minted Ph.Ds. during graduate school is sounding pretty similar to job duties of assistant professors: presentations, publications, proven research agendas, strong and diverse teaching experiences, and service. Graduate education has not avoided the educational push-down, where what was once for next year is instead for now. I think these situations beg a question: with so much more to read and less time allotted to do so, what is the future of academic reading?

I think I am a "good" reader - at least, I feel like I have significant thoughts when I read. But that I love to read is sometimes presented as an obstacle to academic work, where it becomes time to stop reading, and start writing. I'm not so sure about writing, however, when I do not feel like I can casually generate something valuable to say. The most difficult part of this dissertation has been writing, especially deciding what not to say. I am meant to prove my standing in the

field, and provide direct and compelling (or at least acceptable) answers to why my dissertation matters and how it demonstrates I belong in the academy. The high stakes of the dissertation is somewhat ironic, however, when almost nobody will read it (some of my peers have suspected even their committee members did not make it through their whole document). The credentialing involved in dissertations and defenses reminds me of fantasy games, where an initiate takes quests to prove their worth and join a guild.

It is easy to read the question "why are you studying QL" as a request from my dissertation chair to take up that quest and defend myself; Beth's questions can be reworded into something like "why should anyone study QL?" - well within the "so what" brand of questions. I want to play around with the emphasis of her question, however, and frame it instead as "why are you, *Jeff*, studying QL?" – and therefore, a highly personal question (which I think was her point, anyway). I am happy about that, because I have long wanted to explicitly reject the graduate student subject-position of "defender." So - why do I, *Jeff*, study QL and write this dissertation? To that approach that question, I produce a short autobiographical story, with my committee members as the other main characters.

Belonging

In February 2012, I visited Michigan State University (MSU) as an admit to the Graduate Program in Mathematics Education (PRIME). I met with four different professors associated with the program who were chosen for me, in part, based on my interests. One of my interests was quantitative literacy, which at the time I conceived of as a general mathematical applicability, relevant to any person, but absent in only some. My conception of QL also existed in my generally deficit-oriented view of education. In a meeting with Dr. Beth Herbel-

Eisenmann, she questioned my proposed interests, specifically noting how I had already assumed who was "innumerate."

I remember wondering pretty actively whether I belonged in mathematics education, and whether I could make any claims about education at all. My own background, although including four years of teaching mathematics, had several markers of difference within mathematics education: I had not been a K-12 teacher, I was not certified to teach, and I had not taken coursework in a College of Education. I wanted to study education because my teaching had energized me while I was completing a Master's in mathematics. My teacher education, however, was by fire - being placed into classrooms based on my credential as a graduate student in mathematics and not much else. Who was I to say anything about mathematics education? Did I belong in mathematics education?

Welcoming

Despite my first foray with imposter syndrome (even *before* entering the program), I decided to pursue the degree. I suppose I must have rationalized it in a variety of ways: I needed to do something, I liked education, I was open to learning, and my economics and statistics backgrounds might support a research agenda. I entered the program, and during my second year, established a guidance committee of professors associated with my interests in policy, economics of education, quantitative research, and quantitative literacy.

During this doctoral program, I went in some circles that kept returning to quantitative literacy, but every time I came back, my perspective was different; I changed. Although those excerpts have things in common, aspects of my annual review are also unrecognizable. I remember meeting with Dr. Higinio Dominguez in early 2016 for our first meeting where we discussed my dissertation proposal and him potentially joining my committee. My first work

with Higinio began three years prior, during the spring semester of my first year in his course, TE 931: Introduction to Qualitative Methods in Education Research. In contrast to my background in economics, mathematics, and statistics, his course was my first experience specifically organized around considering qualitative methodologies. At this point, I was pretty well indoctrinated into a belief that quantitative data had more authority, but I think I entered the course with a relatively open-mind. Unsurprisingly, I produced ideas about qualitative research that might be expected by a quant-leaning novice. My submission to our first course paper ended:

> Qualitative research is assessed to be "good" when it has high levels of validity and reliability. Using Merriam's framework of questions that help to assess the quality of qualitative research, I conclude that the work [the author] completed was highly valid. [The author] inscribed his research in validity by: triangulation, positional reflexivity, adequate engagement in data collection, and the use of thick, rich descriptions. [The author] was also open with the preconceptions he had about the research he was doing as well as the reasons he had for engaging in the research. Assessing the quality of qualitative research is to a large extent subjective. Using Merriam's instrument, in my opinion, [the author's] piece is high quality qualitative research. (Craig, 2013, p. 5)

My views on qualitative research (which I undertake in this dissertation) have actually moved into fairly radical territory, where I am pretty actively skeptical of all research and knowledge-generation claims, and especially skeptical of casually made claims. In an advanced qualitative research methods course I took three years later, I found language that shaped my dissertation proposal:

> Engaging participatory consciousness means attending a particular quality of human relationships that embraces a holistic combination of knowledge and emotion, knower and known. Further, the participatory mode of consciousness transforms knowing by reconstituting reality not as something to be interpreted by subjectivities, but as something that is mutually evolving and developing through relationships. A participatory mode of consciousness extends past an awareness of subjectivity toward a "deeper kinship between the knower and the known" (Heshusius, 1994, p. 16, cited in Craig, 2016, p. 29)

As I was working on my proposal and forming my dissertation committee, I approached Higinio as a potential member, and sent along my current proposal draft. When I met with him shortly after, I remember he commented, "I am surprised...I did not think you would be doing this work." In the moment, I felt surprised myself, until I revisited some of what I produced in his course. Once I did, all I felt was gratitude that he maintained openness to my ideas during that course, and did not make me feel unwelcome or excluded.

In my second article, I took seriously this premise of exclusion when I wrote about how the courses I helped create might uphold an image of the quantitative reasoner that dehumanizes people. By defending these courses by suggesting that students might become quantitative reasoners that they were not already, I found that I metaphorically, and unintentionally, separated the quantitative reasoner piece of a human from the rest of the complex aspects of human reasoners.

Histories

I remember a conversation about history of education research in a course in Fall 2013 taught by Dr. Jack Smith, CEP 911: Intellectual History of Educational Psychology. In the class, we were in the middle of discussing the emergence of cognitive theories of learning, and I felt on the edge of understanding the challenges involved in positioning a new theory by contrasting it with another. Jack mentioned something to the effect of (I am sure this is not a direct quote), "behaviorism was not necessarily what cognitive scholars say it was." Although the benefits of having something to critique in order to argue for something new became apparent, I realized that to highlight the weaknesses of behaviorist theories of learning was not equivalent to showing the strengths of a cognitive approach. The idea of understanding intellectual history stuck with me, and what that meant to me was well summarized by the CEP 911 course syllabus:

> Because the course takes a historical perspective, it may seem like a survey of "old ideas." Against the idea that only contemporary perspectives can support current research in learning and development, the course argues for a different position—the need to understand the evolution of the present. There are few truly "new" ideas about human learning and development; most of what is presented as "new" in educational psychology involves the reformation, reframing, or transformation of older ideas. In order to understand how to build and use "newer" (and presumably "better") perspectives, we must develop a working knowledge of the ideas that have shaped that field over time. We will not study "old" ideas to accept them as given and sufficient, but to understand their strengths and weaknesses in order, ultimately, to build on them—as all current scholars of thinking, learning, and development are doing. (Smith, 2013, pp. 1-2)

Fast forward two years, three years, and (nearly) four years into my future, respectively. In my comprehensive depth paper, I wrote about the relationship of a newer domain, quantitative literacy scholarship, to an older domain, literacy scholarship. In my dissertation proposal, I was swept up by encounters with Foucauldian ideas about discursive archaeology and genealogy as methods of history, and I wanted to write personalized histories for any critical moments my students might experience. Now, in my dissertation, I historicized quantitative literacy (numeracy) discourse in my first article. *Historicizing* (Popkewitz, 2013) is a methodology for historical research that seeks to write a history of the present by troubling the ideas that are most commonsense.

My motivation to historicize QL is that I noticed when scholars introduce QL, they often do it in a commonsense way, as though it is a foregone conclusion that it is important, and more important now than before. A "deluge of data," on a "world awash with numbers," (makes quantitative literacy "loom as a successor to literacy" (Cohen, 1999, p. 5) when quantitative illiteracy "plagues far too many" (Paulos, 1989, p. 3). It is unsurprising that any group of scholars have shared language, assumptions, or perspectives; but historicizing what is taken-as-shared is a "strategy…of an optimism that to unthink what seems natural is to open other possibilities" (Popkewitz, 2008, p. xv).

Change

I also historicized quantitative literacy as a form of self-critique. This artifact of self-critique was the most tangible from a long string of thoughts I had wondering why quantitative literacy matters to me. I entered my doctoral studies in mathematics education after an interview where I emphasized my interested in quantitative literacy. At that point, I was essentially un-inducted into the scholarly discourse, but aware of its public presence. I was intrigued by the idea of drawing boundaries around mathematics curricula by something other than subject area (algebra, geometry, etc.). Some excerpts from my annual review materials demonstrated my persistent attention to quantitative literacy:

- Year 1: "Quantitative literacy theoretically may occur when a person applies quantitative reasoning to their field"
- Year 2: "For quantitative literacy, [my] interests are reflected by [my] wanting to consider what is important and what we want students to know"
- Year 3: "I want to understand the dispositional effects of taking a course that might be a substantially different mathematical and statistical experience than the students' high school courses"
- Year 4: "I was influenced by a presentation about unique course structures in English around teaching for disciplinary literacy, critical literacy, and inquiry literacy. The courses were designed around a big idea (e.g. Playing with Gender, and Writing the Great American Novel). I think that considering how mathematics and statistics courses could be similarly designed around higher-level learning goals is compelling"
- Year 5: "In my dissertation…I study the potential for quantitative literacy as an alternative mathematics education goal"

There is a sort of irony that I entered the program thinking about quantitative literacy, wrote about my interest in quantitative literacy in each annual review, and wrote a dissertation about quantitative literacy. The irony is that I feel like I have been transforming. The allure of a simple vision for learning, teaching, assessment, and curriculum has faded – changed into complexity. The veil provided by my own multifaceted privileges and a myth of meritocracy has been pulled

back – changed into criticality. The mystique of mathematical power has been tarnished – changed into postmodernism. I sense, therefore, a sort of irony in that my dissertation is nevertheless about quantitative literacy. How could I be transforming, yet still focused on quantitative literacy?

Nowhere was I more self-aware of my own transformation than during my experiences co-creating and implementing two new mathematics courses in quantitative literacy at MSU. I am so grateful for those experiences, because they did not just shape who I am as an educator, they changed who I am as a person and how I treat other people. They represented such meaningful possibilities to me – *humanizing* possibilities – that I felt compelled to talk about them in professional mathematics education spaces in ways I have not felt compelled to talk about other ideas. I do not think my transformation would have been the same without Dr. Vince Melfi working to involve me in developing and teaching new courses in quantitative literacy. Our conversations about what quantitative literacy is or could be, over the course of three years, were critical to how my views about mathematics education.

Leaving

> Beth: "Do you wish you did a more traditional dissertation?"
> Jeff: "No."

No story of how I think I got to this dissertation would be anywhere near complete without talking about my partner, Lynette. Although my journey into the wilderness of postmodern theories and the energy of critical theories was never solo – given the massive number of writers whose work moved me – my journey was also physically shared with her. I cannot give a full account of how her insights have affected me or of how the influence her loving criticisms had on my work.

Together, we also tried to make good trouble for our graduate Program in Mathematics Education [PriME]. We advocated for change, for inclusive practices, and for community. We advocated for welcoming more people with different histories who might change things in unexpected ways. We also advocated on behalf of ourselves and our fellow graduate students, so that we might be embraced more fully as people separate from the graduate student subject-position. Ultimately, I think we did these things because we often feel in-between spaces – millennials who are not old enough to be considered wise but old enough to be expected not to be "foolish." The most in-between space I exist in is within the boundaries of mathematics education. As I leave, my changed self – my critical postmodern self – recognizes these boundaries are troublesome illusions that are very real. Ultimately, living in those in-between spaces – thinking that I may not belong in mathematics education, when I am simultaneously a graduate student *in* mathematics education – helped me reframe the type of scholar I hope to be. Specifically, I will belong in mathematics education spaces as long as those spaces do not tell me I do not.

It is from that position of in-betweenness that I write a dissertation for a Ph.D. in mathematics education about a pair of QL courses that I do not consider mathematics courses. In some real way, that is the overarching theme of my dissertation, to somehow illustrate the possibilities these courses may have for thinking about, *and enacting*, a radically different form of mathematics education: one that is inclusive, welcoming, and potentially transformative.

It is also from that position of in-betweenness that I want to thank everyone who helped me become who I am and who made this dissertation possible.

Overview

Chapter two is where I situate my dissertation study through developing a social theory of quantitative literacy by translating a social theory of literacy (Barton & Hamilton, 2000). I also describe my epistemological stance towards research as a creative act, my theoretical commitments to critical postmodernism, and summarize my methodologies and methods for each of the three articles.

Chapter three is my first article. In this article, I historicize the numeracy discourse by writing a genealogy that traces how statements about numeracy emerge in scholarship, with a focus on the United States. Scholars' statements about numeracy form a discourse that pressures mathematics education to reform. These pressures are sustained when scholars connect numeracy to historically powerful justifications for reform. I name these as three *promises* embedded in the discourse: (1) numeracy promises to reflect modern reality, (2) numeracy promises to empower, and (3) innumeracy promises to have social costs. I conclude with a discussion of the *literacy myth* and its implications for mathematics education.

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Chapter five is my third article. This article describes findings from a study on students' projects during a mathematics course in quantitative literacy. The issues students chose to research turned out to be connected to a particular class of problems. Across places and disciplines, people are working on these *wicked problems* which are messy, global, connected, responsive, and unavoidable. Wicked problems are in contrast to curricula that may center tame problems. This apparent mismatch provided the impetus to consider education for wicked problems. After coding students' projects using the Rittel & Weber's (1973/1984) ten characteristics of wicked problems, I found three themes: complexity, transdisciplinarity, and openness.

Chapter six is my conclusion. In the chapter I synthesize what I have done in my dissertation and revisit some of my theoretical work – most notably my social theory of quantitative literacy. I also use my dissertation to revisit mathematics education as a whole, including research, and try to make some new connections about what is and could be happening, that I call the *possibilities turn*.

Chapter seven is my parting thoughts. In it, I return to my positionality by discussing an aesthetic choice I have engaged during this dissertation. That aesthetic is the *metamodern* aesthetic and it involves the juxtaposition of incredible seriousness with playful detachment. I think about the metamodern aesthetic and my millennial identity in order to reframe doing education research.

CHAPTER TWO:

STUDYING QUANTITATIVE LITERACY: EPISTEMOLOGICAL, THEORETICAL, AND METHODOLOGICAL CONCERNS

In this chapter, my goal is to frame my dissertation study of quantitative literacy (QL). To organize around this goal, I first respond to David Stinson and Erika Bullock (2012; 2013; 2015), who have challenged mathematics education researchers to embrace contemporary theory and methodology, and to more explicitly interrogate and state our epistemological stances. Following Crotty (1998), they noted that at least four interrelated parts of a research program can be identified and should be described. At the heart of research as a knowledge-generating enterprise is the epistemological stance of the researcher. In particular: how does the researcher understand the generation of knowledge, broadly speaking, in order to defend theoretical perspectives, methodologies, and methods?

Within this chapter, I discuss my epistemological stances – *virtue epistemology* (e.g. Battaly, 2006) and *humanizing* research (e.g. Paris & Winn, 2013), and my overarching theoretical perspective – *critical postmodern theory* (Stinson & Bullock, 2013; 2015). In addition, I summarize some of the methodologies and methods that I chose and engaged during each of my three articles in chapters three (p. 45), four (p. 68) and five (p. 96) – though more detailed accounts are usually within the articles, wherein I connect them with analysis, findings, and arguments. In the first article, I historicize QL and connect it to the sociohistorical justifications for mathematics education reform and necessity. In the second article, I use practitioner inquiry to provide an exemplar of how the students in my study helped me interrogate my experiences co-designing and implementing the course on QL. In the third article, I push on the concept of problem-solving by arguing that wicked problems should be a part of curriculum, and sharing a case of what that means for mathematics education and QL.

I focus the majority of this chapter, however, and the beginning of it, describing the theory of QL I am developing, which interlocks with my three articles, my epistemological stances, and my theoretical commitments. That theory is a *social theory of quantitative literacy* (Ares & Evans, 2014; Baker, 1996; 1998; Baker & Street, 1996; Baker, Street, & Tomlin, 2003; Gerger, 2014; Street, 2005; Street, Baker, & Tomlin, 2005), wherein I translate Barton & Hamilton's (2000) social theory of literacy.

A Social Theory of Quantitative Literacy

I begin this chapter by developing a social theory of quantitative literacy. The influence of social theories on education culminated in what some scholars have called the *social turn* (e.g. Gee, 1992; 2010). Scholars have used the "turn" metaphor to retroactively characterize a patterned accumulation of changes within the landscape of research. A turn describes a set of scholarship that emerges across disciplines, discourses, and purposes through its critiques of and departures from the more prominent theories, methods, and assumptions of that time. The social turn involved literacy scholars, and scholars from many domains – including mathematics – challenging the dominant cognitive and behaviorist paradigms by including social activity as generative for "meaning, thinking, and reasoning" (Lerman, 2000, p. 8).

In mathematics education, the social turn has involved accounting for sociological perspectives on understanding classroom interactions and teaching and learning (e.g. Cobb, 1994; Ernest, 1994; Putnam, Lampert, & Peterson 1990). Stephen Lerman (2000a; 2000b; 2006) has made fuller accounts of the social turn in mathematics education, and Paola Valero (2004) has compiled a volume discussing the sociopolitical turn.

The Case for Quantitative Literacy

Quantitative literacy scholarship emerged, at least in the United States, after John Paulos' book, *Innumeracy*: *Mathematical Illiteracy and Its Consequences* (1989). Paulos detailed how he saw people's discomfort working with numbers affecting their lives. In insignificant contexts, such as how many three-scoop ice cream combinations are possible at a shop, and highly significant contexts, such as the scope of the devastation of nuclear bombs, Paulos argued that innumeracy precluded people from making fully informed decisions.

Lynn Arthur Steen has been an influential QL scholar in the United States. In *The Case for Quantitative Literacy,* Steen and colleagues (2001) provided a thoughtful, and significant, anchoring document for work in QL. *Quantitative literacy* is an important "habit of mind" (Steen et al., 2001, p. 4) characterized by a willingness to engage with quantitative information and tools to make sense of the world. They argued that the 21st-century, due primarily to technology changes, is and will continue to be a significantly more quantitative environment than any previous time in history – that our world is "[a] world awash in numbers" (Steen et al., 2001, p.1). As a result, quantitative literacy ought to be elevated educationally as a partner to literacy because "as the printing press gave the power of letters to the masses, so the computer gives the power of number to ordinary citizens" (Steen, 1997, p. xv).

Steen and colleagues carefully separated QL from the skills that supported it, the elements that helped frame it, and from the spaces and places it is expressed. According to Steen et al. (2001) it can be instructive to consider quantitative literacy as a habit of mind through at least three lenses. These lenses do not constitute quantitative literacy; instead they help "to form a more comprehensive portrait of quantitative literacy" (Steen et al., 2001, p. 7).

First, the *skills of quantitative literacy* are the mathematical and statistical tools most readily applied in everyday life. These tools include: arithmetic, quantitative data, and modeling. The team argued that a list of skills can be comforting because it might reflect traditional goals of schooling to master skills that can then be transferred and applied when relevant outside of school. Many of these skills are major parts of typical school curricula (e.g. arithmetic, geometry and algebra); however, they are not necessarily learned in a fashion to support the development of a QL habit of mind that enables the many possible expressions of quantitative literacy.

The contexts within which quantitative literacy are realized are where *expressions of quantitative literacy* can be found. A person can express quantitative literacy by leveraging skills of quantitative literacy when making decisions and constructing arguments in context. The contexts range from financial decisions involving risk calculation, assessing public policy alternatives, and making lifestyle and health choices. The inseparability of quantitative literacy from the contexts in which it is expressed is an idea that appears to have unanimous agreement among scholars working on quantitative literacy. Finally, the *elements of quantitative literacy* combine to elaborate how to develop and use QL, and to enumerate QL learning goals. These elements include mathematical and statistical ideas, for example: interpreting data, number sense, and symbol sense. Less traditional, and perhaps more challenging, elements of quantitative literacy include: confidence with mathematics, cultural appreciation of mathematics, logical thinking, making decisions, and mathematics in context. Additionally, Steen et al. (2001) laid out a list of dispositional elements involved in using QL.

Besides implications for pedagogy, Steen and colleagues (2001) also differentiated QL epistemologically, claiming it "employs and enhances both statistics and mathematics" (p. 5). Whereas mathematics is concerned with deductive reasoning, and statistics is concerned with

uncertainty, QL is concerned with "the logic of certainty" (Steen et al., 2001, p. 5), framing it as an overtly epistemological concept focused on knowledge claims which are socially constructed. In fact, QL scholarship not only acknowledged the roles of mathematics and statistics in making knowledge claims about the world, it has been centrally focused on these roles. Despite attending to the logic of certainty – that is, how people make claims with and about quantitative information – QL scholarship has generally not explored, from an inclusive perspective, how people interact with quantitative information as part of a constellation of ways to reason and make decisions (i.e. moral, scientific, religious, et cetera). As a result, I believe that QL scholarship would benefit from considering and engaging a social theory of QL.

Summary. Steen and colleagues produced an influential document, at least in the United States, regarding QL. Their fundamental goal was to delineate how QL was different from mathematics and statistics, and make the case that QL was increasingly important to modern life, yet underserved by education. Although they detailed the skills of quantitative literacy, elements of quantitative literacy, and expressions of quantitative literacy, they argued that quantitative literacy is best understood as a "habit of mind" – that is, quantitative literacy means an individual has the disposition to see value in, and look to engage, the mathematics and statistics they encounter in everyday life.

The primary influence this work has had on me involves the dispositional dimension of quantitative literacy. In a serious way, this differentiates quantitative literacy in mathematics education, but also connects it quite seriously with other dispositional work, such as "productive disposition" from *Adding It Up* (National Research Council, 2001). Although Steen and colleagues laid out a compelling case for why QL matters, the premise of an individual disposition to engage mathematics and statistics in the social world can be complicated by

thinking about individuals as mutually constitutive with that social world. In the next sections, I outline some of how literacy scholarship has grappled with this individual-social mutual constitution and has taken into consideration issues like power, culture, and history. I then discuss one theory of literacy, Barton & Hamilton's (2000) *social theory of literacy* and translate their six propositions to QL to develop a social theory for QL.

The Social Turn in Literacy Scholarship

Researchers have historically conceptualized QL as intimately related to literacy, but as a younger field, have not explored as many theoretical positions. The most common theoretical stance toward QL is as a critical competency necessary, or at least helpful, for living well in contemporary times. The premise of this stance is that QL can and should be outlined by experts who have insight into what it takes to live well, now. This top-down approach to describing QL mirrors top-down approaches to literacy, where how to read well and use what is read to make decisions is fixed and the goal is to teach students to be literate. Both of these approaches stem from an expert model of education, where subjects and learning are prescribed by experts, and mathematics education research would attempt to facilitate experts realizing their goals.

Not without some merits, this top-down conceptualization of literacy has been challenged in several ways. First, if literacy is empowering because it involves increased agency, that clashes with an authoritarian educational approach that limits agentive possibilities relative to literacy (e.g. Giroux, 1984); that is, telling people how to practice literacy contradicts a hope for literacy to be freeing. Second, the narrower literacy is conceptualized, or the closer to fluent reading and writing, the more social practices are excluded from focus. In other words, top-down conceptualizations of literacy oversimplify the complex ways people practice literacy from a bottom-up conceptualization (e.g. Gee, 1989). Third, the top-down conceptualizations of literacy

attempt to create a general definition of literacy that misses how literacy is contextualized and localized. This critique has generated ideas like multiliteracies (e.g. Street, 1984) and new literacies (e.g. Gee, 1989; Leu et al., 2013).

Each of these critiques offered new possibilities for literacy research. I argue that these new possibilities are also offered to QL researchers if we conceptualize a social theory of QL. In this section, I translate a social theory of literacy (Barton & Hamilton, 2000) into a social theory of quantitative literacy. I begin with an overview of what has been an influential conceptualization of QL (Steen et al., 2001) for me, and transition into the social theory.

Translating a Social Theory of Literacy for Quantitative Literacy

In this chapter, I develop a social theory of quantitative literacy. An immediate challenge to this work comes from within QL scholarship. Steen (2003) argued, "QL explorers have moved beyond debates about the definition of QL, not because they reached consensus but because they recognize that development of QL programs is more important" (Steen, 2003, p. 13). There is merit to that position, as semantics can slow down action; I think, however, that critical discussion of conceptualizations and definitions can also help add clarity to the scholarship and open up new possibilities for research and understanding. Besides the potential benefits of conceptual and analytical work to developing QL programs, nearly fifteen years has passed. Changes to social, cultural, technological, and political contexts suggest that trying to reconceptualize QL is timely.

To direct my reconceptualization of QL, I turn to literacy scholarship, which generates a second challenge to this work. The challenge emerges from concerns about the fidelity of adapting a theory from literacy into another domain. These concerns are not uncommon when "educational research and practice have been net importers of methods, theories, and discourses.

Their histories have been ones of adopting (and sometimes, but certainly not always, adapting) interpretive frames from other disciplines, often with dubious results" (Davis, 2008, p. 50). These concerns solidify my purpose here as productive, not definitive, where my goal is to enhance the dialogic relationship between literacy and QL.

Quantitative literacy has a well-documented relationship to literacy, although the relationship has been differently described, "from distinctly separate, with quantitative literacy as the mirror image of literacy to quantitative literacy as one subset within a broad literacy conceptualization" (Craig & Tunstall, 2016, p. 1086). To describe my theoretical perspective for this dissertation, I sought to translate the six propositions of a social theory of literacy that Barton and Hamilton (2000) made by adapting to quantitative literacy:

1. [Quantitative] Literacy is best understood as a set of social practices; these can be inferred from events which are mediated by written texts.
2. There are different [quantitative] literacies associated with different domains of life.
3. [Quantitative] Literacy practices are patterned by social institutions and power relationships, and some literacies are more dominant, visible, and influential than others.
4. [Quantitative] Literacy practices are purposeful and embedded in broader social goals and cultural practices.
5. [Quantitative] Literacy is historically situated.
6. [Quantitative] Literacy practices change and new ones are frequently acquired through processes of informal learning and sense making. (adapted from Barton & Hamilton, 2000, p. 8)

Each of the propositions offered something to which QL scholarship can respond and be informed. I echo Barton and Hamilton's approach by weaving the six propositions into my discussion of literacy and QL. In what follows, I call attention to each proposition with bold and italic text, followed by a parenthetical note of which corresponding proposition number.

Literacy research has probed at the limits of a top-down conception of literacy, with a "view that reading and writing only make sense when studied in the context of social and cultural (and we can add historical, political, and economic) practices of which they are but a part" (Gee,

1992, p. 3). Quantitative literacy research has probed the boundaries of a privately-owned quantitative literacy by understanding quantities as socially constructed (Best, 2008a, 2008b). Similar to literacy texts, quantities and quantification are regulated by discursive social rules in which quantities are widely distributed and accepted to interact with who has the authority to produce numbers, and whose numbers are trustworthy.

To conceptualize quantitative literacy as solely privately held limits how we can think about, study, and affect quantitative literacy. What has been referred to as the *social turn* (e.g. Gee, 1992) challenged the dominant cognitive and behaviorist paradigms by including social activity as generative for "meaning, thinking, and reasoning" (Lerman, 2000, p. 8). It reflected the increasing influence of sociological perspectives in understanding classroom interactions and teaching and learning. Stephen Lerman (2000a; 2000b; 2006) has made fuller accounts of the social turn in mathematics education, which is beyond the scope of this chapter.

In literacy, the social turn included the generation of social theories of literacy. A *social theory of literacy* describes the relationship between "the activities of reading and writing and the social structures in which they are embedded and which they help shape" (Barton & Hamilton, 2000, p. 7). This theory embraces the simultaneity of individuals, groups, communities, cultures, and histories, because it "straddles the distinction between individual and social worlds" (Barton & Hamilton, 2000, p. 8). For similar reasons, ***quantitative literacy is best understood as a set of social practices; these can be inferred from events which are mediated by quantification*** (Proposition #1). I consider *quantification* to involve the intersection of mathematics and statistics with real world contexts. An event is mediated by quantification if it involves the application of mathematics or statistics, including: modeling, rhetoric such as implying a metric or hierarchy, and producing quantitative data.

What emerged from literacy scholars making the social turn is a new way of thinking about literacy in terms of social practices as opposed to a skills-based orientation. *Literacy practices* exist "in the relations between people, within groups and communities, rather than as a set of properties residing in individuals" (Barton & Hamilton, 2000, p. 8). By introducing relationships to quantitative literacy practices, we must confront important ideas that are obscured by an over-attention to individuals. Those ideas include: power, trust, responsibility, difference, and ethics – all ideas that complexify quantitative literacy while also clarifying what is involved. *Quantitative literacy practices* clarify the link between skills and elements of quantitative literacy and their expressions: the link between the activities of mathematics and statistics and the social structures with which they interact.

The power of conceptualizing QL as a set of social practices is that it decenters a focus on what people *do not do* (i.e. innumeracy or low numeracy), and instead centers the exploration of what people *do*. Questions about mathematics anxiety and discomfort (e.g. Paulos, 1989) are relevant to what people do with quantitative literacy, yet quantitative literacy is not a solely a private act. A person might quantify their thinking, share or hide how they measure or what they chose to count; a person might present their quantification as opinion or fact, or ignore quantities that run counter to their beliefs. All of these actions "connect people with one another, and they include shared cognitions represented in ideologies and social identities" (Barton & Hamilton, 2000, p. 8).

Rather than literacy being limited to an abstract ability to read and write, literacy practices as social events recognizes the plurality of ways that reading, writing, and language mediate our relationships and are reciprocally formed by the qualities of different relationships. Similarly, there is a plurality of ways that people interact with the quantities they encounter. For

example, using quantitative rhetoric (i.e. words like many, some, few) or making the decision to quantify, offer a new concept to be studied.

If literacy events are those "activities where literacy has a role" (Barton & Hamilton, p. 8), *quantitative literacy events*, or *numeracy events* (Baker, 1998; Baker & Street, 1996; Baker, Street, & Tomlin, 2003), might be considered activities where QL has a role. That is, activities where those social relationships involve quantities, quantification, space, or shape, which I tentatively put under the label "quantities". When considering literacy (and QL) as social practices, it becomes apparent that social practices are contextualized and local. The social relationships within school, work life, or home life are qualitatively different, and we expect that literacy and quantitative literacy practices differ across these different spaces. That is, ***there are different quantitative literacies associated with different domains of life*** (Proposition #2). Steen et al. (2001) listed several spaces and domains where people can express QL: citizenship, culture, education, professions, personal finance, personal health, management, work. A social theory of QL suggests that the people engage different QL practices in each of those domains because people have different relationships with different parts of their lives.

As different quantitative literacies are associated with different domains of life, QL practices within different domains have different social value. Beyond the already given domains, one idea from social theories of literacy is that *discursive communities* have "characteristic ways of talking, acting, valuing, interpreting, and using written language" (Barton & Hamilton, 2000, p. 11). Similarly, discursive communities relative to QL can be characterized by the ways they interact with events mediated by quantities and quantification. Different groups practice QL differently, including contentious relationships with pervasive quantification and

calls to quantify. Steen brilliantly summarized Robert Orrill's (2003) autoethnographic account of the relationship between his field of humanities and quantitative literacy:

> As the standard of civil and political evidence transitioned throughout the twentieth century from the arts and humanities to the natural and social sciences, quantification increasingly replaced classical verities as the foundation of accepted truths. The pretense of objectivity in social measurements rankles humanists still. Echoes of opposition to quantification can be heard throughout higher education even today as faculty argue with administrators and politicians about means of assessing the outcomes of liberal education. (Steen, 2003, p. 12)

Quantitative literacy practices can include opposition to quantification. Nevertheless, quantification has continued to be a dominant social and cultural practice in the United States, where ***quantitative literacy practices are patterned by social institutions and power relationships, and some quantitative literacies are more dominant, visible, and influential than others*** (Proposition #3).

Interrogating the role of literacy in democratic life developed into *critical literacy* for emancipatory participation in the contemporary world (e.g. Freire, 1970; Giroux, 1984, Bishop, 2014). Freire (1970) positioned readers as actively constructing truth while reading through reflection. Critical literacy differs from literacy when it refers "only [to] where concerted efforts are being made to understand and practice reading and writing in ways that enhance the quest for democratic emancipation" (Lankshear & McLaren, 1993, p. xix). Specifically, Giroux (1984) discussed the potential for literacy to be used either to emancipate oppressed people or to reconstruct existing social power structures.

Important considerations, like: which social practices are considered literacies and which are not, who determines what constitutes literacy, and the failure of increased rates of reading and writing to bring about its proponents more lofty predictions, all illuminate how conceptualizations of literacy have been used to reify existing social inequities (Giroux, 1984).

QL scholars have made multiple statements that mirror literacy; for example, "in an age dominated by numbers, individuals who lack the ability to think numerically can neither make wise decisions nor participate fully in civic life" (Steen, 2001, p. 10) and "an innumerate citizen is as vulnerable as the illiterate peasant of Gutenberg's time" (Steen, 1997, p. xv). QL scholars would be wise, in my opinion, to avoid falling into the same pitfalls that literacy scholars did in selling the benefits of quantitative literacy, where "numeracy is a key feature of the reforms…but with little consideration of the social context within which judgements about levels of numeracy are being made" (Lerman & Zevenbergen, 2004, p. 27).

If "America is increasingly divided into math-haves and math-have-nots" (Carnevale & Desrochers, 2003, p. 22), then it is crucial to interrogate what qualifies this dividing practice and upon what basis are the "math-have-nots" excluded from their informed participation in democratic and economic life. Moje (2000) described the ways that literacy practices of people who are socially marginalized, in this case gang members, used their "literacy practices as meaning-making, expressive, and communicative tools" (p. 651). She explored the ways that adolescent gang members created graffiti texts in ways that shaped their world and told their stories; further, people outside of their community of discourse could not fully interpret or understand all that the graffiti expressed.

Where Moje (2000) and Hill (2009) highlighted the exclusion of particular literacies from school as detrimental expressions of power, Lave (1988) provided an early example in mathematics and quantitative literacy. She witnessed people doing mathematics in a supermarket context and found similarly that people engaged in precise and accurate mathematics that was unvalued and not recognized within school contexts. Public schooling is paramount to recognizing the dominance ascribed to particular literacies; that is, schools validate particular

literacy practices (i.e. rigid grammar and structure) and, implicitly or explicitly, invalidate others. This work is becoming more prevalent in mathematics education scholarship when "exploring this—in many ways, forbidden—why question, [where] mathematics education as a research domain is cracked wide open, revealing its inclusions and exclusions" (Skovsmose, 2005 as cited in Stinson & Bullock, 2012).

There are significant lines of work that help break open mathematics education - too many to name - but including: criticalmathematical literacy (e.g., Frankenstein, 1983; 1990; 2001; 2009), teaching mathematics for social justice (e.g., Gutstein, 2006), equity (e.g., Aguirre, 2010; Gutierrez, 2012; 2013; Martin, Gholson, & Leonard, 2010), and critical mathematics education (e.g., Ernest, 2010; Skovsmose, 1985; 2010). Mathematics educators can also find some very thoughtful work along similar lines in QL scholarship, which has explicitly challenged and questioned the efficacy of dominant mathematics education. QL scholarship questions the purposes of dominant curricula: "it is not calculus but numeracy that is the key to understanding our data-drenched society. Quantitatively literate citizens need to know more than formulas and equations" (Steen et al., 2001, p. 2).

Which are the dominant, visible, and influential QL practices can be debated. QL challenges to curricula, though, might suggest which quantitative literacy practices are currently the most dominant, visible, and influential – those central to the dominant curricula. These practices might include abstraction, speed, and neutrality. Several scholars contributed to a volume where they tried to "explore ideas with deep roots in the mathematical sciences without concern for the limitations of present schools or curricula" (National Research Council, 1990, p. iii). These scholars identified: pattern, dimension, quantity, uncertainty, shape, and change, as important mathematical ideas that deserve more curricular attention.

There may also be dominant QL practices that are not included in the dominant mathematics curricula, such as: data-based decision making, big data, and quantification. A potentially dominant QL media practice is the juxtaposition of an extreme case alongside large numbers, as Himmelstein (2014) found. Considering what non-dominant, less visible QL practices might be could help the field better understand its possibilities. Non-dominant QL practices might run counter to dominant practices or transform, ignore, reject, or intersect them in compelling ways. Whatever QL practices people engage, they have reasons; whether a person or community chooses to ignore numbers that refute their position or elevate numbers as authoritarian and true, ***quantitative literacy practices are purposeful and embedded in broader social goals and cultural practices*** (Proposition #4).

Reading and writing are only occasionally done for their own ends, and so too mathematics and statistics. Literacy is always purposeful; it is "always literacy for something – for professional competence in a technological world, for civic responsibility and the preservation of heritage, for personal growth and self-fulfillment, for social and political change" (Knoblauch, 1990, p. 76). The broader social goals for literacy are mirrored in calls for QL as a goal-directed practice toward informed decision-making or economic empowerment, for example. Barton and Hamilton (2000) claimed that purposeful literacy practices imply that research on literacy must attend to context and motivations.

The Uses of Literacy by Richard Hoggart (1957) has been called a seminal piece in reconceptualizing literacy. Hoggart implicitly and explicitly deconstructed the notion of an illiterate person who is contrasted against the literate intellectual. He instead argued that people which intellectuals seek to change have co-constructed cultures with sophisticated epistemologies and ontologies. He built his argument by contrasting mass media with localized

newspapers. Hall argued that prior notions of the need for literacy – that if people can read and write at a certain prescribed level, they will become "cultured" – were not only doomed, but highly questionable endeavors, when all people co-created and existed within a complete cultural and social environment.

> It follows that the effects of cultural products cannot be 'read off' or inferred directly from the contents of what is produced for them to consume because to have 'social effects' of any depth they must enter into and be in active negotiation with an already fully elaborated social and cultural world. Reading, in this sense, is always a cultural practice. (Hall, 2008, p. 24)

Giroux (1988) interrogated literacy as a cultural product inseparable from historically powerful perspectives. He emphasized the importance of considering ideologies that intertwine with literacy practices and calls for particular forms of literacy. He recognized that literacy co-existed with a notion of illiteracy not meant to signify an inability to read and write, but "to designate in a negative sense forms of cultural currency that appear disturbingly unfamiliar and threatening" (p. 61). ***Quantitative literacy is historically situated*** (Proposition #5), and has cultural meaning. That history includes how scholars tether it to literacy, with its own history as a marker of difference through the "illiterate" label, which QL scholars have extended:

> The wall of ignorance between those who are mathematically and scientifically literate and those who are not can threaten democratic cultures. The scientifically and mathematically illiterate are outsiders in a society in which effective participation in public dialogue presumes a grasp of basic science and mathematics. (Carnevale & Desrochers, 2003, p. 29)

QL from this perspective is a means to cultural ends, particularly the cultural and social goal of democracy. Besides positioning QL as imperative for particular cultural goals – specifically cultural maintenance – the emergence of QL should be historically situated. A historical approach to QL should attempt to trace the "ideology, culture and traditions on which current practices are based" (Barton & Hamilton, 2000, p. 13). Jablonka (2003) argued that it is "not

possible to promote a conception of mathematical literacy without...promoting a particular social practice" (p. 75).

How QL is conceptualized involves deciding whether a social theory of QL makes sense. It is possible to conceptualize QL as relatively stable; Cohen's (2001) historical account of numeracy in the United States during the 18th and 19th centuries highlighted much the same skills and dispositions as some contemporary conceptions: an ability and willingness to interact with everyday arithmetic and statistics. Cohen argued that discussions of QL "should spark a renewed debate about the adequacy of an arithmetic curriculum that, in its broad outlines, has been in place since the 1820s" (Cohen, 2001, p. 28). A social theory of QL challenges the idea that arithmetic remains the same across contexts, as well as through time. For example, even if counting is conceived of as culturally stable over some time, choices about what to count and what not to count are contextualized. There is also an issue of how technological changes enable contemporary forms of quantification and counting, for example the quantified self (Swan, 2013) and The World Happiness Report (Helliwell, Layard, & Sachs, 2015).

Some literacy scholars have argued that literacy practices are localized, dynamic, and deictic (Leu et al., 2013). A reciprocal relationship between technology and social communities fosters an environment where new and transformed literacy practices develop and some current practices fade. Technological changes like Twitter and other social media platforms change the texts that mediate literacy practices, and people create new practices within those media. Similarly, technological and cultural changes affect quantitative literacy practices (Craig, Mehta, & Howard, forthcoming, 2017). ***Quantitative literacy practices change and new ones are frequently acquired through processes of informal learning and sense making*** (Proposition #6). These changes can happen at several different levels of relationships: groups can valorize

the notions of quantification and big data, as in corporate and education movements for data-based decision making; individuals can also begin practicing quantitative literacy in new ways, "across their lifetime, as a result of changing demands, available resources, as well as the possibilities and their interests" (Barton & Hamilton, 2000, p. 14).

Why Build a Social Theory of Quantitative Literacy

One important question regarding social theories is the role of the individual. This concern is important to me, as erasing individuality seems as flawed as denying social context. Reckwitz (2002) distinguished social theories centered on practices from social theories centered on minds, discourses, and interactions. A social theory focused on practices involves attending to behavior and understanding that "appears at different locales and at different points of time and is carried out by different body/minds" (Reckwitz, 2002, p. 250).

My impetus for developing a social theory of QL comes from the way I read the psychological theories of QL that exist. Despite being grounded in the social world, as Steen et al. (2001) stated, QL is often conceptualized as singular, simple, and preferred; in other words, the simple binary developed in psychological-QL theories is one between the quantitatively literate and illiterate. Within this paradigm I read the QL scholarship to be, in general, collectively arguing for the identification of the innumerate through contrast with the expert numerate followed by the fixing of innumerates to be more like the numerate. There is very little scholarship that I have found which considers whether two "numerate" people might disagree about something. How then do we explain a person choosing to do different practices, at different times, with different purpose?

To me, this lack of plurality in QL scholarship is a fundamental weakness and at odds with grounding QL in the social world. Specifically, I believe that formulating a singular QL

subjects our scholars to essentially arguing *what I do is numeracy, and what I would not do is innumeracy* – a position maybe not be espoused by those same scholars. In contrast, a social theory can open up deeper conversations about why people disagree on quantitative information and issues. Quite simply, there is more going on than the quantitative during these QL events.

Developing a social theory does not suffice for developing a plurality of quantitative literacies. The social theory of QL I outlined can be interpreted as singular, by simply stating that only one set of social practices during QL events is literate, and the rest are illiterate. My own work developing a more radical social theory for QL which is explicitly inclusive is very much ongoing.

Studying QL from a Social Perspective

In the second part of this chapter, I discuss my epistemological stance and theoretical commitments to research. Specifically, I discuss virtue epistemology, humanizing research, and critical postmodern theory. I then use these ideas to frame the methods I use in each of my three articles.

Virtue Epistemology and Humanizing Research

I attempted to engage a research program around an epistemological stance that is rarely explicitly stated. *Virtue epistemology* involves the validation of knowledge based not on the ontological qualities of the reality claimed through belief and justification, but on the motivation and action taken in coming to those beliefs. That is, "virtue theories in epistemology explain (or otherwise ground) justification and knowledge in terms of the intellectual virtues (rather than the other way around)" (Battaly, 2006, p. 193). For research, this epistemological stance suggests that research as a knowledge-creating activity is high quality if and only if it is produced through the application of *intellectual virtues*. Roughly analogous to moral virtues, intellectual virtues

include intellectual activities like open-mindedness, curiosity, and creativity (Baehr, 2013). Although most researchers I know would openly claim that their work involves these types of actions, it changes the endeavor to have intellectual virtues be the epistemological *authors* of truths, as opposed to describing the routes to uncovering, discovering, or understanding truths.

Virtue epistemology is well aligned with taking an asset-oriented stance toward different theories, methodologies, and methods. Virtue epistemology decenters the authority of modes of inquiry by redefining why methods produce knowledge. Instead of being reliable truth-conducive methods, the authors of the research are responsible for the generation of truth by exercising their intellectual virtues.

I am in danger of discarding treasured methods for generating knowledge; my intent, however, is to humanize research by positioning the researcher in particular ways relative to methods. From my perspective, localizing methods is a reality of research that is embedded into most methodological descriptions. Quantitative research methods require exercising expert knowledge of local contexts, variables, and measurements. Qualitative research methods require expert translation of methodologies to fit research questions and theoretical perspectives. There is an interesting multidimensionality to research methods wherein there is knowledge-generating power inherent in the method itself, but that power cannot be fully actualized without an expert research inscribing their particular problem onto the machinery.

Virtue epistemology offers another perspective on this relationship between researcher and methods. The methods a researcher uses are not inherently knowledge-generating, but rather a reflection of creative strategies attempted by that researcher. From this perspective, the creator of knowledge is not the method, but wholly the researcher; therefore, a virtue epistemological stance towards research offers me the opportunity to humanize research. *Humanizing research* is

"a methodological stance, which requires that our inquiries involve dialogic consciousness-raising and the building of relationships of dignity and care for both researchers and participants" (Paris, 2011, p. 137). In their volume on humanizing research, Paris and Winn (2013) compiled compelling entries from qualitative social science researchers who wrote about often unspoken researcher subjectivities, affect, and choices. Although a major focus of the volume is resisting and countering the ways in which qualitative research often dehumanizes the people who participate in studies, it also humanizes the researchers themselves. Each entry illustrates how personal research can be, the dignity and care (and creativity and imagination) that can be in research, and the beautiful messiness of research.

Research as a creative act. The particular intellectual virtue that I believe most clearly illustrates how I conceptualize doing research is *creativity*. Specifically, research as a creative act implies that through research we *create* knowledge, as opposed to *coming to know*. If knowledge is a manufactured product made by people, individually and collectively, then I argue that there are qualities to that manufacturing process that matter. I used virtue epistemology to describe those qualities in the research endeavor. At the same time, the methods themselves still matter. The methodological machinery matters to what researchers create and claim as knowledge. We have established methods for answering (or at least addressing) particular questions; we have analytical technique for illuminating the realities that lay hidden within the data that emerge from those methods; we have dissemination processes – including peer review – that help refine our more raw knowledges.

Conceptualizing methods as machinery, however, causes me to imagine researchers using assembly lines – and I have not met any researchers who do their work in this metaphorical way. Instead, professional judgement and expertise are very relevant. These qualities themselves

might suggest a manifestation of some intellectual virtues. Ultimately, because people do research, I find it humanizing to credit the people, not the methods, for what they create. Indeed, the methods which themselves have been imbued with power, were once unnamed and even not yet created. From this perspective, I can justify the use of longstanding methodologies and methods, but redirect some of the reasons for how they generate knowledge.

Critical Postmodern Theory

My research agenda involves a move away from "primarily questions of *how* to improve possibilities for teaching and learning of mathematics, toward a research agenda strongly concerned with the question of *why* mathematics education" (Pais, Stentoft, & Valero, 2010, p. 369, emphasis in original). My answer to that question is: mathematics education as part of a project of liberation. I take a critical stance towards why we should do mathematics education (e.g. Skovsmose, 1994), but also an uncertain stance towards what liberation ultimately means through acknowledging the simultaneity of liberation and oppression. As a result, I also conceptualize my work as poststructuralist and postmodern, which, like Bullock (2013), I use interchangeably; I want to embrace rather than resolve complex relationships between ideas, people, and structures. In particular, I want to resist making the world an object of inquiry with my students and simply "replacing one regime of truth with another regime" (Stinson & Bullock, 2012a, p. 1167) through transformation. In this way, I see myself working from a critical-postmodern perspective. Stinson and Bullock (2012a) argued that postmodernism can complement critical theory,

> Through deconstructing reductionist binaries and troubling emancipatory régimes of truth, the subject lives in a perpetual state of becoming her or his best self, while working within/against sociocultural, sociohistorical, and sociopolitical discourses. (p. 1167)

My enactment of a critical postmodern theory and methodology involves blurring the distinctions between such binary, practice and research, in several ways. First, I am actively researching myself. Second, I intentionally researched my own classroom. Third, my research methods are non-linear and in dialogue with my classroom activity. I illustrate these ideas by briefly describing my methodologies and methods in each paper.

I approach this work from a critical postmodern theoretical perspective (Stinson & Bullock, 2012a; 2012b; 2013; 2015). I take the critical postmodern perspective to be a reminder that when I choose inaction, particular injustices persist, and when I act to address injustices, I will perpetuate others. This hybrid perspective helps me to purposefully enact what I call *hesitant action*, something that I think results from what Bullock (2013) called "pessimistic activism" (p. 204). I consider *hesitant action* to be a continual process of doing and waiting, across and within interlocking time periods ranging from in-the-moment to multiple years. Across all three articles, I describe a series of interlocking hesitant actions: the process of co-creating two courses; teaching, reflecting on, and revising them; and studying these processes in a research study.

Chapter Three: Historicizing Numeracy through Genealogy

My first manuscript is a historical account of numeracy and QL because I wanted to deconstruct the idea that numeracy exists, is under-realized, and is worthwhile. I used the postmodern method of genealogy (e.g. Bullock, 2013; Fendler, 2011) in order to reveal the ways that numeracy participates in existing discourses about the need for mathematics education, and is sustained by complex and sometimes contradictory purposes. Historicizing and genealogy required me to read an immense amount of literature that involves statements about numeracy and quantitative literacy. Initially I was also producing an archaeological dig of numeracy and

quantitative literacy, seeking to trace back through history the ways numeracy existed as a statement, even before the term emerged. Instead, I focused on genealogical methods in order to tell a history of the present, where the numeracy discourse presents a persistent pressure on mathematics education to reform, while potentially overpromising societal change resulting from increases in numeracy.

Historicizing methodology. In this article, I used a genealogical method to historicize numeracy. *Historicizing* is a methodology that scholars use for historical analysis devoted to challenging the commonsense, with a vision for making the familiar strange. In this case, I troubled the position numeracy takes in scholarship as a commonsense goal, often alongside literacy. My goal was not to dismiss or dismantle the scholarship; instead, I worked to unthink some of the things I personally treasure about it, in search of "an optimism that to unthink what seems natural is to open other possibilities" (Popkewitz, 2008, p. xv). My project was to produce a genealogy of numeracy in order to trace how numeracy became normalized as a policy goal related to mathematics education, and to understand better how mathematics education scholarship is implicated in this normalization. Historicizing involves scholars attempting to produce a history of the present (Popkewitz, 2013). My genealogical method involved studying discourse from a Foucauldian conceptual approach.

Discourse and statements. In this article, I used the term *numeracy discourse* to synthesize scholarship across these terms. I conceptualized discourse from a Foucauldian conceptualization that differs from the more common, though no less complex, use of discourse to refer to talk (cf. Chandler, 2002). I take *discourse* to mean an assemblage of related statements which constitute a collection of relationships that frame "the possibilities [and impossibilities] for thought, speech, and action under particular socio-political and –historical conditions"

(Bullock, 2013, p. 18). The *numeracy discourse*, therefore, is a collection of statements and their relationships to their pasts, presents, and futures. A genealogy of the numeracy discourse involves writing a history of the present by working to understand how it helps to shape and constrain what is possible to think, say, or do.

Statements as data. For Foucault, a *statement* involves the coalescence multiple aspects of text and meaning. Statements rely on conceptualizing signs and referents as positive data, what Herbel-Eisenmann (2007) called "objectively given structure" (p. 346). Similarly, statements have a materiality that makes them a text open to historical analysis. The records of things said and written can be revisited. Nevertheless, statements have a new-ness when pulled through history into the present; in this way, statements "can be retold, but never re-experienced" (Bullock, 2013, p. 16). I take as data the set of things said and written about numeracy. My data generation for this article, therefore, included compiling and reading a significant volume of literature on numeracy, as well as an historical search for documents referring to similar ideas about general citizen capabilities, policy debates, and mathematics. The data I highlighted are what scholars, both inside and outside of mathematics education, have said about numeracy.

The social theory of QL. The most salient features of the social theory of QL in my historicizing article was that quantitative literacy is historically situated combined with the idea that its history is embedded in broader social and cultural goals that are patterned. As a result, my genealogy found that the numeracy discourse re-engages historical justifications for mathematics education reform while also being embedded in social and cultural patterns of technological advancement. As such, it simultaneously represents an old and new pressure to reform.

Chapter Four: Quantitative Reasoners as Fantasy

This article represents one effort to describe experiences I shared with many people related to these QL courses. I consider it to be the result of *practitioner inquiry*, wherein I took "inquiry as stance" (Cochran-Smith & Lytle, 2009; Lampert & Ball, 1998). This methodological approach fits well with a critical postmodern theoretical stance because it involved continuous attention to and reflection on my actions. As a method of inquiry, I followed what Cochran-Smith and Lytle (2009) called "working the dialectic…which refers to the reciprocal and recursive relationships of research and practice (or of theorizing and doing)" (p. x). I considered working the dialectic to be a byproduct of maintaining a critical postmodern perspective, but enhanced by focused writing, extensive reading, and other research methods. For instance, this particular article was only the latest draft of many attempts to communicate what I have learned from my experiences. I have written seven distinct partial drafts (and have fully discarded several) with different themes and purposes – all focused on describing my relationships with my students.

Practitioner inquiry blurs the boundaries between different educational roles, most notably the teacher and researcher. The simultaneity of critical and postmodern is supported by my taking effort to blur the boundaries between roles that are sometimes separated in education research. In this work, I did not fully separate my curriculum design from my teaching practice or from my research work. Certainly, different aspects of my identity were more salient at different times, as when I was a teacher in the classroom, but I was still also a researcher and curriculum designer.

Data in practitioner inquiry. My analysis of our curriculum designing has so far spanned three years. My analysis of my practice regarding these two new courses has so far

spanned two years. My analysis of the particular implementation of one of the courses, which I focus on here, has spanned one year. My data for these on-going analyses are what Cochran-Smith and Lytle (2009) called the *data of practice* which include:

> Students' work of all kinds…observations of students in and out of school, practitioners' plans as well as their journals and other self-reflective accounts of daily life…school and classroom artifacts such as report cards and textbooks, and the talk that occurs. (p. 56)

In this study, I have many of those data of practice, along with some classroom video recordings, curriculum design notes, interviews with students, and course syllabi.

Practitioner inquiry and critical postmodernism. As a methodological stance, practitioner inquiry aligns well with critical postmodern theory because it implies an ongoing process. In addition, it is well aligned with the critical theory concept of *praxis* as the work emerging in the blurry space between theory and practice (e.g. Freire, 1970).

I consider these plural analyses to be ongoing, interlocking, and messy: through my reflections and notes, in my lengthy and frequent conversations about the courses, during my reading related (sometimes retroactively) to the courses, in making decisions to reorganize the curriculum (including creating course projects), and in my daily experiences teaching the courses. I also read extensively across education, social sciences, methodology, and fittingly, the fantasy and science fiction genres. I recursively engaged with my written teacher reflections, student work and statements, and my curriculum development notes.

I would argue that these analyses necessarily imply the generation of knowledges. The enactment of those knowledges can take many forms, including curricular revisions, altered teaching practice, the creation of early teacher preparation projects, and a variety of written documents. This article, as a formal written research document, is one of those forms – but it is not disconnected from the others.

The social theory of QL. Several of the propositions of my social theory of QL were salient in this article. The impetus for creating the courses framed quantitative literacy with broader social and cultural goals, most notably a sense of plurality for the roles of mathematics and statistics, besides technical proficiency. We designed the courses around contextualized modules suggestive of the ways that different quantitative literacies apply to different domains of life. Most significantly, the idea that the person who chooses not to engage mathematics may not be called a quantitative reasoner suggests how some social practices of quantitative literacy are more dominant and visible.

Chapter Five: Wicked Problems and Quantitative Literacy

In this article, I circled back to a 20-year old discussion regarding problematizing and mathematics education (Hiebert et al., 1996; Smith, 1997). By leveraging how Smith (1997) deconstructed what problematizing could imply about mathematics education, I introduced a particular class of problems, *wicked problems*, in order to discuss my students' QL course projects. Although I knew I wanted to discuss my students' work with their projects, I did not settle on the wicked problems theoretical framework until five months into analysis. Through my initial open coding, I identified some themes like complexity, trust, and quantification practices, but when I encountered wicked problems (Rittel & Weber, 1973/1984), I had a sort of "aha" moment. The language of wicked problems, and the ten characteristics Rittel and Weber outlined, spoke to my earlier analysis and thinking about the possible implications of these projects for mathematics education.

Course background. The QL course described within this manuscript is the result of institutional efforts to improve the general mathematics undergraduate degree requirement at Michigan State University. Beginning in June 2014, I joined a small team of scholars working to

design and implement two courses in QL that would provide an alternative (to technical algebra) challenging pathway to fulfill the mathematics requirement. The first pilot implementation in Summer 2015 included several larger course activities (we considered them mini-projects); the Fall 2015 and Spring 2016 pilots included a culminating project in each of the context modules (e.g. Economics, Demographics) of the course.

Project background. In Summer 2016, I was given the opportunity to teach a small section of one of the courses and given considerable latitude over curricular decisions. Along with my colleague, Andrew Krause, who was teaching a second section of the same course, we decided to try integrating the module-based projects into one longitudinal course project. Although we both considered the project a success, there were substantial improvements to be made, that further instructors have already gone beyond.

Over the course of seven weeks, students completed their course projects on a social problem. In brief, students identified a social problem that they wanted to consider and engage, took care in framing the scope and focus of the problem and project, analyzed relevant media discourse, created an infographic of their problem, and reflected on what they had learned and hoped for. Students self-reporting check-ins, our classroom audio-video recordings, and my students' project artifacts, form most of the data I have that affected my thinking about this type of curricular experience.

Wicked problems theory. *Wicked problems* are ill-structured, complex, and unsolvable; according to Rittel and Webber (1973/1984) there are at least ten characteristics of wicked problems:

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rules.
3. Solutions to wicked problems are not true or false, but good or bad.
4. There is no immediate and no ultimate test of a solution to a wicked problem.

5. Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of possible solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The planner has no right to be wrong.

Wicked problems have been conceptualized within many fields, including: environmental studies (e.g. Kreuter, De Rosa, Howze, & Baldwin, 2004; Van Bueren, Klijn, & Koppenjan, 2003), political science and public policy (e.g. Head, 2008), public health (e.g. Blackman et al., 2006), public risk and defense (e.g. Ritchey, 2001), and economics (e.g. Batie, 2008). The move to consider work in their fields as wicked problems generally emerged alongside recognition of non-quantifiable complexity. Ritchey (2001) claimed, "if you work with long-term social, commercial, or organizational planning – or any type of policy planning that impacts *people* – then you've got *wicked problems* (p. 1). The presence of wicked problems can be signified by a sense of *reactivity*, where after attempting resolution, the problem transforms and "fight[s] back when you try to do something" (Ritchey, 2001, p. 1).

Across these disciplines, many scholars have engaged *networks* for attempts at resolution (Van Bueren, Klijn, & Koppenjan, 2003; Roberts, 2000). According to Weber & Khademian (2008), "networks have assumed a place of prominence…as the foremost means to organize to address complex problems" (p. 334). Wicked problems are suggestive of a particular kind of network, specifically *complex* networks where an immense amount of individual actors (usually people) are making many decisions that are interrelated and uncertain. The dominant and traditional methods of quantifying uncertainty which have been historically central to the field of

statistics are challenged by particular forms of uncertainty. Two particular forms of uncertainty resist quantification or prediction, "*agnostic uncertainty* (conscious, self-reflective actions among competing actors) and *non-specified uncertainty* (for instance, uncertainties concerning what types of scientific and technological discoveries will be made in the future)" (Ritchey, 2001, p. 7).

Theory-based coding. I coded all artifacts from all of my participants' projects. My unit of analysis was usually paragraphs of student writing, but also sections of students' infographics. I allowed for multiple codes to be applied to the same unit, meaning a paragraph of text might have illustrated multiple wicked problem characteristics. Given the focus of the particular article, I only shared one exemplar for each of the characteristics.

Thematic analysis. Three themes emerged from my theory-based coding, that I inferred from patterns I saw in the ways different wicked problem characteristics clumped together on single units. I connected those patterns to three ideas: open democratic education, complexity, and transdisciplinarity. I collaborated with my project co-creator in order to verify some of what I was seeing and discuss the potential theme names, over the course of three months of conversations and reading.

The social theory of QL. Approaching complex wicked problems from a quantitative perspective has led to the creation of new quantitative methodologies and theories, which likely has meaningful implications for quantitative literacy and mathematics education. In this article, however, I did not attend specifically to those implications, and instead described the curricular and instructional implications of open problematizing. Although the project had four assigned phases, topic selection for the project was open to students. As a result, there were social practices of quantitative literacy inferable from students' problem choices, how they engaged

with quantitative data, how they worked with media and claims about their problem, and how they conceptualized particular resolutions. Further, these practices were quite evidently embedded into larger social and cultural projects.

Summary

In this chapter, I developed a *social theory for quantitative literacy* by translating Barton and Hamilton's (2000) social theory of literacy. This social theory is embedded into, though not explicitly a part of, my three empirical articles. Interlocking this social theory, though also only implicitly part of my three empirical articles is my epistemological stance towards research – virtue epistemology. That I see research as a creative act helped me to take what I consider to be quite different approaches to each of the three articles. In the first article, I historicize a discourse; in the second, I use practitioner inquiry to discuss how an exemplar curricular topic exposed the limitations of some of our learning goals for the courses I helped design; in the third, I use theory-based coding to do a thematic analysis of wicked problems and consider their possible implications as curricular material for mathematics education. Despite the significantly different foci of each of these studies, my dissertation is a part of my overarching project of critical postmodernism, wherein I attempt to enact hesitant action.

CHAPTER THREE:

PROMISES IN THE NUMERACY DISCOURSE: A PRESSURE ON MATHEMATICS EDUCATION TO REFORM

Background

Numeracy is a concept related to mathematics education that scholars conceptualize in a variety of ways, and relate at different times to mathematical basics, mathematics for citizenry, literacy in mathematics, and mathematics embedded in social life. In the early 2000s, numeracy began gaining traction in public policy discussions and government mission statements internationally about mathematics education reform (Zevenbergen, 2004). Around the same time, Lerman and Zevenbergen (2004) highlighted a problem:

> Numeracy is a key feature of the reforms and hence serious considerations are made of what it is to be numerate, but with little consideration of the social context within which judgements about levels of numeracy are being made. (p. 27)

The social context of judgements about numeracy involves people exercising power. In particular, who assesses others' numeracy levels, and how, is tethered to the usual exercising of authority to measure and report on learning and ability. Tsatsaroni and Evans (2014) provided an exemplar for the critique of numeracy policy documents and assessments as another revivification of a competency model of knowledge. From this perspective, a focus on numeracy implies a simple form of curriculum and pedagogy "that a group of experts can simply assemble" (Tsatsaroni & Evans, 2014, p. 178). The authors' approach to thinking about the implications and dangers of numeracy as an educational goal illustrates how the government-organized top-down approach to numeracy served to reproduce historically marginalizing curricula and pedagogies. Their work responded to the problem Lerman and Zevenbergen highlighted, as does others' (e.g. Street, 2005; Baynham & Baker, 2002; Prince & Archer, 2016)

Theoretical Framework and Methodology

In this article, I address the problem of the social context of numeracy from a different direction: historical. In particular, I trace how numeracy "emerge[s] in discourse as a product of multiple influences" (Fendler, 2003, p. 17). I produce a Foucauldian *genealogy* of numeracy from an analysis of numeracy scholarship to understand the multiple ways numeracy is sustained as a concept. I use genealogy as a post-structuralist methodological name for "a strategy to undermine the naturalization" (Fendler, 2003, p. 17) of numeracy as a term. Instead of considering directly the social context and power relationships within which judgements about numeracy are created, I focus on the discourses within which the act of judging numeracy emerged as sensible. I work from the perspective that these discourses are embedded within scholars' justifications for studying and promoting numeracy.

I do not attempt to settle on one particular conceptualization or role for numeracy in this article. Instead, I try to consider the pressures – both inside and outside of mathematics education –that scholarship on numeracy put on mathematics education to reform. I argue that numeracy emerges within, and is sustained by, at least three different historical justifications for mathematics education and reform: technological progress, equity and empowerment, and social costs and efficiency.

Historicizing Numeracy Discourse through Genealogy

In this article, I use a genealogical method to historicize numeracy. *Historicizing* is a methodology that scholars use for historical analysis devoted to challenging the commonsense, with a vision for making the familiar strange. In this case, I trouble the position numeracy takes in scholarship as a commonsense goal, often alongside literacy. My goal is not to dismiss or dismantle the scholarship; instead, I work to unthink some of the things I personally treasure

about it, in search of "an optimism that to unthink what seems natural is to open other possibilities" (Popkewitz, 2008, p. xv). My project is to produce a genealogy of numeracy in order to trace how numeracy became normalized as a policy goal related to mathematics education, and to understand better how mathematics education scholarship is implicated in this normalization. Historicizing involves scholars attempting to produce a history of the present (Popkewitz, 2013).

Historicizing QL and numeracy may seem an odd choice when some of its scholars claim that these are relatively marginal concepts where "in the discipline-dominated K–16 education system in the United States there is neither an academic home nor an administrative promoter for this crucial competency" (Madison, 2003, p. 3). In the United States, ideas about QL can be found mostly prominently in book volumes (The College Board, 1997; National Council on Education and the Disciplines, 2001; Mathematical Association of America, 2003; 2004; 2005) and thereafter in the *Numeracy* Journal (www.scholarcommons.usf.edu/numeracy). Internationally, *Educational Studies in Mathematics* has been a relatively frequent journal for publishing about numeracy, along with *Literacy and Numeracy Studies*. Work in numeracy, and related ideas, has histories across the world. The relative absence of QL and numeracy in discipline-oriented mathematics education research journals, however, is not necessarily surprising, when QL scholars describe it as applicable to all disciplines, and distinct from mathematics or statistics (e.g., Steen et al., 2001).

Without a clear home or concerted promotion, numeracy may seem destined to remain marginal and fade. Simultaneously, however, "scholarship in the interdisciplinary world of quantitative literacy is thriving" (Karaali, Villafane Hernandez, Taylor, 2016, p. 1). Not having a single home, set of supporters, or clear boundaries can help sustain numeracy as a powerful,

commonsense discourse. In fact, genealogical methods take an "assumption that the durability of a concept is enhanced by the heterogeneity of traditions that use that concept" (Fendler, 2003, p. 17). QL may be a marginal concept, but it is a marginal concept in many different fields, including historically powerful discourses like law (e.g., Rowell & Bregant, 2014), science (e.g., Kahan et al., 2012), politics (e.g., Rose, 1991), economics (e.g., Lusardi, 2012), and business (e.g., Falk, 2002).

Across these fields, and in education scholarship, scholars have used different but related terms: numeracy, quantitative literacy, quantitative reasoning, and mathematical literacy, among others. At least two thorough efforts to understand the relationships among, and differences between, some of these terms exist (Vacher, 2014; Karaali, Villafane Hernandez, & Taylor, 2016). I do not differentiate between these terms here, however, because "the vast majority of proponents of quantitative literacy consider numeracy, quantitative literacy, and quantitative reasoning to be synonymous at least in some contexts" (Vacher, 2014, p. 1).

Discourse and statements. In this article, I use the term *numeracy discourse* to synthesize scholarship across these terms. I conceptualize discourse from a Foucauldian conceptualization that differs from the more common, though no less complex) use of discourse to refer to talk (cf. Chandler, 2002). I take *discourse* to mean an assemblage of related statements, which constitute a collection of relationships that frame "the possibilities [and impossibilities] for thought, speech, and action under particular socio-political and –historical conditions" (Bullock, 2013, p. 18). The *numeracy discourse*, therefore, is a collection of statements and their relationships to their pasts, presents, and futures. A genealogy of the numeracy discourse involves writing a history of the present by working to understand how it helps to shape and constrain what is possible to think, say, or do.

Statements as data. For Foucault, a *statement* involves the coalescence multiple aspects of text and meaning. Statements rely on conceptualizing signs and referents as positive data, what Herbel-Eisenmann (2007) called "objectively given structure" (p. 346). Similarly, statements have a materiality that makes them a text open to historical analysis. The records of things said and written can be revisited. Nevertheless, statements have a new-ness when pulled through history into the present; in this way, statements "can be retold, but never re-experienced" (Bullock, 2013, p. 16). I take as data the set of things said and written about numeracy. My data generation for this article, therefore, included compiling and reading a significant volume of literature on numeracy, as well as an historical search for documents referring to similar ideas about general citizen capabilities, policy debates, and mathematics. The data I highlight are what scholars, both inside and outside of mathematics education, have said about numeracy.

There are many ways to interpret these numeracy statements. I focused on how scholars positioned numeracy as relevant to educational reform for two primary reasons. First, as I started to engage theories of discourse and different analytical strategies, I began questioning the moments when numeracy (and other education scholars) used the word *need* in relation to education. I inferred definiteness, universality, and some form of causality from scholars' use of the word *need* – none of which seemed to be questioned, but rather assumed. I think I fixated on *need* because it sometimes appears in education discourse rather casually, despite what educational needs might imply. Second, I started developing sensitivity toward how education scholars portray education work as urgent. I think that sense of urgency facilitates a cycle of reform in which we must reform education because bad education is a primary reason for problems in the world and good education is a remedy for those problems. When the problems discussed persist (poverty, racism, sexism, et cetera), calls for educational reform reignite. From

my perspective, a view of education as a fix for societal problems oversimplifies the complex, systematic ways these problems exist.

For my genealogy, these two perspectives combined to focus my attention on what scholars have written about numeracy's importance, how innumeracy was framed, and what the benefits of numeracy were. As a result, I shared my data in the form of direct quotations. As positive material, at times I did limited interpretation, in order to have these statements be retold in the current socio-historical moment. Nevertheless, beyond considering these statements solely at the level of material existence, I also treated them as involved in establishing current conditions of a numeracy discourse about mathematics education reform. In other words, part of the genealogical method was to propose how these statements helped to constitute the present. For me, that meant conceiving of the numeracy discourse as a collection of statements that imparted an impetus for mathematics education reform through making promises.

The concept of a promise in numeracy discourse. These justifications take different forms, but I summarize them as three promises of numeracy. I use *promise* to highlight the ways the discourse about numeracy involves statements about what happens for people who are numerate and what happens to people who are not. Together, I argue these promises put pressure on mathematics education to reform.

A first promise was that numeracy is a necessary educational response to technological progress in the form of computers and computing power, so people should be numerate in contemporary society. A second promise was that numeracy can empower – empower people to new heights of democratic participation, empower people to better social mobility, and empower people to redress persistent social grievances – so people should be numerate to create a more just and flourishing society. A third promise was that numeracy is a safeguard of democracy and

Western scientific rationality, so that collective innumeracy results in a societal threat. Numeracy emerged as the reflection of the threat innumeracy poses to cultural and political stability, so people should be numerate to protect against misinformation and pseudoscience.

Each of these promises connects to historical justifications for mathematics and mathematics education, which I reference to support my hypothesis that the numeracy discourse will continue to exert a perpetual pressure on mathematics education to reform. I conclude the article by discussing "the literacy myth" (Graff, 1979; 2010) and how overpromising through numeracy discourse may result in support to reform mathematics education while simultaneously creating a problematic situation where the promises fail to be actualized.

Brief Background to Numeracy

Patricia Cline Cohen has contributed significant work on the history of numeracy in the United States:

> Somewhere roughly around 1820, I noticed, numbers started cropping up with predictability in political and social debate, sometimes as an argument for a position, sometimes simply as raw data intended to describe some social phenomenon. By the 1830s numbers were invoked with great regularity, and they were celebrated for their precision and objectivity. (Cline Cohen, 1999, p. ix).

As Cline Cohen (1999) traced what she called "the slow evolution of the propensity to use numbers and statistics" (p. ix), she realized that her "central topic was both a frame of mind and a concrete skill that was perfectly captured in the word *numeracy*" (p. ix, italics in original). Cline Cohen's significant archiving of historical and contemporary documents about numeracy demonstrated how numeracy was embedded into the intersection of social life and mathematics. Her book, *A Calculating People* (1999), provided an account of numeracy in early American history, as well as a series of important readings on the history of mathematics and statistics in European history beginning in the fifteenth century.

These works collectively indicate that numeracy discourse – or something similar to it - has a long history. Nevertheless, numeracy and QL as conceptual terms did not emerge in Western cultures until the mid-twentieth century. The earliest reference to numeracy appears to be a 1959 policy report produced in London, England (Crowther, 1959). The report positioned numeracy as "the mirror image to literacy" (Crowther, 1959, para. 398) and connected numeracy to science and modern life:

> On the one hand is an understanding of the scientific approach to the study of phenomena – observation, hypothesis, experiment, verification. On the other hand is a need in the modern world to think quantitatively, to realise how far our problems are problems of degree even when they appear as problems of kind. (Crowther, 1959, para. 401)

In the United States, Harl Douglass used QL related to mathematics for all and World War II, saying "the present crisis has revealed the importance, in total war, of quantitative literacy in the citizen" (Douglass, 1942, p. 212). These early references to numeracy and QL remain fairly isolated, with renewed attention beginning a few decades later with the Australian Studies in Student Performance (1976), Cockcroft's (1982) *Mathematics Counts* in Europe, and Paulos' (1988) *Innumeracy: Mathematical Illiteracy and Its Consequences* in the United States.

Paulos' (1988) *Innumeracy* gained critical public acclaim and entered the New York Times Bestsellers list for eighteen weeks. In the book, Paulos connected innumeracy to education, referring to innumeracy as an affliction that "plagues far too many otherwise knowledgeable citizens" (p. 3). His rhetoric connected to the educational crisis discourse that blossomed in the United States after the release of *A Nation at Risk* (National Commission on Excellence in Education, 1983). As *Innumeracy* was released, the National Research Council [NRC] organized a volume led by Lynn Arthur Steen called *Everybody Counts* (NRC, 1989) that voiced support for significant educational change. Both *Innumeracy* and *Everybody Counts*

emerged alongside the National Council for Teachers of Mathematics [NCTM] influential document, *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989).

Promises in the Numeracy Discourse

Innumeracy released and gained acclaim alongside mathematics education reform discourse, which scholars continued, positioning numeracy as a worthy and underachieved educational goal. The numeracy discourse embedded into this set of scholarship involves several repeated justifications for why numeracy is important, and these promises sustain both the numeracy discourse and pressure on mathematics education to reform. I name and describe three of those promises.

Numeracy Promises to Reflect Modern Realities

The first promise that numeracy scholars make is that numeracy is important to living in modern times. Education for numeracy, therefore, represents a progressive response to technological change that "reach[es] deep not just into the environment in which we live and work, but also the entire framework of civic life" (Orrill, 1997, p. xi). This first promise has a lineage in the idea that societal and technological change has implications for mathematics education:

> The case is different with commercial arithmetic. The subjects taught under this head have been greatly multiplied and enlarged in recent years, in consequence of the popular demand for a system of education which should be more practical and better suited to the demands of modern commercial and business life. (Eliot et al., 1893, p. 133)

For numeracy, the new demands of modern commercial and business life derive from the use of computing technology to quantify.

Modern life is quantified, where "the relentless quantification of society continues unabated" (Orrill, 1997, p. xi). What Porter (1997) deemed "the triumph of numbers" (p. 1) involves the proliferation of quantities and numbers throughout society. The quantification of

society is a hallmark of modernity, where "with hundreds of other matters small and large that command our daily attention, these constructs of modern civilization depend at their deepest level on *quantitative* information" (Steen, 1997, p. xv). From this perspective, numeracy is the means for dealing with these modern constructs and their quantitative foundations.

An educational response to the idea that mathematics is now everywhere is to prepare students for this new reality. Policy efforts reflect this perspective, for example in the International Life Skills Survey numeracy is defined as:

> An aggregate of skills, knowledge, beliefs, dispositions, habits of mind, communication capabilities, and problem solving skills that people need in order to engage effectively in quantitative situations arising in life and work. (ILSS, 2000)

Similarly, the Programme for International Student Assessment, responds to the new demands of modern life:

> An individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgements and to engage in mathematics in ways that meet the needs of that individual's current and future life as a constructive, concerned and reflective citizen. (PISA, 2000)

At the same time that numeracy is emerging as a critical response to the demands of modern life, scholars argue that mathematics education fails to adequately prepare numerate people. For example, in *The Case for Quantitative Literacy*, Steen and colleagues stated:

> Unfortunately, despite years of study and life experience in an environment immersed in data, many educated adults remain functionally innumerate. Most U.S. students leave high school with quantitative skills far below what they need to live well in today's society. (Steen et al., 2001, p. 1)

Not only is numeracy essential to living well in an environment where quantitative data seems omnipresent, but education fails to prepare even those adults who are otherwise considered educated because "as it turns out, it is not calculus but numeracy that is the key to understanding our data-drenched society. (Steen et al., 2001, p. 2)

The first promise embedded into the numeracy discourse is that numeracy is a reflection of modern life. In response a social environment where mathematics is everywhere, where "by now numbers surround us [and] no important aspect of life is beyond their reach" (Porter, 1997, p. 2), mathematics education should adapt to reality. Numeracy is important because it helps people to live well now, and continue participating in society.

Numeracy Promises to Empower

A second promise scholars make about numeracy is that numeracy is empowering for shaping the future. Individuals can use their numeracy to liberate, both themselves and others. The power that numeracy has to liberate can be thought of as the connection of two ideas. First, that mathematics has power to control and conquer nature as stated in an influential mathematics education document from the late nineteenth century:

> The key to the outer world in so far as the objects of the latter are a matter of direct enumeration, capable of being counted, it is the first great step in the conquest of nature. It is the first tool of thought that man invents in the work of emancipating himself from thralldom, to external forces. For by the command of number he learns to divide and conquer. (Committee of Ten, 1895, p. 145)

The second idea is that mathematics is now actively used in the social world, not just the natural world – a theme present in the first numeracy promise of a changed world. The connection of these themes is that the effective use of mathematics in social life has the power to conquer social problems. This connection illustrates the second promise of numeracy scholarship: that numeracy can empower people in their liberation. For instance, Schoenfeld (1992) wrote:

> From this perspective, learning mathematics is *empowering*. Mathematically powerful students are quantitatively literate. They are capable of interpreting the vast amounts of quantitative data they encounter on a daily basis, and of making balanced judgments on the basis of those interpretations…They are flexible thinkers with a broad repertoire of techniques and perspectives for dealing with novel problems and situations. They are analytical, both in thinking issues through themselves and in examining the arguments put forth by others. (p. 5, emphasis in original)

Schoenfeld summarized the ways in which becoming numerate positions a person to thrive in the world, and through numeracy.

This power is magnified by the expansion of mathematics and quantification into all aspects of social life, and by the potential of computers to further quantify and tame the world. Now that mathematics is everywhere, gaining numerate power over mathematics involves gaining some form of power over the world. For the numerate, "the new conditions are extraordinarily empowering" (Orrill, 1997, p. xi). The numerate are positioned to take advantage of a unique time, where "as the printing press gave the power of letters to the masses, so the computer gives the power of numbers to ordinary citizens" (Steen, 1997, p. xi). The numerate have the potential to transform the world, because: "quantitative literacy empowers people by giving them tools to think for themselves, to ask intelligent questions of experts, and to confront authority confidently" (Steen et al., 2001, p. 2).

This promise of empowerment mirrors literacy scholarship following Freirean critical theory and literacy. Freire's work on critical pedagogy, and the immense scholars and scholarship he inspired, has connected education explicitly with the potential to liberate and create a more just world. Wiest, Higgins and Frost (2007) joined numeracy to critical mathematics education:

> We argue that developing a quantitatively literate citizenry is not only important for creating a more effectively functioning society but also is a matter of social justice in that it places numeric understanding in the hands of "ordinary" citizens, preparing them to function—for example—as informed voters and consumers. Without quantitative understanding in this Information Age, laypersons may be relatively powerless compared with a small number of individuals with specialized knowledge. (p. 47)

To conceptualize numeracy as empowering involves an assumption that numeracy redistributes power, often through improved (or, at least, different) decision-making where "for individuals who have required this habit, mathematics is not something done only in mathematics class but a

powerful tool for living" (Steen et al., 2001, p. 8). The technological change that validates the importance of numeracy also imbues it with the potential for liberation,

> Potentially, if put to good use, this unprecedented access to numerical information promises to place more power in the hands of individuals and serve as a stimulus to democratic discourse and civic decision making. (Orrill, 2001, p. xvi)

Critical mathematics education (CME) evolved from mathematics educators' attempts to adapt theories of critical literacy and critical pedagogy to mathematics education. CME has historically focused on the ways that mathematics interacts with the social, in particular justices and injustices. Numeracy is politically important in the fight for justice because the omnipresence of mathematics creates a vulnerability, from which numeracy helps liberate:

> Mathematical literacy focusing on citizenship should refer to the aim of critically evaluating aspects of the surrounding culture – a culture that is more or less colonised by practices that involve mathematics. (Jablonka, 2003, p. 76)

Frankenstein (e.g. 1983, 1990) highlighted the connection between numeracy, or her term *criticalmathematical literacy*, and the power to understand how mathematics is used in the world. Numeracy empowers people because it "enables them to act from a more informed position on societal structures and processes" (Frankenstein & Powell, 1989, p. 105, cited by Frankenstein, 1990, p. 337). Numeracy represents a critical lens on the intersection of mathematics and the social world, where mathematics can be used to understand and transform or "*to 'read and write the world' with mathematics*" (Gutstein, 2006, p. 4, emphasis in original).

Numeracy has value because it can empower. When scholars construct the image of the numerate person as empowered and well-suited for contemporary society, they simultaneously construct, either explicitly or implicitly, the image of the innumerate who is disempowered and marginalized. Cohen claimed that, in contemporary society, numeracy represents *the* dividing quality "between the powerful and the powerless" (1999, p. 5). She argued that the role

numeracy has as a dividing line mirrors how literacy functioned for the last 500 years because after technological changes, numeracy "looms now as the successor to literacy" (Cohen, 1999, p. 5).

Innumeracy Promises to Have Social Costs

The dividing line drawn along innumerate and numerate produces a third numeracy promise: without numeracy there have been, and will be, social and personal costs. Whereas the numerate are empowered to thrive in a contemporary society immersed in number, the innumerate may not survive. I separate the empowering promise from this social cost promise in order to highlight how the numeracy discourse can function very explicitly to distribute people into a binary system: numerate and innumerate. Through this binary there is not only an exclusionary effect, that is, those labeled innumerate are assumed to be unable to participate fully, there is also a cost to the "numerate." In other words, the numeracy discourse excludes the innumerate as well as describing them as a threat to the numerate.

The innumerate person is "profoundly disable[ed] in every sphere of human endeavor" (Orrill, 2001, p. xvi). Outside of education, the field where numeracy is most commonly studied is medicine. Studies of patient numeracy have primarily focused on understanding risk in health decisions (Reyna, Nelson, Han, & Dieckmann, 2009). Specifically, scholars in medicine have searched for correlations and causality between numeracy and understanding the benefits of screening mammography (Schwartz, Woloshin, Black, & Welch, 1997) and dietary management (Rothman et al., 2006). A common thread of concern for scholars from medicine and other fields outside education is that there are social costs to public innumeracy. In medicine, for example, innumerate patients may be less likely to choose to get mammography, "numeracy was strongly related to accurately gauging the benefit of mammography" (Schwartz et al., 1997, p. 966).

Coben and Weeks (2014) studied the effects of innumeracy on medical efficiency from the perspective of medical professionals, rather than patients. They argued that safety is put at risk by innumerate nurses, "where errors can and do cause patient morbidity and mortality" (Coben & Weeks, 2014, p. 253).

I provide these examples of scholarship in medicine on numeracy to illustrate a third promise that scholars make about numeracy. That promise is reflected within the threat of social costs - mostly in the form of inefficient decision-making. Along with this concern about social cost comes external pressure on mathematics education to produce better "numeracy" across society, and external attention on schools' failure to do so. I trace this third promise as emerging from literacy scholarship and adult education scholarship. Literacy is mentioned in many introductions to numeracy scholarship, and literacy and numeracy are often found together in manuscript titles, for example:

- Numeracy, Literacy and Earnings: Evidence from the National Longitudinal Survey of Youth (Dougherty, 2003);
- The Polarizing Impact of Science Literacy and Numeracy on Perceived Climate Change Risks (Kahan et al., 2012);
- Patient Understanding of Food Labels: The Role of Literacy and Numeracy (Rothman et al., 2006);

Seeing literacy and numeracy juxtaposed follows a long history of thinking about basic skills, for example *The Three Rs* of reading, writing, and arithmetic, which dates back at least to the early nineteenth century. Steen (1997) tethered literacy and numeracy together when he wrote, "an innumerate citizen today is as vulnerable as the illiterate peasant of Gutenberg's time" (p. xv). The vulnerabilities he referred to likely involve the susceptibility to others' using mathematics to control, but might also include a collective loss of control gained through mathematical power:

> The primary purposes of the teaching of mathematics should be to develop those powers of understanding and of analyzing relations of quantity and of space which are necessary to an insight into and control over our environment and to an appreciation of the progress

> of civilization in its various aspects, and to develop those habits of thought and of action which will make these powers effective in the life of the individual (MAA, 1923, p. 395).

Orrill prefaced *Mathematics and Democracy: The Case for Quantitative Literacy* by responding to Steen contemplating the vulnerability of modern society in the face of innumeracy:

> This warning about the possibility of a return to pre-Enlightenment conditions is profoundly troubling. Such a reversal is undesirable at any time and absolutely unacceptable in a democracy. But how can it be avoided? (Orrill, 1997, pp. xi-xii)

Considering democracy as a cultural value illustrates how innumeracy is sometimes framed as a threat to societal stability and heritage. Madison (2003) argued that the "needs for QL extend across the traditional American guarantees of life, liberty, and pursuit of happiness" (p. 3). Cohen (2003) expanded on this relationship between mathematics and democracy by arguing that mathematics and statistics are integral to democracy. Rose (1991) detailed the ways that democratic power relies on number, where a numerical subjectivity was to replace a moral one in a democracy that "requires citizens who calculate about their lives as well as their commerce" (p. 683). Collective public innumeracy threatens the social structures at the heart of western democracies:

> The wall of ignorance between those who are mathematically and scientifically literate and those who are not can threaten democratic cultures. The scientifically and mathematically illiterate are outsiders in a society in which effective participation in public dialogue presumes a grasp of basic science and mathematics. (Carnevale & Desrochers, 2003, p. 29)

These statements make the stakes of numeracy scholarship staggeringly high; collective innumeracy apparently threatens social apparatuses often uplifted as the most centrally important to a healthy society. Beyond that collective threat is an accumulating burden borne by society (especially by the numerate) on the healthcare, justice, economic, and political systems.

Pressure to Reform Mathematics Education

If the first two promises about a changing world and empowerment regard the benefits that a numerate individual has in contemporary society, this final promise shifts to the dangers of an innumerate collective. Each of the promises I traced along the surface of the numeracy discourse connects to longstanding traditions in educational reform discourse. At the same time, that scholars outside of mathematics education operationalize numeracy in a simple way that connects undesirable outcomes in their field (i.e. worse health) to low numeracy is meaningful. To finish this article, I summarize the three numeracy promises and conclude with a discussion of the literacy myth (Graff, 1979; 2010) and how it might relate to numeracy scholarship.

The first promise, that numeracy responds to a changing world in a way that traditional educational subjects do not, has analogues in most disciplines and history in mathematics education. Stanic (1986) followed the pressures from technological and societal changes into a crisis discourse in mathematics education. Educational reform in response to a changing world is a fundamental premise in most numeracy scholarship. For example, Steen (1989) argued that "to prepare students for the future, mathematics teachers must change their curriculums, teaching methods, and assessment techniques" (p. 18). That the world is changing, and education should respond, are commonplace statements among literature arguing for educational reform, and persistent in the current age of educational reform (Popkewitz, 2008). Multiple sources, often with opposing goals, generate energy for educational reform. Stanic (1986) demonstrated how rhetoric about educational reform could not be separated from the results and criticisms of any reforms that occur thereafter; if we are overstating our case, this connection between scholarly and public rhetoric about educational change has major implications for numeracy scholars, (Craig, Guzmán, & Harper, forthcoming).

The second promise, that numeracy can empower all people, mirrors the "mathematics for all" discourse (e.g. Yolcu, 2017; Valero, 2013). The mathematics for all discourse responds to historical marginalization and the use of mathematics as a gatekeeper (e.g., Moses & Cobb, 2001). Danny Martin (2003) unpacked mathematics for all as a slogan, or rallying cry, for educational change – a critical response to educational and societal injustices. He concluded that mathematics for all has, in part, replaced specialized education for the "best" students as the primary concern for maintaining national competitiveness (Martin, 2003, p. 12). His reflection on the shortcomings of mathematics for all, and the complicity of that slogan in perpetuating the same injustices it speaks out against, led him to create a new goal for the research literature: to empower students and communities to use mathematics for justice. When numeracy scholars tether numeracy to powerful discourses in educational research, such as equity, justice, and empowerment, they gather some of the energy within those discourses and direct it toward reform.

The third promise, that numeracy is critical to faithfully maintaining society's core values, is linked to the position that mathematics has within United States society. When progress is associated with quantification, mathematics, and statistics, then multiple pressures are placed on mathematics education to accommodate that progress. If mathematics education fails to accommodate a changing society, then pillars of society are put at risk. This perspective, concerned with the stability of societal apparatuses such as capitalism and democracy, arguably finds roots in the reform movements of social efficiency educators (Stanic, 1986). Social efficiency educators argued that schooling should prepare students to function in society. In the 1920s, these educators responded to "so many changes in the wider society… [by] promising to hold together American society by efficiently preparing students for their predetermined roles"

(Stanic, 1986, p. 196). Those predetermined roles are calculated within the social boundaries of democracy, where "democratic power is *calculated* power, *calculating* power and requiring citizens who *calculate about* power" (Rose, 1991, p. 673). From this perspective, any argument claiming public innumeracy exerts substantial pressure on education to reform.

That numeracy scholars sell the importance of numeracy in multiple ways is not surprising if we also assume that being numerate is generally underappreciated. In 1989, Paulos claimed that the same people who would be ashamed to be found illiterate brag about their innumeracy: "unlike other failings which are hidden, mathematical illiteracy is often flaunted" (Paulos, 1989, p. 4). This idea that numeracy is undervalued and misunderstood persists nearly 30 years later:

> Innumeracy refers to one's inability to understand mathematics. Or, more simply, innumeracy is mathematical illiteracy. The main problem with innumeracy is the fact that most of society does not see it as a problem. In fact, many people boast about their innumeracy. (Cundiff, 2016, p. 1)

It is a tough position to be in, to feel like you have something important to say, but are not heard. At the same time, it seems important to consider how we might overestimate, or at least oversell, the importance of numeracy. Even when numeracy is taken seriously, the pressures it puts on mathematics education to reform may actually increase. For example, Steen and Madison (2011) reflected on *The Case for Quantitative Literacy* and the state of numeracy education ten years later:

> Even as interest in QL grows in many places, evidence of need also grows. Moreover, well-meaning programs with other goals—especially at the K-12 level—*often channel education in directions that fail to advance numeracy*. Examples show that both students and teachers are enthusiastic when offered QL opportunities, but that individual beliefs and public decisions often belie the goals of QL. (p. 1, emphasis added)

I would be disingenuous if I argued that numeracy scholars should not do their work; in fact, I have already researched numeracy and QL and intend to continue doing so. I historicized

numeracy with "an optimism that to unthink what seems natural is to open other possibilities" (Popkewitz, 2008, p. xv). Numeracy scholars continue to inspire me to do work, and I hope to follow Foucault's lead in actively doing this work, despite my self-skepticism:

> My point is not that everything is bad, but that everything is dangerous, which is not exactly the same as bad. If everything is dangerous, then we always have something to do. So my position leads not to apathy, but to a hyper- and pessimistic activism. (Foucault, 1982, pp. 231-232).

I believe that mathematics education should reform: societies do change and education should reflect those changes, education should be for justice, and education can play a role in both perpetuating societal structures and transforming them. Nevertheless, I am concerned about the extent to which numeracy scholarship - and for that matter mathematics education as a whole - makes promises we cannot keep. Can education in numeracy adequately prepare people for a future we cannot predict accurately, especially when its importance is underscored by continuous and accelerating change? If we want to argue numeracy succeeds literacy, can we admit a successor to numeracy? What role does numeracy have in addressing interlocking, complex, and systematic injustices, and how do we need to situate that role among an interlocking, complex, and systematic redress of those injustices? How does conceptualizing collective innumeracy as both real and as potential threat participate in the *politics of urgency* (e.g., Wexler, 2009)? To conclude this article, I consider the *literacy myth* as a perspective on the promises of numeracy and the pressures those promises exert on education.

The Literacy Myth and Implications for Mathematics Education

I start with a definition of the literacy myth:

> *Literacy Myth* refers to the belief, articulated in educational, civic, religious, and other settings, contemporary and historical, that the acquisition of literacy is a necessary precursor to and invariably results in economic development, democratic practice, cognitive enhancement, and upward social mobility…literacy in this formulation has been invested with immeasurable and indeed almost ineffable qualities…linked to

> progress, order, transformation, and control. Associated with these beliefs is the conviction that the benefits ascribed to literacy cannot be attained in other ways, nor can they be attributed to other factors, whether economic, political, cultural, or individual. Rather, literacy stands alone as the independent and critical variable. (Graff & Duffy, 2008, p. 457)

I doubt that I need to state that Harvey Graff's positions in *The Literacy Myth* (1979) have sparked both exciting scholarship and intense criticism. Before continuing with implications of the literacy myth on literacy scholarship, I pause and reflect on the criticism he received. Graff (2010) stated that in the thirty years after he published *The Literacy Myth*, critics often accused him of being "somehow anti-literate and a traitor to the beliefs of the academy" (p. 657). I think it is important to state that I am both actively in support of numeracy and QL curricular movements (I have helped lead one myself) and skeptical of them. My contradiction lies in my beliefs that numeracy is important and overestimated.

Graff (2010) expressed some of the same types of contradictions when he emphasized how purposeful his choice of the term *myth* was. He conceptualized myth separately from falsehood; indeed, he argued:

> By both definition and means of cultural work, myths can *not* be wholly false. For a myth to gain acceptance, it must be grounded in at least some aspects of perceived reality and can not explicitly contradict all the ways of thinking or expectations. Partial truths are not falsehoods. (Graff, 2010, p. 638, emphasis in original)

The same partial truths may hold for the promises in numeracy scholarship. The world is changed, but to what extent has technology change altered social and cultural structure and opportunity? How do we admit the potential that numeracy may be used as a cultural relabeling of existing inequalities, with the marker of difference shifting from illiterate to innumerate? Graff commented on how the literacy myth waxes and wanes within different groups:

> For many blacks today and recently, the power of the literacy myth has waned, in part owing to contradictory outcomes. For others with initial social and cultural advantages, the power of the promise seemed true. (Graff, 2010, p. 643)

If these same differential outcomes occur with "numeracy," what does that mean for our scholarship? I believe it demands us to be vigilantly opposed to simple causal claims about numeracy, and hesitant to use bold rhetoric about cultural decline or empowerment. Our vigilance is crucial because "myths are powerful: they often feel more real than anything" (Wagner & Herbel-Eisenmann, 2009, p. 3).

The literacy myth also highlights how partial truths exist with contradictions among themselves. At the heart of these complex contradictions is the persistence of both a progress discourse and a decline discourse. Within the same societies at the same time are notions of progress and decline. The progress is sometimes attributed to powerful new literacy and the decline to rising rates of illiteracy. Similarly contradictory scholarship surrounds mathematics and mathematics education, in which declining mathematics achievement scores mark failure of our educational systems and the fragility of our society, which is simultaneously using mathematics to achieve previously unimaginable progress. These apparent contradictions mirror historical tensions in literacy scholarship and can inform different positions from which we can consider numeracy, such as the one Wadsworth (1997) took regarding public policy:

> Defining this issue in terms of public innumeracy feeds into a view that is all too common among the national leadership, and one that is deeply resented by the public. It suggests the public is stupid and the experts are smart, and if people were just a little less dumb or a little more mathematically sophisticated, we could balance the budget and solve more of our national problems…We see the root problem not as a conflict between an innumerate and uneducated public versus a numerate and sophisticated elite, but as a conflict between the public's moral and value-driven perspective on issues and an expert perspective that is increasingly technical and value-free. (p. 12)

Part of the response by literacy scholars to increasing evidence that improving, and even nearly saturated, literacy rates were not resulting in the promises made about literacy was to embrace alternative conceptualizations. The literacy myth offered numeracy scholars a way to

reconsider some of their most commonsense assumptions. This reconsideration involved constructing social theories literacy, wherein scholars argued that, "literacy is best understood as a set of social practices" (Barton & Hamilton, 2000, p. 8). Scholars have taken a social perspective to problematize and extend the numeracy concept (e.g., Baynham & Baker, 2002; Best, 2008; Ewell, 2001; Craig, Mehta, & Howard, forthcoming). For example, Black, Yasukawa, and Brown (2015) found that the rhetoric about the importance of numeracy to workplace efficiency did not align with the realities of job demands.

Conclusion

In this article, I highlighted three other common assumptions, which I framed as promises. The first promise of numeracy scholarship is that numeracy represents a legitimate and urgent response to rapid technological change – that numeracy is a newly important competency for the twenty-first century. The second promise is that numeracy can be used in the projects of liberation and justice through empowered numerate people. The third promise of numeracy scholarship is that collective innumeracy will result in regression away from societal ideals.

Each of these promises help to sustain numeracy discourse as a pressure for mathematics education reform. I believe the challenges to mathematics educators established in numeracy scholarship will persist and simultaneously offer opportunities and pose dangers to future work. The dangers include overpromising the benefits of numeracy on producing a more just or equitable world, which, when these promises do not come to fruition may cause pressure to reform (or even deform) mathematics education in counterproductive, past-oriented ways. At the same time, it remains important to consider how the numeracy discourse may still represent a pressure to reform mathematics education in meaningful, lasting ways.

CHAPTER FOUR:

THE QUANTITATIVE REASONER AS A GOAL OF MATHEMATICS EDUCATION: IN THE BOUNDARY BETWEEN FANTASY AND REALITY

"It is our choices that show who we truly are, far more than our abilities."
-J.K. Rowling, as Albus Dumbledore

In this article I sketch a persona developed within mathematics education research (and elsewhere): the *quantitative reasoner*. The quantitative reasoner persona does and feels particular things with and about mathematics, but I claim that no person does and feels those things all the time. In particular, people engage in complex reasoning of which quantitative reasoning is only one part, and during that reasoning people make choices.

I highlight an example from a mathematics course in quantitative literacy that I taught at a large Midwestern University. During our first week of class, we focused on happiness: its measurement, its meanings, its definitions, and whether it is quantifiable. I chose this week because it exemplifies the challenge of involving dispositional elements to our educational goals. I focus specifically on *productive disposition,* which "refers to the *tendency* to see sense in mathematics, to perceive it as both useful and worthwhile.... (NRC, 2001, p. 131, emphasis mine).

My primary question about this productive disposition is: *how might we grapple with moments when people do not see sense in mathematics, or perceive it to be not useful, or not worthwhile?* Put another way: *when might a quantitative reasoner not quantitatively reason?* It is my sense that even when we embrace a productive disposition that involves a tendency, we still tend to think about mathematics teaching and learning in absolute terms. In this article, I explore mathematics and statistics learning that involved choosing to ignore mathematics and statistics. My students' choices not to measure happiness, and to reject others' claims to have

done so, involved complex and thoughtful reasoning. That reasoning can be nearly invisible in mathematics education scholarship, however, if we focus on the mathematics students do produce.

Confronting the ways in which our students reject the quantitative is important if we want to embrace complex views of the world, and mathematics' role therein. Specifically, my students' choices to keep happiness as not a number illustrated the limitations of considering mathematics and statistics teaching and learning separate from other ways of knowing; that is, in choosing not to quantify happiness, my students argued from multiple ways of knowing about happiness, some of which clashed with quantification.

Quantitative Reasoners as a Goal of Mathematics Education

I take the *quantitative reasoner* to be one name for a persona constructed within mathematics education scholarship. The quantitative reasoner takes shape across differently named forms: a mathematically proficient person (CCSSM, 2014), a mathematical thinker (e.g. Schoenfeld, 1992), a quantitatively literate or numerate person (e.g. Steen et al., 2001), a mathematically powerful person (e.g. Romberg, 1992), and a mathematical reader and writer of the world (e.g. Gutstein, 2003). Across these examples are two commonalities: a person who both does things with *and* feels things about mathematics and statistics. For example, the authors of the Common Core State Standards for Mathematics (CCSSM) constructed a goal for mathematics education: to create a student who not only is proficient in the Mathematics Content Standards, but also actively embodies the Standards for Mathematical Practice (SMP). The SMP collectively suggest a list of things people should know and do with regards to mathematics. If you are a quantitative reasoner, you:

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.

3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

These SMP describe a mathematically active person who is a capable and willing quantitative reasoner. The quantitative reasoner acts as they do, because they have developed mathematical habits of mind and positive dispositions toward mathematics (Steen et al., 2001; Gordon, 2011; Gutstein, 2003). The authors of the SMP cited *Adding It Up* (2001) and its vision for a *productive disposition* toward mathematics.

> Productive disposition refers to the tendency to see sense in mathematics, to perceive it as both useful and worthwhile, to believe that steady effort in learning mathematics pays off, and to see oneself as an effective learner and doer of mathematics. (NRC, 2001, p. 131).

The quantitative reasoner embodies this productive disposition. If you are a quantitative reasoner, beyond being able to do mathematics, you regularly *choose* to do mathematics because you have a positive affective relationship with it.

I choose quantitative reasoner to name this persona for several reasons. First, I prefer quantitative to mathematical because it is more directly inclusive of statistics, as well as computer science; it is also specifically anchored to the real world and resistant to abstraction. Second, I like the term reasoner because it connects well with the idea of complex reasoning, which involves quantitative considerations among many others. Third, I prefer reasoner to reasoning to highlight the way affect (usually disposition) is involved with this persona; the persona does not just do particular things with mathematics, they feel particular ways about it, too. Finally, I prefer quantitative reasoner to quantitatively literate because reasoner less easily divides into a possessive binary, as in literate and illiterate (or numerate and innumerate).

My goal here is to sketch the quantitative reasoner, rather than define them. Specifically, I use quantitative reasoner to indicate a persona differently constructed across mathematics education scholarship. That there are intricate differences between Schoenfeld's mathematical thinker and Steen's quantitatively literate person is beyond the scope of this paper. Instead, simply acknowledging that an image of people doing mathematics and feelings a particular way about it (for instance, cognitive and affective domains) has emerged within our scholarship is sufficient for my purpose in this article: to consider one example of students choosing to reject quantitative reasoning.

Studying students as quantitative reasoners. One focus of my broad research project, of which this article is on part, was students' affect. I took a multi-dimensional approach to studying affect and learning. My students and I generated data of other forms (classroom video, teacher reflections, student artifacts, curricular artifacts). I also asked students to generate emotional self-reports as check-ins during class. They reported their emotional intensity on a seven-dimensional report, and had the option to leave written comments, three times per class session. I also intentionally developed curricular materials that considered the measurement of affect, for example we studied the *World Happiness Report* and *Happy Planet Index* during the first week of the course. Although my initial purpose was not to study my students as quantitative reasoners, the affective focus of my study and affective dimension of my conceptualization of a quantitative reasoner made it possible.

Theoretical Framework and Methodology

I approach this work from a critical postmodern theoretical perspective (Stinson & Bullock, 2013; 2015). I take the critical postmodern perspective to be a reminder that when I choose inaction, particular injustices persist, and when I act to address injustices, I will

perpetuate others. This hybrid perspective helps me to purposefully enact what I call *hesitant action*, something that I think results from what Bullock (2013) called "pessimistic activism" (p. 204). I consider *hesitant action* to be a continual process of doing and waiting, across and within interlocking time periods ranging from in-the-moment to multiple years. In this particular article, I describe a series of interlocking hesitant actions: the process of co-creating two courses; teaching, reflecting on, and revising them; and studying these processes in a research study. Specifically, I focus here on my study of one part of one week of one implementation of one of these new courses in order to interrogate my three years co-designing and implementing these two courses.

I acted as a member of a quantitative literacy course design team and as an instructor to provide what I considered to be a legitimate alternative pathway to fulfill a mathematics requirement for undergraduate degree credentialing. These new courses in quantitative literacy offered undergraduate students a choice in how they might fulfill the university's general mathematics requirement. Several of my students referred to how relieved they were to have this choice, having failed to fulfill the requirement by other means. Two of my students shared with me that they returned to university after several years away to finish their final degree requirement, the general mathematics requirement, because they had been told about these new courses.

Despite the purpose with which I engaged this critical work, and the pride I feel about it, I am hesitant to proclaim the courses a success. I try to deconstruct their inevitable flaws. In this article, for instance, I discuss how my students quickly dispelled the illusion that they could not already do quantitative reasoning, despite what the university mathematics placement exam said

about them. They exposed one way in which the two courses we created were problematic, and opened another opportunity to critically co-engage in improving these courses.

Practitioner Inquiry Methodology

This article represents one effort to describe experiences I shared with many people related to these courses. I consider it to be the result of *practitioner inquiry*, wherein I took "inquiry as stance" (Cochran-Smith & Lytle, 2009; Lampert & Ball, 1998). This methodological approach fits well with a critical postmodern theoretical stance because it involves continuous attention to and reflection on my actions. As a method of inquiry, I followed what Cochran-Smith and Lytle (2009) called "working the dialectic…which refers to the reciprocal and recursive relationships of research and practice (or of theorizing and doing)" (p. x). I consider working the dialectic to be a byproduct of maintaining a critical postmodern perspective, but enhanced by focused writing, extensive reading, and other research methods. For instance, this particular article is only the latest draft of many attempts to communicate what I have learned from my experiences. I have written seven distinct partial drafts (and have fully discarded several) with different themes and purposes – all focused on describing my relationships with my students.

Practitioner inquiry blurs the boundaries between different educational roles, most notably the teacher and researcher. The simultaneity of critical and postmodern is supported by my taking effort to blur the boundaries between roles that are sometimes separated in education research. In this work, I do not fully separate my curriculum design from my teaching practice or from my research work. My stance is connected both to what Fine (1994) called "working within the hyphen." I consider this work in the hyphened space between curriculum designer-teacher-researcher and critical-postmodern. Certainly different aspects of my identity were more salient

at different times, as when I was a teacher in the classroom, but I was still also a researcher and curriculum designer.

Data in practitioner inquiry. My analysis of our curriculum design process has so far spanned three years. My analysis of my practice regarding these two new courses has so far spanned two years. My analysis of the particular implementation of one of the courses, which I focus on here, has spanned one year. My data for these on-going analyses are what Cochran-Smith and Lytle (2009) called the *data of practice* which include:

> Students' work of all kinds…observations of students in and out of school, practitioners' plans as well as their journals and other self-reflective accounts of daily life…school and classroom artifacts such as report cards and textbooks, and the talk that occurs. (p. 56)

In this study, I have many of those data of practice, including some classroom video recordings, curriculum design notes, and syllabi.

Practitioner inquiry and critical postmodernism. As a methodological stance, practitioner inquiry aligns well with critical postmodern theory because it implies an ongoing process. In addition, it is well aligned with the critical theory concept of *praxis* as the work emerging in the blurry space between theory and practice (e.g. Freire, 1974). I consider these plural analyses to be ongoing, interlocking, and messy: through my reflections and notes, in my lengthy and frequent conversations about the courses, during my reading related (sometimes retroactively) to the courses, in making decisions to reorganize the curriculum (including creating course projects), and in my daily experiences teaching the courses. I also read extensively across education, social sciences, methodology, and fittingly, the fantasy and science fiction genres. I repeatedly engaged with my written teacher reflections, student work and statements, and my curriculum development notes, through four coding passes I describe in the next section.

I would argue that all of these analyses necessarily imply the generation of knowledges. The enactment of those knowledges can take many forms, including curricular revisions, altered teaching practice, the creation of early teacher preparation projects, and a variety of written documents. This article, as a formal written research document, is one of those forms – but it is not disconnected from the others. As such, I explicitly give credit to each of my passes through data related to what emerged in this article. Through the four coding passes, I grappled with what I found to be incredibly interesting and important situations, in which my students quantitatively reasoned but came to many different conclusions including choosing to reject quantitative reports and information. In this article, I discuss one such situation as an exemplar of this challenge to myself (and perhaps other mathematics educators) to accept a plurality of quantitative reasoning outcomes.

Exemplars as Method

By focusing on an exemplar of my experiences, I hope to do three things. The first is to explore how small moments can have major implications for critical projects of reforming mathematics education. The second is to illustrate the depth of meanings present within small moments. The third is to avoid erasing too severely the complexity of these long processes, despite focusing on short moments. Tracy (2013) defined exemplars as:

> *Embodiments* of an inductive construct or claim, or, put another way, as "rhetorical device[s] which may help the readers enter into the author's argument" (Atkinson, 1990, p. 91). They are more than just examples; rather they illustrate many, if not all, facets of the emerging analysis…The significant and multi-faceted examples researchers *identify in the data through coding*. Indeed identifying exemplars is like finding jewels through an ongoing process of digging, sorting, coding, and reflecting. (p. 207, emphasis in original)

I completed three distinct coding attempts that helped me recognize an exemplar of how my students shattered a fantasy I had about the courses. The analysis of that fantasy is the subject of this paper.

First coding pass. My first coding pass was open and informal, and focused on improving the course by attending to our course goals and our judgments regarding how well we had met those goals in previous semesters. I co-conducted it with a peer curriculum designer and instructor, Andrew Krause. This pass helped me solidify the idea that my students were already accomplished in some ways in terms of what we laid out as objectives for the course, and convinced us that we should try to offer more opportunities for sustained quantitative reasoning. One result of this pass was that we decided to create and implement course-long projects to engage with our students in inquiry from a quantitative literacy perspective about a topic of their choosing.

Second coding pass. My second coding pass was completed from my teacher position, when I assessed my students' work for how they engaged with the work during their first week. I also worked to note what my students were already doing quantitatively. In this pass, I was confronted with my students' already deep thinking about complex and detailed quantitative reports, and ability to quantitatively reason.

Third coding pass. My third coding pass was a thematic analysis of two terms, *quantitative rhetoric* and *quantification*, which I conceptualized as social practices involved in quantitative literacies (Craig, this dissertation, chapter two, p. 14). Although neither of those particular ideas directly enters into this article, what they illustrated to me was that my students made strategic choices when engaging quantitative information, including creating and ignoring it.

Fourth coding pass. My fourth coding pass was a theory-based coding of the first implementation of our course projects. I used the theory of *wicked problems* (e.g. Rittel & Weber, 1973) to analyze how my students chose and completed projects about social problems that mattered to them which were complex, transdisciplinary, and democratic. I discuss the results of this coding in another article (Craig, this dissertation, chapter five, p. 96).

Finding language as result. The exemplar that emerged for me out of these passes was our first week of class during our 2016 summer semester; specifically, my students' interactions and work regarding the first topic of our course, *happiness*, provided an exemplar of how these students were already quantitative reasoners who could deeply engage with complex quantitative reports and methodologies. That they were already quantitative reasoners disrupted the idea that these courses were designed to help them become quantitative reasoners. As a result, I engaged directly with the meaning of this disruption – what did it mean for students to enter the course as quantitative reasoners? I found that the language of fantasy helped me make sense of these experiences, which I discuss as a conceptual framework later in this article.

Background: Creating Quantitative Literacy Courses

On June 10, 2014, I was one of three mathematics education graduate students who attended a first meeting about the development of an alternative pathway to fulfilling the undergraduate mathematics requirement at our institution, Michigan State University [MSU]. Our task was fairly straightforward. MSU required all undergraduates to obtain five credits in mathematics, regardless of their major, so we were to design two three-credit courses to fulfill that requirement that would better serve a significant population of students. One idea for an alternative to an algebra sequence which had some institutional history was quantitative literacy

(QL). We also faced an immediate challenge from the dean: that these courses needed to have the same level (though perhaps a different form) of intellectual rigor as the algebra sequence.

Divergent thinking about the intellectual value of quantitative literacy complicated our choice. Fortunately, Steen and colleagues (2001) preempted the intellectual rigor debate:

> Quantitative literacy is more a habit of mind, an approach to problems that employs and enhances both statistics and mathematics… Surprisingly to some, this inextricable link to reality makes quantitative reasoning every bit as challenging and rigorous as mathematical reasoning. (Steen et al., 2001, p. 5)

These statements by Steen and colleagues in *The Case for Quantitative Literacy* (2001) provided us not only with language, but also with credibility, for defending these courses as intellectually rigorous. We extended that credibility by arguing that the quantitative reasoner can thrive in a quantified contemporary society reformed after "the triumph of numbers" (Porter, 1997, p. 1). Within this environment, people needed to live differently in order to flourish because for quantitative reasoners, "the new conditions are extraordinarily empowering" (Orrill, 1997, p. xi). A course designed to support the creation of quantitative reasoners is, we argued, a valid response to a world in which "the productive practices of a mathematically-inclined mind [should be] considered as content…for promoting a robust society" (Gordon, 2011, p. 457).

Figure 1 shows how we framed the purposes of the courses in our syllabus:

Goals. The purpose of this course is to provide you with opportunities to consider quantitative information that matters to you and your classmates, with your classmates (including your instructors). We will critically consider the quantitative information that we encounter in the world and that affects our lives. We will learn appropriate math, statistics, and technology skills and use them as a lens to explore complex real-life situations in global demographics, the media, and health and risk.

Objectives. Several of the main content-specific learning goals are listed below. These learning objectives will be addressed throughout the course, and are incorporated into each context-based module.

1. Make predictions about quantitative situations and check predictions against data in order to determine reasonableness, identify alternatives, and make choices.
2. Critically analyze quantitative information and recognize that mathematical and statistical methods have limits.
3. Interpret mathematical models of social issues and public policy in the form of formulas, graphs, tables, and images, and draw inferences from them.
4. Represent mathematical information in different ways including: visually, numerically, verbally, and symbolically.
5. Use arithmetic, algebraic, geometric and statistical methods to understand problems.

Figure 1. An excerpt from our course syllabus, June 2016.

This syllabus reflected how we collectively conceptualized the goals of courses in quantitative literacy. We hoped that students would care about the content of the course - that as students, they would engage with "quantitative information that matters to you" - and that students would do specific things, like: predict, critically analyze, interpret and draw inferences, represent information, and use quantitative techniques. One way to summarize our objectives for the course is that we wanted students to become quantitative reasoners.

In the next section, I detail the first week of a course in quantitative literacy. Specifically, I share some elements of curriculum, my teacher reflections, classroom talk, student reflections, and student work related to our work on happiness.

The First Week of a Course in Quantitative Literacy

I focus on the first week of one session of a quantitative literacy course. Specifically, I focus on one thread of the first week of our class – our consideration of happiness. First, I detail some of what happened during that first week, including parts of the curriculum, my reflections as the teacher, and students' responses to their first homework assignment. After sharing some aspects of our first week of collective experiences, I introduce a specific conceptual fantasy term, *horcrux*, to reframe that first week in a way to distances the realities of quantitative reasoning from its simpler, fantasy form. Specifically, my students demonstrated that our course was in danger of focusing solely on quantitative reasoning in ways that limit its educational possibilities.

Students as Quantitative Reasoners about Happiness

I began the first class by going over the course syllabus, our goals and objectives. We organized these quantitative literacy courses around contextual modules. Each was approximately one-third of one course. The first module was called "The World and Its Peoples"

and focused on things like *The World Happiness Report*, *The Happy Planet Index*, and the United Nations' Sustainable Development Goals. The primary task for the first day of our course is watching a YouTube video, *25 Happiest Countries in the World*. The speaker counts down the top 25 happiest countries and gives a brief description of the country related to the report overlaying images of each country.

I paused the video twice as we watched. The first pause was after the United Arab Emirates portion, at rank 20. We discussed what we had been seeing and hearing, what it made us think about, and what we expected was a part of the *World Happiness Report* researchers' measurement and methodology. The second pause came after the Israel portion, which was the eleventh ranked country in the 2016 report. Students commented further on the patterns they were noticing: not only on which countries we expected to see in the top ten, but also on how the video was portraying the countries. I noted in my reflection that students inferred geographical patterns quickly from the video:

> It seemed like several students were already thinking geographically at country #11 - very few Asian, no African countries – "are those countries not happy?" (Teacher Reflection, Day 1)

After we finished the video, students took some individual time to reflect on what they had seen and come up with their own list of what it takes for them to be happy – to consider what happiness means to them. The students then shared in small groups and contributed to a whole class list. The discussion involved students suggesting new aspects to happiness and measuring happiness. I summarized the list in my reflection:

> The class happiness list: Money, Family, Friends, Sex, Relationships, Food, Making others happy, Shelter, Job, Safety. (Teacher Reflection, Day 1)

I turned the conversation back toward the *World Happiness Report* by asking about measuring the happiness of a country. To conclude my reflection, I wrote:

> I was really encouraged with how quickly students seemed to pick up the concept of measurement challenges during our discussion of whether there would be a clear way to measure our classroom's happiness, when we have such differences in concepts. Also the number of things that contribute - can/should we isolate them? (Teacher Reflection, Day 1)

For the first day of a class, I was very enthusiastic about how it went. On the second day of class, we did not directly follow up on the happiness, but near the end of class we discussed the first homework assignment: to watch a TED Talk on Happiness and respond to a series of prompts. I let the students know that we would discuss some of their experiences and responses in class on Friday. I also let them know that my colleague would be coming in at the beginning of class to discuss my dissertation research project, answer questions, and distribute, collect, and keep consent forms.

Part two. The third day of class began with my exiting the room while my colleague and students discussed the choice to consent to participate in my dissertation project. My colleague made clear that their consent would not affect their grade, as I would not know their participation choice until after the course finalized. All participants' names are protected through pseudonyms. When I re-entered the classroom, we turned to the students' first homework assignment.

The assignment was for students to watch a TED Talk on Happiness of their choosing. Table 1 shows students' video selections.

Table 1
Students' Choices for TED Talk Video on Happiness

Video Title	Speaker	Watched
My Philosophy for a Happy Life	Sam Berns	4
What Makes a Good Life? Lessons from the Longest Study on Happiness	Robert Waldinger	3
Happiness Is All in Your Mind	Gen Kelsang Nyema	2
Want to Be Happier? Stay in the Moment	Matt Killingsworth	2
Breathing Happiness	Emma Seppala	2

Table 1 (cont'd)

What I've Learned from Studying Happiness	Agnes Török	1
What Nobody Told You About Happiness	Saisha Srivastava	1
Want to be happy? Be grateful	Brother David Steindl-Rast	1
Life is easy. Why do we make it so hard?	Jon Jandai	1
The Happiness Advantage: Linking Positive Brains to Performance	Shawn Anchors	1

After watching the video, students responded to a set of prompts that I posed to them. The third prompt is was:

> How would you measure what this person is talking about as happiness or related to happiness? Is it measureable? Did they measure it? How are they making claims about happiness? (Happiness Videos Homework, Jeff, Prompt Three)

One of the creators of the first *World Happiness Report* in 2012 described how they asked similar questions of themselves:

> When thinking about increasing happiness, one of the most important aspects is measurement. Is there a way to accurately measure people's happiness, both within and across societies? … [This report considers] whether measures can provide valid information about quality of life that can be used to guide policy-making. It considers the questions of the reliability and validity of well-being measures; how happiness can be compared; whether or not there is a happiness set point; and if happiness is "serious" enough to be taken seriously. (Sachs, 2012, p. 9)

He went on to say:

> A generation of studies by psychologists, economists, pollsters, sociologists, and others has shown that happiness, though indeed a subjective experience, can be objectively measured, assessed, correlated with observable brain functions, and related to the characteristics of an individual and the society. (Sachs, 2012, p. 6)

Sachs was describing the rationale for their work. Although these researchers understood happiness to be a subjective experience, they nevertheless understood its measurement to be objective; that is, what a person considers happiness is personal, but the markers of happiness are observable and detached from individuality. In the next section, I share excerpts of my students' responses to similar questions.

The Choice Whether to Keep Happiness as Not a Number

Students' responses to this our third homework prompt provide an exemplar of how they were already capable quantitative reasoners who understood and could engage with some of the most challenging parts of quantitative methods, in much the same way that professional quantitative reasoners did when they created *The World Happiness Report*. I purposefully share large excerpts from my students' responses, and then unpack them collectively.

> It actually reminds me of the song "Seasons of Love" from Rent: Five hundred twenty-five thousand six hundred minutes. Five hundred twenty-five thousand moments so dear. Five hundred twenty-five thousand six hundred minutes. *How do you measure, measure a year*? In daylights, in sunsets? In midnights, in cups of coffee? In inches, in miles? In laughter, in strife? In five hundred twenty-five thousand six hundred minutes? *How do you measure a year in the life?* (Aisha, Happiness Videos Homework, Prompt Three, emphasis mine)

> The cool thing about Sam is that he didn't put an exact measurement on happiness. Happiness to him is a way of being and thinking. He lives through his own three step philosophy. The key points to his philosophy were loved ones, positivity and perseverance. *I think that everyone can have their own method to happiness though. Happiness is measured different to every person. What might make one person happy can be something totally different than what makes another person happy.* (Nicole, Happiness Videos Homework, Prompt Three, emphasis mine)

> She didn't measure happiness at all, she didn't even attempt it, *I would actually say what she was trying to get at was that you can't measure happiness, you can't measure what it takes to make someone happy, because their happiness should come from within not from tangible things or other people*. She states that you control your happiness and that you are the only person that knows your own happiness. (Lila, Happiness Videos Homework, Prompt Three, emphasis mine)

> *I'm still skeptical on whether happiness can truly be measured*. I realize that one can look at a community or country that is going through harsh times or being ruled by an undesirable and/or controlling leader and then look at a community or country that doesn't have any of these problems and argue through comparison that one is happier than the other, but I'm still not convinced that countries can truly be ranked in order of happiness. *There are too many cultural biases and intricate details that cannot be measured against each other because what makes one happy can make another miserable. I guess what I'm trying to say is that I'm not convinced yet.* (Beth, Happiness Videos Homework, Prompt Three, emphasis mine)

> I do not think that Steindl-Rast's definition of happiness could be measureable in a larger context, but we could measure the smaller aspects of happiness…Steindl-Rast's claims about happiness are that when a community becomes grateful, they interact more with one another, and their happiness spreads. He does not mention how he would measure this, but I think it is possible. I think we can measure the results of this type of happiness, and what people achieve from attaining happiness. For example, you could do what Steindl-Rast did and put stickers on the things in your home you are grateful for. *Then you could take emotional measurements, like the ones we do in class, of your emotions at the end of every day. At the end of a week, you could see if your happiness level rose due to noticing things to be grateful for.* (Marilyn, Happiness Videos Homework, Prompt Three, emphasis mine)

> The measurable evidence from the speaker's claims came from a data-collecting app in which users would respond to a site-master's inquisitions about their mood, behavior, and thought-process. *This seems like a good way to collect evidence, but the three questions that users were asked seemed very generalized to me. "How happy are you," "what are you doing right now," and "is your mind wandering." To me this seems a bit more qualitative, but the data stands*. (Chloe, Happiness Videos Homework, Prompt Three, emphasis mine)

These student responses provide an important lens with which to critique how we construct the quantitative reasoner, especially affectively. Whereas the creators of the *World Happiness Report* judged happiness to be objectively measurable and quantifiable, many of my students, after reasoning about what that would imply, decided that happiness could not be measured – a position that Aisha and Nicole thoughtfully exemplified. Students' thinking about measuring happiness was still more complex than that, though – as Marilyn and Chloe both interacted with quantifying as inherently limited, and Beth remaining skeptical but not closed to the idea of quantifying happiness.

These students' responses exemplified the complexity of thinking about quantitative reasoners who have a productive disposition toward mathematics. If these students stated that happiness cannot be measured, would we judge them not to be quantitative reasoners? This question frames the next part of this article, wherein I problematize the quantitative reasoner.

An Emerging Conceptual Language: The Fantasy Genre and Education

In this section, I problematize the quantitative reasoner. Specifically, I suggest that an isolation of quantitative reasoning from the rest of human reasoning, and from choices, dehumanizes people both when they choose to quantitatively reason and when they choose not to. I introduce a conceptual term from the Harry Potter universe to illustrate my meaning.

I consider problematizing to be a part of the project of critical postmodernism. Problematizing involves critical inquiry into how realities are being enacted, and postmodern deconstruction of how those realities are co-constructed. In thinking about research from the critical postmodern perspective, I have found the fantasy genre to be a well-suited conceptual language. As an umbrella term, *fantasy* generally connotes what emerges from a person using their imagination to think about an alternative or altered reality. That fantasy is commonly considered impossible, or at least unlikely. Sometimes *fantasizing* may be used to suggest "improper" sexual thoughts or unproductive daydreaming; at the same time, fantasizing can have a positive association when it relates to hopes and dreams. Fantasy has a complex relationship with reality. If education researchers attempt to analyze and scrutinize reality, and education "cannot fear the analysis of reality" (Freire, 1974, p. 34), then fantasy is a relevant concept to educators' scholarship. That fantasy commonly has both good and bad overtones also makes it helpful to work in critical postmodernism in its dialogic relationship between action and skepticism.

Quantitative Reasoners as a Fantasy of Mathematics Educators

How might the quantitative reasoner image be considered a fantasy? I want to return to the earlier description of a productive disposition toward mathematics, and pose some questions.

> Productive disposition refers to the tendency to see sense in mathematics, to perceive it as both useful and worthwhile, to believe that steady effort in learning mathematics pays

> off, and to see oneself as an effective learner and doer of mathematics. (NRC, 2001, p. 131).

Is the choice not to measure happiness mutually exclusive from seeing oneself as an effective learner and doer of mathematics? If you choose to see measuring happiness as nonsensical, not useful, or not worthwhile, does that mean you do not have a productive disposition towards mathematics? How can mathematics educators complexify the productive disposition into something that is more dynamic and connected to other aspects of being human? How often do we label people as ineffective learners and doers of mathematics (i.e. innumerate, quantitatively illiterate, and mathematically illiterate) who see themselves as effective? Some of the answers to these questions might rely on how the word "tendency" in the productive disposition in the definition. Nevertheless, I ask these questions to frame a discussion of the quantitative reasoner as a fantasy and to interrogate my course.

The quantitative reasoner may be a fantasy because it has a mythical status. Valero (2005) argued that mathematics education, and other education research, has constructed the "*myth of the active learner*" (p. 1). She chose *myth* to illustrate how the image of an active learner "does not give a full picture of the beings it intends to talk about" (Valero, 2005, p. 3). In a similar way, the quantitative reasoner might be considered a myth when quantitative reasoning is discussed disconnected from other forms of reasoning. Take the beginning description of the first SMP, *Make sense of problems and persevere in solving them*:

> Mathematically proficient students start by explaining to themselves the meaning of a problem and looking for entry points to its solution. They analyze givens, constraints, relationships, and goals. They make conjectures about the form and meaning of the solution and plan a solution pathway rather than simply jumping into a solution attempt. They consider analogous problems, and try special cases and simpler forms of the original problem in order to gain insight into its solution. They monitor and evaluate their progress and change course if necessary. (CCSSM, 2014)

This description draws a distilled, and almost robotic, image of quantitative reasoning that erases the messiness of problem solving. From this perspective, the fantasy is that the quantitative reasoner can be isolated and abstracted. Through this isolation, a person seems divisible into the quantitative reasoner piece and the rest - what Valero called a schizo-being with two parts: "the one that has to do with mathematics, and the one that has to do with other unrelated things" (Valero, 2002, p. 5). With regards to how I have constructed the quantitative reasoner, this division is a fantasy because (1) there are many actions a person might choose to do when reasoning that are not mathematical and (2) those choices, and the reasons for them, involve both mathematical and non-mathematical considerations. In other words, the choice to do quantitative reasoning is not separated from the choices not to do other reasoning, the choice not to do quantitative reasoning is not separated from the choices to do other reasoning, *and* both quantitative and other types of reasoning are happening. Each of these relationships highlights the limitations of thinking about quantitative thinking and learning in isolation.

The quantitative reasoner fantasy may take shape in the mathematics classroom, where they may be living in *Mathland* (Boaler, 2015), a self-contained universe in which mathematics-only problems are solved. A fantasy in its own right, *Mathland* stands in contrast to "real real-life mathematical problems [that] occur in broad contexts, integrated with other knowledge of the world" (Frankenstein, 2010, p. 251). The quantitative reasoner who embodies the SMPs is a fantasy because the problem solver is not transcendent to the problem – which changes; therefore, any list of problem solving strategies (such as the SMPs) is incomplete without nuanced consideration of when those strategies should happen. If the answer to that consideration is "always," then I would argue the quantitative reasoner (or problem solver) is a fantasy that does not exist. Although a long-held hope in mathematics education, from mental

discipline theory (e.g. Colburn, 1830; Brooks, 1883) to metacognition and problem solving (e.g. Schoenfeld, 1992), research in situated learning counters the idea of an overriding quantitative reasoner (e.g. Greeno, 1998; Lave & Wenger, 1988; Lave, 1992).

At this point, I think it is important that I pause and try to clarify my use of fantasy to preempt readers who may not be as familiar with the genre. In particular, I am exploring the fantasy language for possibilities as allegory, parable, and metaphor. Often, the fantasy genre acts in that way in practice by ignoring what is considered impossible or not real, and using the new possibilities to reexamine and interrogate the world and realities. My purpose is not to claim that the CCSSM authors, or those who have formulated, theorized, and studied quantitative reasoners or related ideas, do not understand and appreciate the complexity and messiness of what they are discussing. From my own reading of most of the work, I would infer the opposite. I choose the SMPs to illustrate the quantitative reasoner image because, in what are relatively brief descriptions, much of the complexity of human reasoning – our affect, history, experience, differences - is not present. That the SMPs and the CCSSM documents have withstood, to an extent, ferocious scrutiny and political backlash nevertheless might be considered a testament, at least in part, to the power of the quantitative reasoner image as a fantasy. The quantitative reasoner image is powerful enough to be sundered from the complexity of human reasoning and exist on its own.

The Course as a Horcrux

Within a fantasy genre conceptual framework, I use a particular fantasy concept to reconsider our quantitative literacy course. In the Harry Potter fantasy universe, a *horcrux* is created by a wizard or witch to contain a part of their soul. The horcrux is usually an inanimate object, and in the story the predominant antagonist Voldemort protects his horcruxes with

dangerous spells, as well as obstacles and illusions. In order to create a horcrux, however, the creator must first split their soul. I argue that the course acted as a horcrux for a piece of soul called the quantitative reasoner. Fantasizing about my own work as creating a horcrux is unsettling, but helpful to remaining self-critical about my work in mathematics education. Obviously, this quantitative reasoner piece of soul belongs to an imagined person; nevertheless, when I use the concept of a horcrux to problematize our courses, I argue it helps illustrate three things.

First, along with the horcrux comes and explicit focus on the concept of *soul*. The idea of education being concerned with the soul is central in the work of Thomas Popkewitz (e.g. 1997; 2004; 2008):

> It may seem odd to talk about school subjects and the soul in the same sentence because modern pedagogy does not speak directly about the soul. Instead, it speaks about the governing of the conduct, personality, relationships, and emotions of the child. This modern soul takes shape from the pedagogical psychology that renders the child's "problem solving" and participation in the social networks of a "learning community" observable and governable. (Popkewitz, 2004, pp. 4-5)

For me, the purpose of introducing the concept of soul into educational research is to interrogate the ways that educationalists have moved beyond debating which knowledges people should know to how people should feel about those knowledges, specifically attention to affect. Second, because the horcrux only ever contains a piece of soul, considering a course (or some other aspect of education) to involve this type of magic helps illustrate how we might isolate aspects of being human by how we organize schooling into subjects. Third, despite Popkewitz' and my own hesitancy in establishing affective goals to be achieved through education, the concept of a horcrux illustrates how we might still consider affective situations we would want to avoid.

Affect Theory and Mathematics Education

The idea of an affective objective for mathematics education has been central to significant research, including in: attitude (e.g. Fennema & Sherman, 2001), beliefs (e.g. Leder, Pehkonen, & Tomer, 2006), disposition (e.g. Gresalfi & Cobb, 2006), and identity (e.g. Boaler, 2002). I consider all of these concepts to be part of the broader concept of affect (e.g. McLeod, 1992; Roth & Walshaw, 2015; Zan, Brown, Evans, & Hannula, 2006). Within affect theory research in mathematics education, "arguably the most important problem…is the understanding of the interrelationship between affect and cognition" (Zan, Brown, Evans & Hannula, 2006, p. 7). This question is very relevant to understanding the quantitative reasoner with a productive disposition toward mathematics.

Historically, affect researchers presumed that "affect is like the gasoline that drives the motor, the intellect, but does not modify its structure" (Roth & Walshaw, 2015, p. 219). From this perspective, affect is generally considered separate, and often inhibitive of cognition. Roth and Walshaw, using a poststructuralist paradigm, questioned the binary between emotion and cognition, positing instead their unity. Their work focused on how anxiety about mathematics is a manifestation of larger societal processes:

> Thinking, acting, and feeling are assumed to be intervolved with and constituted by the individual's relation with history and culture. Environmental, dispositional, and situational characteristics do more than mediate students' affective responses, such as anxiety; they are its origins. Applying these ideas to the classroom leads us to propose that affect occurs as part of, and constitutes one reflection of, a layering of complex systems of relationships—past, present, and potential—and within constantly changing circumstances and conditions. (Roth & Walshaw, 2015, p. 228)

What they call their neo-Vygotskian approach has major implications for affective educational goals, such as the quantitative reasoner productive disposition. Through a societal-historical perspective, individual moments experienced by specific people in a particular space and time

can be considered as representative instantiations of societal relationships to mathematics and schooling: actualizations of discourses, cognitive, emotive, and active, performed through the uniqueness of individual agents.

Mathematical Jokes and Societal Affect

One societal activity that mediates and mutually constitutes affect related to mathematics is by motivating mathematics learning through what Grawe called mathematical "jokes." Grawe (2015) used comedy theory to describe a comedy form that John Allen Paulos (1989) used in his book, *Innumeracy*:

> In *Innumeracy*, the joke form is often quite apparent because it is [the public] who are, in fact, the butts of a grand joke, the great unwashed in need of conversion to thinking in mathematics and getting Got when we don't…And Paulos' writing talent, we can hope, will be remembered as inciting – or shaming – Americans into mathematical literacy amidst the computational complexities of modern popular culture. (Grawe, 2015, p. 6)

The joke form to which Grawe referred is *gotcha* jokes, a particular kind of humor where the joke author sets-up the butt of the joke by first adopting an exaggerated, yet common stance toward some idea. Often that common stance is built up as complex, complicated, and informed. The butt of the gotcha joke is the person who takes up that stance. The joke turns when the joke author reveals the butt's stance as actually uninformed and wrong – the "gotcha" moment. Despite the fact that this joke form is rooted in pain humor, Grawe (2015) still hoped for it to be effective in shaming people into change.

He also argued that this gotcha joke form is extremely common in mathematics educational discourse, particularly in the QL discourse. For instance, Paulos repeatedly demonstrates the innumeracy of the general public through playing gotcha jokes on their mathematical ignorance. This kind of gotcha joke was embedded into the QL course, and in the first World Happiness Report in 2012.

The World Happiness Report gotcha joke. In the first *World Happiness Report*, one co-creator discussed the measurability of happiness in a similar gotcha joke form:

> Yet most people probably believe that happiness is in the eye of the beholder, an individual's choice, something to be pursued individually rather than as a matter of national policy. Happiness seems far too subjective, too vague, to serve as a touchstone for a nation's goals, much less its policy content. That indeed has been the traditional view. (Sachs, 2012, p. 6)

Here, Sachs is setting up the butt of the joke – most people – by presenting their, perhaps well-reasoned "belief" that happiness is personal, and therefore, subjective. He continued:

> Yet the evidence is changing this view rapidly. A generation of studies by psychologists, economists, pollsters, sociologists, and others has shown that happiness, though indeed a subjective experience, can be objectively measured, assessed, correlated with observable brain functions, and related to the characteristics of an individual and the society. (Sachs, 2012, p. 6, emphasis mine)

Sachs' words follow the flow of a gotcha joke on "most people," who believe happiness is not objectively measurable, by declaring that happiness can - as fact, not belief - be measured objectively and across people. Within the course there were many instances during which dehumanizing gotcha jokes may have been told to shame my students into thinking the content of the course was important. In the next section, I explore how I attempted to avoid telling gotcha jokes in part through telling *sympathetic pain* jokes instead.

Reversing the Horcrux: Complex Choices

The idea of somehow shaming my students into appreciating mathematics is repulsive to me, and runs contrary to my hopes for humanizing mathematics education. Likewise, Grawe (2015) complexified his perspective on the humor form embedded in mathematics education, however, emphasizing "the need to take seriously pain in humor" (p. 7). When we engaged activities involving prediction or data exploration, I avoided positioning my students as the butts of gotcha jokes about their ignorance. To an extent, when we engaged those activities, the joke

took the form of *sympathetic pain*, which Grawe (2015) proposed as an alternative way to talk about ignorance.

Sympathetic pain jokes in class. When I prefaced one TED Talk students would be watching and reflecting on for homework, *How Not to Be Ignorant about the World* (Rosling & Rosling, 2014), I talked sympathetically about my own experiences being wrong and surprised about the content of the video. Instead of taking the opportunity to tell a gotcha joke regarding the accuracy of my students' predictions about the "If the world were 100 people" infographic, I recalled my first encounter with it – my surprise, inaccuracies, and questions. We interrogated our "gotcha" feeling by questioning how variables might be defined or measured differently, by asking: "Is this representation accurate?" and by collectively coping and grappling with our potential ignorance about the world.

Student projects as no jokes. As part of the course, students completed course long projects on a topic of their choosing. The project had four phases: proposal, media analyses and synthesis, infographic creation, and reflection and creative expression. Table 2 shows the students' project topics.

Table 2
Student Projects Titles and Descriptions

Title	Description
Censorship	Internet censorship policies and histories across countries
Climate Change	Looking at the impacts of polar ice shifts on climate from a religious perspective
College Athletes Getting Paid	Case of Northwestern University Football attempting to unionize
Cultural Differences in Mental Health	Cultural differences in what is considered a mental illness and treatment options
Do Schools Kill Creativity?	Budget cuts to arts and humanities programs in K-12 public schools in the United States
Domestic Violence	The perpetual cycle of domestic violence across generations

Table 2 (cont'd)

Drug Abuses and Overdoses	The prevalence of heroin abuse in specific cities across the United States
Flint Water Crisis	How the Flint Water Crisis could have happened and the possibility of its recurrence in another city
Flint Water Crisis	Humanizing and personalizing the effects of the Flint Water Crisis
Gun Violence	Advocating ways to avoid gun violence, specifically preventative learning about guns
Gun Violence	How gun violence affects communities, particularly gun violence against children
How Social Media has Changed the World	The impact of virality on people who go viral, especially the emotional fallout
Impact of Big Money in Politics	Looking at the results of the Citizens United court decision on money entering politics
Overpopulation	The effects of a one-child policy on China and the persistence of problems of resource use
People of Color in Media	The erasure of entertainment and media achievements of actors of color
Racism in the Academy Awards	The evolution of racism in the entertainment industry
Recycling Practices	Cross-country analysis of recycling practices and constraints on recycling
Representation of Women in Media	The disparities in gender representation in political news reporting
Stigmas around Mental Illness	How different cultures respond to depression and stigmatize the illness

The purpose of the project was to offer students a chance for extended inquiry into a topic of their choosing, for which they acted as an expert quantitative reasoner. Although details of students' projects are beyond the scope of this paper (see chapter five, this dissertation, p. 96), I wanted to share excerpts from two students' reflections here.

> This was probably one of my favorite projects that I have ever done…Whenever you gave us an assignment and said "pick anything you want" it was like hearing foreign words because that is something I never hear unless there is a catch, but this time, there was no catch. I was able to pick a topic that I was interested in and really learned from it. (Makayla, Course Project Reflection)

Makayla's reflection illustrates how the follow-through on relinquishing the authority over the project to my students may have contributed to humanizing her course experiences. Another student wrote:

> These past few weeks working on this project have been way more awesome and way more fun than I thought that they would be. I was able to spend the last 5 weeks or so thinking very critically about an issue that I care very deeply about. (Aisha, Course Project Reflection)

Aisha highlighted how engaging in a course-long project involving quantitative reasoning was not what she expected from a mathematics course.

Humanizing each other. My students did something incredibly humanizing for me. They helped me recognize the ways in which our course, though potentially a more humanizing mathematics education experience, still deformed and dehumanized when we kept the quantitative reasoner separate from other human reasoning. How might education generally consider this dehumanizing separateness? I have some evidence that for at least some of my students, having their quantitative reasoning validated by a mathematics teacher relative to issues they cared about may not have been a familiar experience. Marilyn, for instance, commented on how different our classroom environment was from her previous experiences:

> During the class so far, I kept writing "happy" as my response often because I feel calm most of the time in class, and that is about as close to happy that math class has ever made me! (Marilyn, Fourth Week)

Three other students shed tears while recounting their experiences with mathematics to me during the first two weeks of class. With three other students, on separate occasions, I had a conversation in our classroom for over an hour after class finished: about mathematics, about school, about life. These experiences reflected something important about this course, and this classroom space: a certain level of trust between me and my students, something established

during over the duration of the course. At the same time, I was troubled that my students felt this way about mathematics.

Epilogue: Another (Quantitative) Reasoner Fantasy

"We could all have been killed – or worse, expelled."
-J.K. Rowling, as Hermione Granger

I am acutely aware of how the concept of a horcrux is jarring. I am highly concerned that as I blurred the boundary between fantasy and reality, so too people might (and probably should) blur the boundary between productive metaphor and destructive accusations. I want to acknowledge directly that I am accusing myself of making the horcrux. Nevertheless, I hope using this fantasy language helped to make the strange familiar and the familiar strange. I personally find it clarifying to think about how I am complicit in dehumanization through education, despite my efforts to the contrary.

I think one task for mathematics educators is to continue humanizing our subject. By that, I mean considering how humans do mathematics and how they do not, and work to collectively continue evaluating the uses of mathematics and statistics throughout social life (e.g. Jablonka, 2003). Wadsworth (1997) highlighted her views how mathematics education generally forms a public joke about public issues:

> Defining this issue in terms of public innumeracy feeds into a view that is all too common among the national leadership, and one that is deeply resented by the public. It suggests the public is stupid and the experts are smart, and if people were just a little less dumb or a little more mathematically sophisticated, we could balance the budget and solve more of our national problems…We see the root problem not as a conflict between an innumerate and uneducated public versus a numerate and sophisticated elite, but as a conflict between the public's moral and value-driven perspective on issues and an expert perspective that is increasingly technical and value-free. (p. 12)

I think it is important to consider how we might humanize who she labeled the experts, complexifying what they create as opportunities for continued conversation and reasoning, rather

than as finding numerical answers to complex problems. At the same time, I think QL should focus on aggressive skepticism towards simple solutions.

The quantitative reasoner, by many names, is a powerful image in mathematics education. That it may be a fantasy might seem disheartening, but I actually find a good deal of hope from the thought that our work is fantasy. First, it relieves a bit of pressure. We are given a massive burden when societies' ills are placed on the shoulders of education. Part of the reason we bear that burden might be because we overstate the possibilities of schooling, by designing fantasy goals and making them appear achievable and assessable. Second, the overtones of good and bad in fantasy suggest that we might imagine something different.

What are the implications for mathematics education? In light of seeing my students' choice not to quantify as a form of quantitative reasoning, I revisit my prior conceptualization of a quantitative reasoner and adjust the SMPs to express what might result from complexifying our educational vision:

1. Make sense of problems and persevere in solving them, *but scrutinize what constitutes a problem*.
2. Reason abstractly, quantitatively, *morally*, *socially*, *politically*, *emotionally*, et cetera.
3. Construct viable arguments and critique the reasoning of others, *and yourself*.
4. Model with mathematics, *and humanize those who do so*.
5. Use appropriate tools strategically, *responsibly, and ethically.*
6. Attend to precision, *but do not sacrifice intuition or a wider vision.*
7. Look for and make use of structure, *while recognizing how structures constrain thinking*.
8. Look for and express regularity in repeated reasoning, *but appreciate uniqueness*.

Although I think there is something useful in taking educational action around these complexified practices, I still hesitate to prescribe a particular kind of person as a goal for education. I wonder how these eight practices are still yet a fantasy in some ways. More work in fantasizing about alternative forms of education awaits.

CHAPTER FIVE:

WICKED PROBLEM (RE)SOLVING AS A BASIS FOR REFORM IN CURRICULUM AND INSTRUCTION: THE CASE OF QUANTITATIVE LITERACY

I mirror the title of this article to a 1996 piece in *Educational Researcher*, "Problem Solving as a Basis for Reform in Curriculum and Instruction: The Case of Mathematics" (Hiebert et al., 1996), in which the authors argued:

> Rather than mastering skills and applying them, students should be engaged in resolving problems. In mathematics, this principle fits under the umbrella of problem solving, but our interpretation is different from many problem-solving approaches. (p. 12)

These authors extended their particular interpretation of problem solving using Dewey's (1910; 1929; 1938) work. Hiebert and colleagues (1996) summarized Dewey's (1933) concept of reflective inquiry as having three primary parts: "(1) problems are identified; (2) problems are studied through active engagement; (3) conclusions are reached as problems are (at least partially) resolved" (p. 14). They extended Dewey's work by arguing that reflective inquiry is fostered when students "problematize" what they are studying, which is to "wonder why things are, to inquire, to search for solutions, and to resolve incongruities" (Hiebert et al., 1996, p. 12).

The initial article and the authors' (1997) rejoinder to responses by Smith (1997) and Prawat (1997) seemed to accumulate into an agreement about the need for reform and the potency of problem solving, but also questions about what problematizing really implied for schooling. Smith (1997), for instance, focused on the social question of what students might choose to problematize. In particular, he considered traditional mathematics curricular content to be relatively poorly aligned with the concept of "problematizing," and stated:

> If students are encouraged to engage in that process seriously and articulate what they find interesting and problematic, and do not expect to be assigned problems to solve, their interests will inevitably lead them to ponder a much richer and wider range of mathematical ideas. Problematizing, if pursued seriously, will burst the boundaries of the traditional school mathematics curriculum. (Smith, 1997, p. 22)

In this article, I report on a case study of what happened in an undergraduate mathematics course where students pursued serious problematizing, and the resulting ways in which the boundaries of the traditional mathematics curriculum burst. I begin by briefly describing the setting of the study and introducing *wicked problems* (Rittel & Weber, 1973/1984) as a theoretical framework that I used to code students' course project artifacts. I hoped to explore what was involved in students' projects. Out of the coding, three themes emerged: *open democratic education*, *complexity*, and *transdisciplinarity*. I conclude with a reflection on the obstacles to reforming mathematics education to address wicked problems.

A Quantitative Literacy Classroom Example

My quantitative literacy (QL) classroom was located at a large Midwestern university. The university was a predominantly white institution (PWI) located in what is often described as a "college-town." The course was a seven-week summer class that met in-person for two hours a day, three days a week. This semester was only the second time the course was offered. It was one-half of a two-course sequence in quantitative literacy that emerged from institutional efforts to improve student experiences with the university's general mathematics degree requirement. Beginning in June 2014, I joined a small team of scholars working to design these courses.

Each course is organized around three different context-based modules. The three modules in this instance were *The World and Its Peoples*, *Numbers and Media*, and *Health and Risk*. In *The World and Its Peoples*, we organized materials around the choices and power involved in counting people and quantifying the world; in *Numbers and Media*, we designed around the flexibility of numbers as socially constructed, rhetorical, subjected, and powerful; and in *Health and Risk*, we created materials related to considering the quantification in health and risk and its implications on fear and safety narratives.

Over the course of seven weeks, we enacted a curriculum focused on reasoning about and with quantities, shapes, and measurement. Alongside planned activities for the whole class were students' individual course projects. During my post-course analysis of students' projects, I came across the idea of wicked problems, which became a theoretical framework for my inquiry. As I argue here, the concept of wicked problems might offer language to consider anew several ideas in education: a building blocks mentality, education centered on preparation for a future, and the relationship between justice and education.

In this article, I share my experience with wicked problems based coding, which helped me understand different qualities of education that involves wicked problems: open problematizing, complexity, and transdisciplinarity. By connecting my experiences with these ideas I was able to give language to some of the ways in which education as usual can be challenged. Students open problematizing disrupts the power relationship between curriculum and students; engaging complexity disrupts the power relationship between teachers and students; transdisciplinarity disrupts the hyper focus on educational problems within disciplines (i.e. how to teach mathematics better).

Wicked Problems

> It seems as though some problems are tame, such as factoring a quadratic equation, traversing a maze, and solving the tower of Hanoi puzzle. But problems of importance… are invariably 'wicked.' (pp. 5-6)

Coyne (2005) defined *wicked problems* by contrasting them with *tame problems*. In this description, he chose three kinds of common school mathematics problems: factoring, navigating a maze, and the tower of Hanoi puzzle. These three tame problems involve major ideas of mathematics education like spatial reasoning and algebra. The tower of Hanoi puzzle represents a class of mathematics curricular content that is sometimes uplifted as challenging, fun, and

meaningful. Calling attention to tame problems, Coyne (2005) used these three examples to subtly criticize the prevalence of tame problems in mathematics education at a time when many people were alarmed by global and local challenges. He posed a challenge to mathematics education to consider problems of importance, which he called "wicked."

To move beyond a binary contrast, however, I turn to Rittel and Webber (1973/1984), who first conceptualized wicked problems in design and planning. They argued that there are ten distinguishing characteristics of wicked problems:

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rules.
3. Solutions to wicked problems are not true or false, but good or bad.
4. There is no immediate and no ultimate test of a solution to a wicked problem.
5. Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of possible solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The planner has no right to be wrong.

I used these ten characteristics to produce a theory-based coding of students' project artifacts, out of which three themes emerged. In the next section, I report moments in student projects that exemplify the presence of each of the ten characteristics of wicked problems. I sorted Rittel and Weber's (1973) list to illustrate three emerging themes: open democratic education and wicked problematizing, complexity, and transdisciplinarity. Each of the three themes has a header below and I sorted characteristics under those headers. I sorted after my coding, as I saw particular characteristics clustered together. This coding and thematic analysis is not meant to be

exhaustive or definitive, only productive to begin illustrating some of what education for wicked problems might involve.

Wicked Problem Characteristics in Student Projects

The course projects began the first week of the course and had four phases. Students (1) identified and framed the scope and focus of an issue that they wanted to consider and study, (2) analyzed and synthesized relevant media, (3) created an infographic about their problem, and (4) reflected on what they had learned. During each of these four phases, students generated project artifacts, which I coded using the ten wicked problem characteristics and construct three themes: *open democratic education*, *complexity*, and *transdisciplinarity*. I use *exemplar* data (e.g. Tracy, 2013) to illustrate these three themes as they emerged from my wicked problems theory-based coding.

Open Democratic Education and Wicked Problematizing

Many scholars have theorized about democratic education (e.g. Darling-Hammond, 1996; Gutmann, 1999; King, 2016; Mirón & Dhillon, 2004). One claim is that for education to be organized around democratic principles, it must attend to authentic, meaningful problems. Freire (1974) insisted that this is foundational to the endeavor:

> Democracy and democratic education are founded on faith in [people], on the belief that they not only can but should discuss the problems of their country, of their continent, their world, their work, the problems of democracy itself. (Freire, 1974, pp. 33-34)

According to Freire, democratic education involves a curriculum designed around problems, but to add to Apple (2004) asking "whose knowledge?" is the question of "whose problem?" The open problematizing which students engaged involved me relinquishing some authority over curriculum, which involved partially democratizing curriculum by *opening* it to a small "reversal of power relations" (Butin, 2002, pp. 15-16).

Rittel and Weber (1973/1984) claimed that between any two problems (wicked or otherwise), it is common to be able to note a list of similarities and a list of differences. Wicked problems, however, are essentially unique in that prior resolutions to similar or other wicked problems cannot be grafted in the new context. I had only one criterion for the students' project choice: to pick something about which they cared and wanted to know. They did not have to consult me regarding their topic choice, and they did not have any constraints or list of acceptable or unacceptable topics.

(Characteristic #7) Every wicked problem is essentially unique.

Table 3 is a list of their project topics. All student names are pseudonyms.

Table 3
Student Projects Titles and Descriptions

Title	Description
Censorship	Internet censorship policies and histories across countries
Climate Change	Looking at the impacts of polar ice shifts on climate from a religious perspective
College Athletes Getting Paid	Case of Northwestern University Football attempting to unionize
Cultural Differences in Mental Health	Cultural differences in what is considered a mental illness and treatment options
Do Schools Kill Creativity?	Budget cuts to arts and humanities programs in K-12 public schools in the United States
Domestic Violence	The perpetual cycle of domestic violence across generations
Drug Abuses and Overdoses	The prevalence of heroin abuse in specific cities across the United States
Flint Water Crisis	How the Flint Water Crisis could have happened and the possibility of its recurrence in another city
Flint Water Crisis	Humanizing and personalizing the effects of the Flint Water Crisis
Gun Violence	Advocating ways to avoid gun violence, specifically preventative learning about guns
Gun Violence	How gun violence affects communities, particularly gun violence against children

Table 3 (cont'd)

How Social Media has Changed the World	The impact of virality on people who go viral, especially the emotional fallout
Impact of Big Money in Politics	Looking at the results of the Citizens United court decision on money entering politics
Overpopulation	The effects of a one-child policy on China and the persistence of problems of resource use
People of Color in Media	The erasure of entertainment and media achievements of actors of color
Racism in the Academy Awards	The evolution of racism in the entertainment industry
Recycling Practices	Cross-country analysis of recycling practices and constraints on recycling
Representation of Women in Media	The disparities in gender representation in political news reporting
Stigmas around Mental Illness	How different cultures respond to depression and stigmatize the illness

The students chose a wide variety of issues to study, but formulating the particular problem or set of problems was challenging. Many students asked about the suitability of a particular topic for this project. My first impression of students' topic choices was that many had developed ideas around problems of massive scope (e.g. racism, climate change). Despite students completing the same project phases, their work was unique content because they focused on different problems and formulated similar problems differently.

(Characteristic #1) There is no definitive formulation of a wicked problem.

> Another issue that internet censorship is tied to is that sometimes internet censorship can be a good thing. For example, I don't think it is okay for people to be posting pro-terrorist webpages, or terrorist recruitment forms online. If it really is a threat to national security, then I believe that the government has a right to restrict that. (Matt, Phase 2, Media Synthesis)

Matt confronted the challenge of formulating what the problem of censorship entirely involved. Rittel and Weber (1973/1984) stated that "the formulation of a wicked problem *is* the problem!" (p. 137). To formulate a wicked problem involves establishing a discrepancy between

what *is* and what *should be*. But there are multiple explanations for that discrepancy, and therefore multiple possible formulations.

(Characteristic #9) The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.

> There are a few different issues revolving around the stigma that exists around mental illness; the first being that people sometimes avoid or bully those suffering from mental illness just due to their differences, the next is that mental illness is often misrepresented in the media, those suffering from mental illness in television shows or movies are almost always depicted as some sort of antagonist, murderer, or criminal. (Beth, Phase 2, Media Synthesis)

Beth's project on mental illness evolved into an investigation of cultural differences in identifying and treating mental illness. She focused on a discrepancy between perceptions of mental illness taking the form of stigma and the realities of people suffering from mental illness. She had different explanations for that discrepancy which she explored during her project.

Complexity of Wicked Problems

Ritchey (2001) claimed "if you work with long-term social, commercial, or organizational planning – or any type of policy planning that impacts *people* – then you've got *wicked problems* (p. 1, emphasis in original). The presence of wicked problems can be signified by a sense of *reactivity*, where after attempting resolution, the problem transforms and "fight[s] back when you try to do something" (Ritchey, 2001, p. 1).

As this reactivity challenged and displaced some quantitative techniques, statisticians and mathematicians responded with new theories and methodologies focused on systems with *complexity* where "many of the factors involved are not meaningfully quantifiable, since they contain strong social, political, and cognitive dimensions" (Ritchey, 2001, p. 7). The elements involved in these systems necessarily interact and affect each other. In fact, these systems are

notable precisely because they have a "sizable number of factors which are interrelated into an organic whole" (Weaver, 1948, p. 5). By coding these projects with wicked problems theory, I found a cluster of characteristics, below, that signified to me a relationship to complexity.

(Characteristic #8) Every wicked problem can be considered to be a symptom of another problem.

> After doing the research, I found the issue is not only too many people, but also pollution, land, resources and other issues. (Leilei, Phase 4, Written Reflection)

Leilei produced a project on China's One-Child Policy and concluded that overpopulation itself is an amalgam of other interlocking problems. Although the first phase of the project was the explicit time when students formulated their topic, the challenges to problematizing wicked problems persisted through complexity. I had five students make significant changes to their topics during the second phase of the project, as they clarified their own interests, but all students reformulated their problems at some point during the course.

(Characteristic #3) Wicked problems have no stopping rules.

> The one child policy was published to limit people to have only one child. This stopped the growth of population. And people's life changed a lot from this. Then, population aging became another issue for China. Population aging hurts the economy and the government decides to end the one child policy. The new policy is "One Couple, Two Children. (Leilei, Phase 2, Media Synthesis)

That wicked problems have no stopping rules also implies they have a history. The media analyses and syntheses involved students engaging with the histories of these complex wicked problems. The piece of media usually included their own formulation of the problem, and explanation for the cause. The reintroduction of the initial problems underscored the complexity and fluidity of these projects. The challenges involved in testing solutions to wicked problems are underscored by the idea that those solutions cannot be evaluated in the same way that tame problems can.

Although I hesitate to describe these projects as attempts to resolve wicked problems, the complexity of wicked problems implies that these projects matter. In fact, awareness was central to many students' projects and proposals about how wicked problems might be solved. Raising awareness was one commonly cited aspect of addressing wicked problems, and students faced challenges deciding how to increase awareness. The complexity of wicked problems also suggests a resistance to single disciplinary solutions in favor of transdisciplinary resolutions, which complicates how to conceptualize an education for wicked problems.

Transdisciplinary Resolutions to Wicked Problems

Studying complex wicked problems, therefore, poses a challenge to disciplinary approaches to knowledge; in response, *transdisciplinary* approaches "step outside the limiting frames and methods of phenomenon-specific disciplines" (Davis, 2008, p. 55). The transdisciplinary approach mirrors the collective nature of complex problems and values not only the multiplicity of knowledges from different disciplines, but also their fusions (Lawrence, 2008). These fusions help differentiate transdisciplinarity from interdisciplinarity, where multiple disciplines give rise to a new discipline (i.e. biochemistry) with its own new boundaries of inquiry. Transdisciplinarity, in contrast, redraws the boundaries of inquiry (to the extent possible) around the problem itself, to ask what disciplines and their fusions can contribute to addressing and resolving a problem, rather than whether a problem belongs inside a discipline.

For wicked problems where boundaries are elusive (or impossible) to draw, the inquiry process should be inclusive. All knowledges are relevant and applicable to resolving wicked problems, and transdisciplinarity "is created by including the personal, the local and the strategic, as well as specialized contributions to knowledge" (Brown et al., 2010, p. 4). This lack of boundaries is conducive to a *transdisciplinary imagination* (Brown, Harris, & Russell, 2010). In

the transdisciplinary imagination are attempts "to generate fundamentally new conceptual frameworks, hypotheses, theories, models, and methodological applications that *transcend* their disciplinary origins" (Hall et al., 2012, p. 416, emphasis in original).

(Characteristic #4) There is no immediate and no ultimate test of a solution to a wicked problem.

> I think it's interesting that the world measures depression by suicide count. I don't know how accurate I feel that is but it's interesting and I wish that we could change it. *But how do you measure depression? Through chronic, manic, and other forms of breakdown or do we not measure it by severity and simply mush it all together? It's difficult to measure something that can't be seen.* (Beth, Phase 4, Written Reflection, emphasis mine)

Beth summarized how wicked problems change what it means to do problem solving. The choices of what to measure, how, and when, are political and aligned with particular formulations and particular explanations of a wicked problem discrepancy (Best, 2008). Quantitative methods and information cannot provide evidence of improvement on a wicked problem, unless situated within a particular formulation of the problem (cf. Chandler, 2015). Within the boundaries of mathematical problem solving, this deeper consideration of how to engage quantitative methods involves traversing disciplinary boundaries for other information.

(Characteristic #6) Wicked problems do not have an enumerable (or an exhaustively describable) set of possible solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.

> I'm not entirely sure what the plot of the story that I am hoping to tell is but I know *that I want to talk about the collective solution to the problem from multiple sources*. That community awareness, education on certain matters revolving around mental health, and acceptance are the ideal ways to combat more easily preventable mental health problems or at least to lessen the effects of the problem. (Beth, Phase 3, Infographic Check-in, emphasis mine)

This aspect of wicked problems came out the most in a class check-in where I asked students to report the plot of the infographic they were creating for the third phase of the project. There

are no limits on what can be included in resolving a wicked problem, and the acceptance of multiple forms of data and engagement of multiple forms of reasoning across and outside of disciplinary boundaries is central.

(Characteristic #3) Solutions to wicked problems are not true or false, but good or bad.

> I think we can measure improvement with the issue of the lack of diversity by continuing to take data on how diverse film characters are in general. But, by how many women are directing mainstream? People of color? Who are running these networks? Who are writing these shows? Orange is the New Black has one of the most diverse casts on television right now. The writing room is mostly women, but no people of color. Do we chalk this up to a win anyway? (Aisha, Phase 4, Written Reflection)

Aisha's reflection further complexified the relationship between mathematics and statistics as disciplines and the resolution of wicked problems. In particular, she recognized the limitations of mathematics in determining the quality of a solution. The transdisciplinary reasoning emerged from how open problematizing, as Smith (1997) predicted, burst the boundaries of mathematics curriculum.

Obstacles to Reforming Education for Wicked Problem (Re)solving

I conclude this article with an overview of potential problems of practice involved in education for wicked problems. Within broad conceptualizations of instruction and curriculum, I discuss the final two wicked problem characteristics, and sketch how they relate to framing curriculum and instruction in particular ways.

Instruction

Having students do extended, deep inquiry into topics of their choosing – the authentically *open democratic* aspect of wicked problems - changed the ways that I interacted with my students as learners. Across all of my students' projects, their thinking took them into depths of expertise that surpassed my own on their topic. I definitely learned alongside and from

my students as they worked. Besides students' extending expertise on their topics that I did not match before the course started, I also could not keep up intellectually with the cumulative amount of work my students produced. For example, during the media phase of the project students collectively produced analyses on over 100 pieces of media, many of which were lengthy videos or complicated research reports – and each student also produced a synthesis of their (usually five) media sources. In response, I altered the assessment so I would only read and assess one media analysis per student, of their choosing, and each student's media synthesis.

What does it imply about education when students are more expert on the subject of educational inquiry than curriculum designers and teachers? First, my disciplinary knowledge – specifically my mathematical knowledge for teaching, or MKT (Ball, Thames & Phelps, 2008) – was relevant to every project. My cynical perspective on that statement is that I imposed mathematics onto my students' projects. Transdisciplinarity suggests, however, that all forms of knowledges are applicable and relevant to wicked problems (Brown, Deane, Harris, & Russell, 2010). At the same time that my expertise was necessarily limited regarding each of my students' projects, I also could not take a scaffold-and-fade, or "standing to the side," approach to my teacher role (Lampert, 1990; Leinhardt & Steele, 2005), and expect "better" learning, because of another feature of wicked problems.

(Characteristic #5) Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.

> He brings up the fact that there are so many murders in Central America and Mexico and other parts of the world, prisons packed, the global black market is estimated at 3 hundred billion a year, *all due to the war on drugs. Yet more people are using drugs than there ever was before.* (Diana, Phase 2, Media Analysis, emphasis mine)

Diana's analysis of a piece of media reflects something critical about the urgency of these wicked problems. Despite this course being labeled mathematics, many forms of reasoning were salient. Specifically, quantitative methodologists would have very particular and technical strategies for determining the effects of the war on drugs (not the least of which would be formulating what that means). At the same time, there is very serious moral, social, historical, psychological, and intuitive reasoning involved in my students' projects.

From a moral position, not engaging fully and dialogically with my students about their projects was not an option. Each project contributed to the collective planning regarding and resolutions to these wicked problems, and therefore "counted significantly". There is a particular urgency to learning about wicked problems that might be instead reframed as active, collective resolving through partnership.

Open partnership is central in transdisciplinary inquiry. By actively working as partners, we did more to contribute to resolving these wicked problems than we could separately. The position of expert teacher was only partially available to me relative to these problems; the position of expert student was also partially available to the students – and vice versa. For example, during the second week of class, I sat with each student individually during class and we just talked about their goals and initial plans for the project. I made contributions from my different kinds of expertise, my students made contributions from theirs, and students made contributions to each other when they shared their on-going projects. We also made shared contributions through our dialogue.

Curriculum Design

Rittel and Weber (1973/1984) concluded their list of wicked problem characteristics by discussing a fundamental difference between scientific experimentation and social policy-

making. They claimed that the scientist's ethical commitment is to the process and scientists are not responsible for their hypothesis being refuted. In contrast, people planning resolutions to wicked problems do not have the luxury of relinquishing responsibility. Wicked problems affect people directly and deeply, and despite being resistant to resolution, especially sustained resolution, inaction is unacceptable. Further, when actions are found not to help or even exacerbate wicked problems, planners are accountable.

(Characteristic #10) The planner has no right to be wrong.

> …In 2014 it is estimated that at least 6,800 overdose deaths occurred in the European Union. In Oceania, which includes Australia and New Zealand, there were 1,700 and 2,100 drug related deaths in 2013. In Scotland there were 613 drug related deaths in 2014. In South America, the Caribbean and Central America reported between 4,900 and 10,900 drug related deaths in 2013. In the United States, overdose deaths from opioids, including prescription opioids and heroin, have nearly quadrupled since 1999. Overdoses involving opioids killed more than 28,000 people in 2014. During 2014, a total of 47,055 drug overdose deaths occurred in the United States. *These statistics make it known that the use of drugs is a very serious issue that needs to be fixed somehow***.** (Diana, Phase 2, Media Synthesis, emphasis mine)

Diana's project on the opioid epidemic developed out of her hometown struggling with drug addiction. Although Diana herself formulated the problem in a particular way with a particular resolution – "our drug policies care more about criminalization over health and this has to be changed" (Diana, Phase 2, Media Analysis) – she explicitly noted the seriousness, urgency, and responsibility for policy planners to act.

That wicked problems theory emerged from design theory is ironically suitable to thinking about curriculum design. Intuitively, I think designing curriculum is also a wicked problem, involving reactive, complex, and transdisciplinary *students* (not problems) – and mutually constitutive with reactive, complex, and transdisciplinary social institutions. What right do we have to be wrong about education? In other words, we share responsibility for the social problems caused by and embedded in how schools, curricula, assessments, and teaching are

designed and planned (Butin, 2002). Is one way we are currently wrong that, although some argue we prepare students to be wicked problem resolvers, we still generally avoid these problems during schooling? For instance, wicked problems are not explicitly part of the Common Core State Standards, which Porter, McMaken, Hwang, and Yang (2011) argued represents "the New U.S. Intended Curriculum" (p. 103).

These wicked problems facing the world are staggering in scope, and elusive (Peterson, 2016). Nearly two decades ago, education for wicked problems was "taken seriously by no one, even if they are included with some regularity in official curriculum documents" (Parker, Ninomiya, & Cogan, 1999, p. 119). Serious consideration of these wicked problems as justifiable school curriculum remains uncommon. Despite the apparent scope and potential urgency of these wicked problems, curriculum discussions remain much the same as they were when:

> Chief among these marginalized goals is civic education of a global kind---education for shared problem solving on messy international problems and, thereby, the cultivation of a global perspective on such problems. (Parker, Ninomiya, & Cogan, 1999, p. 119)

What would it take to do this – to organize education around constantly working to resolve wicked problems? Open inquiry on wicked problems seems to run counter to the role of curriculum as directing inquiry. Specifically, open transdisciplinary inquiry challenges both the disciplinary organization of curriculum domains (i.e. mathematics, history, etc.) and the specialization of curricula within those domains (algebra, geometry, etc.). The wicked problems that are at the center of transdisciplinary inquiry require imaginative approaches because they cannot be (or at least, have not been) solved by any singular disciplinary techniques (Brown, Deane, Harris, & Russell, 2010).

That wicked problems are likely not resolvable through disciplinary technique does not mean disciplinary knowledges and techniques have no role – quite the contrary in open

transdisciplinary inquiry. Nevertheless, that disciplines are necessary but not sufficient creates issues. As Morrison (2008) asked: "how can freedom, diversity, autonomy and choice be exercised within centrally-prescribed curricula" (p. 20)? Ladson-Billings (2016) suggested one approach for education researchers:

> Perhaps the real future of the curriculum among education researchers will be to defend the right for the curriculum to be fluid and changing rather than fixed and rigid. (p. 104)

I would suggest that something like a *Wicked Problems Curriculum* might be one of those fluid and changing curricula, if it involves openness, engaging complexity, and transdisciplinary thinking.

CHAPTER SIX:

THE POSSIBILITIES TURN AND THE EDUCATIONAL GAME WE PLAY SO SERIOUSLY

> Democracy and democratic education are founded on faith in [people], on the belief that they not only can but should discuss the problems of their country, of their continent, their world, their work, the problems of democracy itself. Education is an act of love, and thus an act of courage. It cannot fear the analysis of reality or, under pain of revealing itself as a farce, avoid creative discussion. (Freire, 1974, p. 34)

This excerpt from Paulo Freire's *Education for Critical Consciousness* is one of my favorite quotes on education, and it has been incredibly influential to how I conceive of my work. I envision schools being places where people come together to discuss authentic and serious problems, and come to understand realities within the world through the relationships they develop. To me, that he ends the excerpt by attending to creativity implies something about the relationship between education and reality. Specifically, something I would like to append onto his words: that education cannot fear the possibilities of fantasy.

In the chapter I recapitulate what I did in my dissertation. I also synthesize what I have done and revisit some of my theoretical work – most notably my social theory of quantitative literacy. I also use my dissertation to talk back to mathematics education as a whole, including research, and try to make some new connections about what is and could be happening, that I call the *possibilities turn*.

Revisiting My Dissertation

This dissertation is centered on the three articles in chapters three (p. 45), four (p. 68), and five (p. 96) which focus on different aspects of my experiences the past three years designing, implementing, and studying two new courses in quantitative literacy (QL). In chapter three, I historicized the numeracy discourse through genealogy to explore the promises scholars have embedded into that discourse and consider whether or not these promises might be myths.

In chapter four, I reported one result from my ongoing practitioner inquiry across and between my different roles relative to these courses. I attempted a critical postmodern self-critique of whether I was complicit in creating courses that dehumanized my students and how that dehumanization might have been countered with my students through humanizing each other. In chapter five, I shared another result of that practitioner inquiry, wherein I used wicked problems theory to code my students' projects. Out of that coding, I emerged with three salient themes: open democratic education, complexity, and transdisciplinarity. In this conclusion, I revisit those chapters with another round of self-critique, considering more explicitly the limitations and questions of what I have written in them. In order to reframe my study, I first introduce another part of my emerging fantasy conceptual framework (Craig, this dissertation, chapter four): gaming.

The Educational Game We Play So Seriously

At my first-ever meeting of the *Mathematics Education and Society* conference, I had the privilege of sharing session time with Dr. Gregory Larnell, who also co-facilitated the working group I attended each day of the conference. In his presentation, he used the concept of the "cooling out" phenomenon in education, abbreviated COPE (Larnell, 2017). He argued that the COPE concept illustrated the way institutions and people within them may do similar actions to those perpetuated by street hustlers. He highlighted the idea that COPE describes some of the patterned ways students are pushed away from mathematics during the transitions between courses (Larnell, 2017, p. 654). The gaming metaphors involved in his conceptual framework resonated with me very loudly, so I was thrilled when we sat for lunch together afterwards.

During that conversation, I told him about my still developing dissertation thoughts and how difficult a time I was having communicating what I was learning through my analyses and

study. I told him that I could not say enough about how well his conceptual framing of his work helped me understand what he was trying to say. We began talking about games, and how interesting it is that in THE GAME OF LIFE, a popular board game, players start the game by choosing whether or not to go to college. We discussed how that mirrored real life situations, and how it oversimplified them. We also talked about how we had experienced advice such as "you gotta play the game" with regards to education.

I have not stopped thinking about Dr. Larnell's presentation and our conversation. In fact, I would argue those experiences have helped give me the courage to explore unusual conceptual language when I try to communicate about complex ideas in order to destabilize the commonplace. Although I was already approaching my dissertation from a critical postmodern theoretical perspective through which critique and deconstruction were central, I could not find language to describe what I was doing, thinking, and learning. It was not until after this conference that I realized I already had the language; I just did not yet consider it suitable for academia.

The Language of Fantasy Games

The language that helps me describe what I was doing, thinking, and learning is fantasy, the possibilities of which I explored to an extent in chapter four of this dissertation. In that chapter, I unpacked how the conceptual language of fantasy, and a particular concept from fantasy literature – Harry Potter universe creator, J.K. Rowling's *horcrux* - helped me make sense of my experiences. In this section, I discuss another part of the fantasy genre, online fantasy games, which I also consider for possible productive language to describe aspects of education.

Online fantasy games often involve the creation of worlds. One (hopefully) upcoming game, *Star Citizen*, is a famous game literally set in intergalactic space, meant to be an entire galaxy and even universe. *EVE Online* is a long-running exemplar of a space game with a full universe. Although not always set in space, many other Massively Multiplayer Online Role Playing Games (MMORPGs) involve the co-habitation of a universe by many players, for example *World of Warcraft*. Oftentimes, thousands of players simultaneously live in and interact with each other and with the game universe.

It has not gone unnoticed by education scholars that these games involve the creation of dynamic universes that in some ways mirror the physical world we inhabit. Some education scholars have done considerable work on how to *gamify* education. The *gamification* of education refers to the conversion of education into a game-based environment, through "the use of game design elements and game mechanics" (Domínguez et al., 2013, p. 380). Much of the motivation to gamify education comes from an expectation that the immense learning people do when immersed in gaming environments might be reproduced intentionally, and redirected toward the goals of schooling (de Castell & Jenson, 2003); that is, the idea of gamifying education rests on a hope to "harness the power of games in education" (Squire & Jenkins, 2003, p. 1).

The premise behind scholars' attempts to gamify education is that games have an immersive environment in which meaningful learning occurs. The process to gamify education involves mapping the qualities of game environments onto real-world schooling environments, with appropriate translations and restrictions. Education is to remain, however, not a game, lest it be exposed as casual or even farcical. Nevertheless, the "education as game" metaphor is prevalent. In my life, I have been told something akin to "just play the game" or "gotta play the

game to change it" many, many times. The fundamental idea is that the *rules* that construct school, work, and societal relationships are arbitrary and questionable. Nevertheless, if you want to achieve within the system, you need to follow the rules – play the game – or you will fail to succeed. My issue with using this logic is that I think it often defines success using the very rules being scrutinized or dismissed as arbitrary.

Sociopolitical perspectives (e.g. Valero, 2004) nevertheless illustrate how the rules of the educational game are not arbitrary. Educators purposefully choose how to organize education through a confluence of philosophies, theories, practice, research, and policy. One dominant organizational rule in education is that school is to be split into disciplines. Within each discipline, students learn specialized tools for inquiry that provide different claims, evidence, and arguments. That organizational rule provides a challenging environment for QL and other educational ideas that transgress disciplinary boundaries because they are concerned with social life, where those boundaries are often blurred.

As a result, I think it is important to revisit the social theory of QL specifically with an asset-oriented perspective. I frame the idea that quantitative literacy and other literacies (literacy, digital literacy, information literacy, mathematical literacy, statistical literacy, science literacy, et cetera) together form a complex *constellation of literacies* that are always present, because social life involves complex wicked problems that are transdisciplinary.

Quantitative Literacy among a Constellation of Literacies

In my second chapter, I developed and discussed my overarching theoretical framework for QL, a *social theory of quantitative literacy*. To do so, I translated one social theory of literacy (Barton & Hamilton, 2000) into my more familiar QL related language. In this section, I revisit

that social theory to conceptualize *literacy constellation events* as events mediated by multiple considerations.

By revisiting my social theory of quantitative literacy, I think I can take my dissertation and speak back to (mathematics) educators in three ways. The first way is by redrawing the mathematics disciplinary boundary through questioning the isolated prominence of mathematics. Many mathematics educators have engaged this work by attempting to broaden what counts as "mathematical;" for instance, ethnomathematics (e.g. d'Ambrosio, 1985) has pushed us to introspect on the imperialist history of narrowing what is mathematics to exclude plural forms. I think this work is incredibly valuable, but constrained within disciplinary thinking that has itself imperialist history. Instead, I would have us move toward transdisciplinary thinking, where we work from perspectives of unification and inclusivity by disassembling established boundaries and refusing to reassemble them. To that end, I do not consider the QL course I have taught to be mathematics, nor do I consider this work on QL as situated within any boundary of mathematics education scholarship.

The second way this dissertation might speak back to mathematics educators is through the idea of complicity. In my first two articles, I explored the potentially mythical status of numeracy and of the quantitative reasoner. My purpose in doing so was not to counter scholarship in these domains, but to illustrate how we are complicit in creating the problems we then look to solve. Paulos (1989) published innumeracy with essentially no citations, sometimes committing the very "quantitative fallacies" he claimed others committed. That does not make him wrong, but it is important to wonder how his work contributed to an accumulation of educational peril and decline narratives in the 1980s and 1990s in the United States, which culminated in creating many of the problems we now face. We are certainly creating, or

sustaining, those problems now through a hyper focus on problems – which we freely define and therefore never exhaust. But we are then complicit when the educational reform discourse sees schools as failing, teachers as incompetent, students (millennials and thereafter) as lazy or entitled, and researchers as elitist.

Finally, I hope this dissertation springboards further work around fantasy in education. I think that *we can and should fantasize about education* and that *parts of education are already fantasy.* These two ideas combine to blur the boundary between fantasy and reality in education. Juxtaposing education and fantasy has helped me understand how our individual and collective imaginations about the world come to shape what happens within it. From my perspective, we (education scholars) spend an inordinate amount of time focused on what is, and not enough time focused on what could be. I think fantasy can offer scholars productive language to find relief from seeking redress to injustices within an unjust system, and instead fantasize about full alternatives and what it might take to realize those fantasies. For example, the injustices surrounding algebra's college and career gatekeeping role likely cannot be fully addressed while mathematics education remains organized around a linear, building blocks course structure; I think we need to fantasize about full alternatives and act towards those ends, instead.

Ultimately, I feel discomfort attempting to speak back to mathematics educators because I cannot predict nor control others' reactions to my work. My concluding chapters, therefore, focus primarily on speaking back to my own dissertation. I speak back to each of my four body chapters (methods and the three articles) and use that work to launch into my more recent thinking. I start by revisiting the social theories of literacy and QL.

Revisiting the Social Theory of Literacy

The process of doing my dissertation is not disconnected from my other experiences, both inside and outside of graduate school. My comprehensive exam paper, for example, focused on what the New Literacies Theory (Leu et al., 2013) might contribute to thinking about quantitative literacy. Through that work, I commented on the potential to thinking about quantitative literacy in: a dynamic way that keeps it changing along with a changing world, a critical way that keeps it tethered to morality and ethics, and a dispositional way that has major implications for pedagogy and curriculum (Craig, 2016). At the time I wrote that paper, I was deciding between anchoring it in the New Literacies Theory or multiliteracies (e.g. Street, 1985; 1995; 2003; 2016). Although different in their approaches, both help represent the influence of social theory on literacy studies. Social theories of literacy often involve reconceptualizing literacy as a set of practices people engage when interacting with text (Barton & Hamilton, 2000). These theories can flip the directionality of determining what counts as "literacy;" whereas predecessors may have defined literacy before their study, and used that definition to assess who are literate, social theorists on literacy proposed to allow multiple forms of literacy (or literacies) to emerge organically within the ways different people interacted with different texts across different spaces.

If literacies are those social practices inferred from people interacting with texts, the idea of circumscribing a boundary around literacy becomes more challenging. The a priori defining of literacy draws a strict border between who is literate and who is not, by prescribing which practices constitute literacy and which do not. In contrast, a social theory of literacy admits that defining literacy rigidly involves a particular exercise of power, and allows the set of all social practices mediated by text to be literacies. As a result, people sending text messages (txt msgs)

are doing a literacy practice; people making graffiti are doing a literacy practice; people writing academic theses are doing a literacy practice. Those practices are localized and tethered to the text events during which they emerge.

As text permeates most of our environment, the question of what is *not* literacy becomes salient. At a colleague's, Dr. Rohit Mehta's, recent dissertation defense (Mehta, 2017), this question circulated among the audience and we all seemed to struggle to bound literacy. The problem is compounded by this Dr. Mehta's (and my) choice to adopt a wide vision on what constitutes "text," as well. From my perspective, texts are not limited to written alphanumeric symbols, but also include verbal speech, drawing, graphical representations, and audiovisual productions, among others. Given that any social practiced patterned within interactions with text are literacies, and any social creation that involves symbolic representation is text, it seems reasonable to say that everything is literacy. Of course, this position is somewhat untenable, because literacy has the potential to become too nebulous to discuss meaningfully. This same issue arises with other concepts in education and social science research, such as: discourse, politics, ethics, teaching, and learning.

One approach to this issue is to reverse some of our theoretical positions and draw rigid boundaries. For example, Barton & Hamilton (2000) very explicitly define texts to be written alphanumeric symbols. There are serious benefits to drawing these boundaries in terms of research, evidence, and claims. Literacy events, for Barton and Hamilton, become precisely those events mediated by written alphanumeric symbols; in turn, literacy practices become precisely those social practices patterned within those literacy events. This has the satisfying result of circumscribing a particular methodological focus and adds clarity to evidence and claims made about literacy practices. At the same time, I am dissatisfied by this rigid boundary.

Important social practices seem also to occur during interactions with oral speech (i.e. music, conversation), non-alphanumeric texts (i.e. gender symbols, religious iconography), and different representations (i.e. drawings, graphs). In addition to events being mediated by things other than text, there are also those events that may be one event removed from text (such as a book club or discussing a piece of news) or texts one event removed from non-texts (such as blogging about a movie or commenting on a YouTube video). Maybe "what counts as literacy?" is an irresolvable question.

I propose an alternative question, however. Instead of thinking about *what* is literacy, maybe we can think about *when*. Specifically, rather than framing the position as "everything is literacy", we can consider the possibility that "literacy is always involved." Perhaps simply a semantic shift to some, for me this change refocuses my attention. When I take the "everything is literacy" position, I feel overwhelmed to describe what I mean; in contrast, when I take "literacy is always involved" as my position, I immediately consider different questions, such as: how important is literacy to this event?, what else is central to people interacting in this event?, and how do literacies ebb and flow throughout people's social practices during the progression and overlap of events?

Quantitative literacy as always involved. Despite my critical deconstruction of the concepts of quantitative literacy, numeracy, and quantitative reasoners in this dissertation, I remain an advocate for quantitative literacy as a worthy goal for (mathematics) education. The reason for my advocacy comes out of a reframing of chapter four, where I argued that the course acted like a horcrux that sundered and isolated the quantitative reasoner from the rest of the human reasoner. In that article, my tone was meant to complicate the ways that mathematics education acts to focus only on quantitative reasoning at the expense of complex and

simultaneous reasoning. By revisiting my three articles, I want to consider another potential implication.

Chapter three: myths as partial truths. In chapter three, I historicized the numeracy discourse and the promises scholars make within it, to expose how we may be complicit in developing a myth about the power of mathematics to overcome and prevent social problems. As Graff (1979, 2010) discussed, however, myths are partial truths. I think this has a critical implication that is perhaps a more charitable or accurate reading of what scholars really intended to say about numeracy. That implication is that numeracy has an omnipresent potential; that is, engaging particular numeracy practices generates knowledges and information about social problems, and suggests things about their resolution. For instance, I want to once again take seriously the idea that numeracy can *empower*.

In the genealogical tone I tried to use, I sought to take the idea that numerate people are empowered and destabilize it through repeated focus. I hoped to unsettle the idea that numeracy can empower in a savior-like way wherein a "vulnerable" (Steen, 1997, p. xv) innumerate person can overcome injustices by becoming numerate, because interlocking systems of oppression (e.g. Hooks, 1992) are wicked and reactive. For example, during a visit to MSU Dr. Danny Martin posed a thought experiment to the group of graduate students meeting with him. He asked us to imagine for a moment that STEM outreach programs succeeded in making everyone proficient in engineering, what would change? During the thought experiment, we discussed how wages for engineers – a highly paid profession - would decline. We came to this conclusion by understanding the mathematics of supply and demand in a capitalist-organized society. In this way, the thought experiment was a *quantitative literacy event.* At the same time, while considering the thought experiment Dr. Martin proposed you might think about morality,

science, technology, education, and politics, among others – a constellation of ideas. In this way, his thought experiment reflects what I am thinking about as a *literacy constellation event*.

Chapter four: remaking a real quantitative reasoner. That you might think about a variety of different issues, suggests that this thought experiment is not only a quantitative literacy event, other literacies or knowledges are relevant and important. At the same time, it is a quantitative literacy event, too – and importantly so. By engaging in particular ways with mathematics, we could understand the thought experiment and imagine economic changes that might result. Without engaging that mathematical, economic thinking, it may be easier to subscribe to higher mathematics achievement as necessarily causally linked to higher wages – thereby missing the complexity and reactivity of wages in modern capitalist society.

As a result, I think it is critical to reconsider how quantitative reasoning interacts with other forms of human reasoning. Specifically, wherein chapter four I argued that we ought to complexify the quantitative reasoner by reconnecting it to other forms of reasoning, I think it is also critical to think about the reasons why people might sunder, or ignore, their quantitative reasoning. That this thought experiment is also a literacy constellation event does not make it any less of a quantitative literacy event, and *not* engaging quantitative reasoning seems to constrain possibilities for thinking in a similar way that *only* engaging quantitative reasoning would.

Chapter five: wicked problems and shared expertise. It seems unlikely that mathematics education will successfully prepare everyone to be professional engineers. Given that, how might mathematics and statistics experts interact with those who are not as expert? I think this question suggests something about the relationship between specialists and generalists. In the recent past in the United States, we seem to be celebrating specialization over becoming a

generalist, which complicates the endeavor of talking across and with multiple forms of expertise.

Transdisciplinary education might include some focus on the idea that people might dabble in many ways of thinking, including how different ways of thinking might be related or come together in complex ways. Some educational theorists have considered the implications of complexity theory for education (Davis & Sumara, 2006; Mason, 2008; Morrison, 2008). They suggested that being able to talk across complexity is an important reaction to the emergence of complex problems and complexity theory. The set of authors who contributed to the book *Tackling Wicked Problems* (Brown, Harris, & Russell, 2010) suggested that serious imagination is necessary to do the work of talking across disciplinary structures. In response to that call for imagination, I return to the fantasy gaming genre to develop metaphors for two educational philosophies that interact with transdisciplinary and complexity in different ways.

Educational Metaphors in MMORPGs

In this section, I return to fantasizing about education in order to think further about what transdisciplinary education for wicked problems might involve. Specifically, I apply two metaphors from MMORPGs to education, and freely speculate and construct a working version of two corresponding educational philosophies. There are two popular metaphors for MMORPG universes: theme park and sandbox. The *theme park* game metaphor is the idea that every player in the game (theme park-goer) pays to have the same experience (i.e. *World of Warcraft*). The role of theme park game designers, therefore, is to fill the game with precisely planned experiences that optimizes (meaning, maximizes) the average gamer experiences. The *sandbox* game metaphor connotes the idea that ultimately the player will have more fun if they have a constitutive role in the universe surrounding them (i.e. EVE Online). The role of sandbox game

designers, therefore, is to fill the game with conditions that encourage meaningful player interaction, so each gamer has different, but hypothetically better, experiences than those that could be planned. Most, if not all, MMORPGs have aspects of both theme parks and sandboxes, but usually pretty clearly align with one over the other. Hybrid games are sometimes referred to as *sandparks*.

On a Reddit thread, a user asked, "I've never heard the term theme park MMO, what is it?" (Binch101, 2017, unpublished). As of June 4, 2017, the thread has 28 comments before being removed by a Reddit algorithm. The comments, in a very metamodern fashion, define, redefine, and blur the boundary between these two game metaphors. One user, Havesh, had the most up-voted comment:

> Theme Park MMORPGs are very designed experiences, where there is content designed to be consumed. Sandbox MMORPGs are generally a bunch of features that are thrown to the players to peruse and create content for each other with (usually through conflict). In short: In Theme Parks, the dungeons, bosses battlegrounds and raids are the content, in Sandboxes, other players are the content. (Havesh, 2017, unpublished)

I use Havesh's descriptions to frame *theme park* and *sandbox* as metaphors for different philosophies of education.

A Theme Park Educational Philosophy

A theme park educational philosophy is focused on the establishment and achievement of legitimate educational goals that are applicable and valuable to every individual, and to collective society. These educational goals are often associated with a prized western scientific rationalism. For the theme park educational philosopher, what is good for one person is good for all, and the task is to determine what those goods are.

The theme park curriculum designer's goal is to create a curriculum that "optimizes learning," which in educational terms can be understood as a multivariable function of: useful,

engaging, efficient, and rigorous. The primary obstacle of the theme park curriculum designer is quality assurance. The rides (courses, units, lessons, activities) that the theme park curriculum designer builds must be consistent, steady, and precise.

Every bolt on every ride concerns those who maintain the theme park rides, as every moment of classroom time for every student concerns the teacher. If a single bolt fails, the entire ride is at stake. Of course, the engineering principle of redundancy applies: if a single bolt fails, there are other bolts meant to fill in while the bolt is repaired or replaced. For theme park teachers, these redundancies take the form of practice and review. Teaching is very systematic, and expert teachers are those who can enact that system (e.g. Stigler & Hiebert, 2009). Theme park teachers construct scripted lesson plans, and the quality of their enactment can be measured as how closely those lessons went to plan. Classroom management, discipline, and focus are critical to sticking to the script.

A theme park educational philosophy seems central in the movements for national standards and the discourses of teacher accountability. I would argue it is also salient in dominant equity discourses, where access and standardized achievement is of primary concern (e.g. Martin, 2003). The primary goal is to get every single student to achieve a certain level of learning in well-established directions that are often considered to be unanimously agreed upon. The theme park educational researcher is concerned by dropout, achievement decline, achievement gaps, misconceptions, and creating acceptably rigorous standards. In some ways, the theme park educational researcher studies along what Gutierrez (2003) called the *dominant axis* which includes access and achievement as primary foci (whereas the *critical axis* involves identity and power). They study how to mitigate these issues, and more efficiently achieve the certain level of learning, so that raising that level can come under consideration.

A Sandbox Educational Philosophy

A sandbox educational philosophy involves recognizing a plurality of educational possibilities and worthy goals, and the fundamental uniqueness of the human person and their knowledges (see Fasheh, 2015, for a description of a mindprint that is analogous to a thumbprint). For the sandbox educational philosopher, this uniqueness is an undeniable fact. For the sandbox curriculum designer, the classroom environment is critical. Designing a flexible, responsive curriculum in which students can explore and discover is paramount. The sandbox must be filled by material with which, and around which, students and teachers will interact to create both the expected and unexpected.

For sandbox teachers, the unexpected moment is a treasure. Their premise is that those unplanned moments offer unique, and better, opportunities to learn and grow, in unexpected but nevertheless valuable, ways. Those unplanned moments may be facilitated by a rich learning environment, that is a high quality sandbox, but are contingent on the qualities of the relationships among teachers and students. Dignity, love, trust, and closeness inspire unplanned moments where collective growth can happen which is un-scriptable.

As an educational philosophy, sandbox curriculum and instruction is central in work on play in elementary education (e.g. Wager & Parks, 2014) and in educational freedom (e.g. Rogers, 1969). It is also salient in some curriculum theories, such as curriculum integration, where co-constructed emergence around themes is a curricular perspective (e.g. Beane, 2016). The primary goal is to have every student become a more full self, and to develop symbiotic social relationships for learning. The sandbox educational researcher is concerned by standardization and narrowly constructed assessment, teacher deprofessionalization, the enactment of educational injustices through false consensus, unworthy educational goals. They

study how the educational institution perpetuates inequities – for example the myth of meritocracy, how teachers can differentiate instruction toward plural goals,

Reflection: Dewey, the Child, and the Curriculum

Both of these metaphors can only go so far. The classroom is not a theme park or a sandbox, and it cannot be either. Nevertheless, the fantasy gaming genre offers another perspective on education, and language to describe it anew. I find it offers me a language for a contemporary form of a problem John Dewey (1902) described:

> It is easier to see the conditions in their separateness, to insist upon one at the expense of the other, to make antagonists of them, than to discover a reality to which each belongs. The easy thing is to seize upon something in the nature of the child, or upon something in the developed consciousness of the adult, and insist upon that as the key to the whole problem. When this happens a really serious practical problem—that of interaction—is transformed into an unreal, and hence insoluble, theoretic problem. Instead of seeing the educative steadily and as a whole, we see conflicting terms. We get the case of the child vs. the curriculum; of the individual nature vs. social culture. Below all other divisions in pedagogic opinion lies this opposition. (p. 340)

To what extent are we dealing with a similar competition to the ones Dewey identified? Is there a contemporary competition, this time, organized around theme park vs. sandbox educational philosophies? Pais, Stentoft, and Valero (2010) framed a sociopolitical turn in mathematics education, that feels similar to me, when they argued for a move from "primarily questions of *how* to improve possibilities for teaching and learning mathematics, towards a research agenda strongly concerned with addressing the question of *why* mathematics education" (p. 398, emphasis in original). In other words, they argued for a move away from researchers maintaining the theme park mathematics educational rides that we currently have, and toward considering alternatives to those rides.

For sandbox educational philosophers, the work to maintain the mathematics education institution as it stands is counterproductive to liberatory change. Tolstoy (1860/1911) wrote about this problem 150 years ago:

> Don't be afraid! There will be Latin and rhetoric, and they will exist in another hundred years, simply because the medicine is bought, so we must drink it (as a patient said). I doubt whether the thoughts which I have expressed perhaps indistinctly, awkwardly, inconclusively, will become generally accepted in another hundred years; it is not likely that within a hundred years all those ready-made institutions-schools, gymnasia, and universities -- will die, and that within that time there will grow freely formed institutions, having for their basis the freedom of the learning generation.

Tolstoy (1860/1911) identified the powerful institutional inertia that works to constrain future possibilities for organizing school in radically different ways.

Theme Parks, Sandboxes, and John Dewey

At present, I find myself to be fairly significantly a sandbox educational philosopher. I am troubled by the way the theme park we have currently built is still centered on the idea that we should plan to make children into adults. As Dewey (1902) in *The Child and The Curriculum* wrote:

> Upon the whole, it was the weakness of the "old education" that it made invidious comparisons between the immaturity of the child and the maturity of the adult, regarding the former as something to be got away from as soon as possible and as much as possible. (pp. 346-347)

He went on to write:

> Once more, the "old education" tended to ignore the dynamic quality, the developing force inherent in the child's present experience, and therefore to assume that direction and control were just matters of arbitrarily putting the child in a given path and compelling him to walk there (p. 348)

These two Dewey quotes both seem to me to describe a theme park educational philosophy, wherein children are put on paths that take them from childhood into adulthood (Parks, 2010).

What Dewey (1902) referred to as “old education,” he contrasted against a “new education” perspective that had its own problems:

> So it is the danger of the "new education" that it regards the child's present powers and interests as something finally significant in themselves. In truth, his learnings and achievements are fluid and moving. They change from day to day and from hour to hour. (p. 347)

He went on to write:

> This "new education" is in danger of taking the idea of development in altogether too formal and empty a way. The child is expected to "develop" this or that fact or truth out of his own mind. He is told to think things out, or work things out for himself, without being supplied any of the environing conditions which are requisite to start and guide thought. (pp. 348-349)

Whereas the theme park “old education” was too rigidly directed, Dewey constructed an image of “new education” which was too loose and directionless. He argued in *The Child and The Curriculum* that adherents of both the old and new educational philosophies misrepresented the other. As a middle ground, which he argued also more realistically represented what each group championed, the child and the curriculum were reciprocally related. The curriculum was not so rigid as to be unresponsive to the individual classroom full of individual children, from whose experiences and curiosity, a unique path of learning might arise. Similarly, the child was not left to their own devices, as the curriculum and teacher combined to move individual children toward overarching educational goals, what he called learning in an *educative* direction.

Ultimately, I find our current realities suitable to rethinking Dewey’s compromise between the child and the curriculum, in the form of a new compromise between the theme park and the sandbox, which because of the digital age, is much more heavily weighted towards a sandbox. I imagine the impetus for this shifted comprise to be fairly straightforward: because of the internet, many of the rides we maintain in our theme park schools are not nearly as good as those accessible online. The historical facts, the mathematical techniques, the canon literature,

and the scientific discoveries, are all available digitally – and in many forms. Additionally, if theme park educators are concerned with speed and efficiency, the relationship of one teacher to many students cannot compete with the qualities of what I call *digital knowledge material* (Craig, Appendix F).

The compromise, therefore, relies on a collective acknowledgement of the unsuitability of curriculum and instruction that meant to be stabilized and finalized, and that rests on improving how we enact schooling now: in disciplinary silos, with national standards for all children, and a hope to mass produce the same kind of adult regardless of who the child originally was. In contrast, the possibilities for schooling should be opened up in the digital age.

I believe that these possibilities can be partially realized by thinking about educational content and goals that are transdisciplinary, complex, wicked and incomplete, personalized, pluralized, and unstable (Craig, chapter five, this dissertation, p. 96). Educational ideas that traverse disciplinary boundaries, like a complex quantitative literacy, can become fluid, responsive educational goals. Educational content can become things like politics, love, life, philosophy, civics, environment, and relationships. Education from this sandbox-y perspective involves a serious reorganization around generalist, exploratory, and unfinished subjects and goals, rather than around specialist, prescribed, and stable disciplines.

An Emerging Possibilities Turn

> With this last bit of advice we invite you to read on and enjoy a "world" where the fantastic is fact and magic really works!
>
> –Gary Gygax, Co-creator of Dungeons and Dragons, 1973

In this conclusion, I have so far done five things: (1) I introduced my conception of the metamodern aesthetic and connected it with my positionality as a millennial; (2) I used my metamodern millennial position to re-explore the epistemological stance I took toward research

as a knowledge production process in a digital age; (3) I argued that digital knowledge material (DKM) can democratize knowledge production and sharing in ways that offer possibilities for a radically different educational system; (4) I used two gaming metaphors, theme park and sandbox, to explore new language to describe two contemporary philosophies of education; (5) I looked to Dewey for an analogous historical account of two similar philosophies of education, and for advice on how to resolve their conflict.

I concluded by arguing that contemporary society is being reorganized around DKM, which frees educationalists not to simply theorize about a radically different educational system, but find legitimate space and leverage to begin enacting such a system. I want to finish this conclusion, and this dissertation, by thinking once more about my experiences as a researcher and teacher in contemporary times. Specifically, I offer a reflection on how my experiences and roles as a teacher and curriculum designer, might be reconsidered in a sandbox environment, again taking my inspiration from gaming.

Teachers as (Loving) Dungeon Masters

How would the teacher's roles change in this sandbox environment? What are the student's roles in this environment? In order to begin considering those questions, I want to return to the idea of the educational game, this time focused on a sandbox teacher in the digital age. The famous game *Dungeons and Dragons* involves the co-construction of a universe. Although there is a primary guide, the *dungeon master* (DM) – every player is irreplaceable in creating the world in which the game is played. In a very serious way, creating the world *is* the game. My favorite description of *Dungeons and Dragons* is as collaborative storytelling.

I find the DM to be a suitable metaphorical repositioning of a teacher (Garcia, 2016). The *Dungeons and Dragons Fifth Edition Dungeon Master Guide* authors listed six primary roles for

the DM: “inventing, writing, storytelling, improvising, acting, refereeing – every DM handles these roles differently, and you’ll probably enjoy some more than others” (Crawford, Perkins, & Wyatt, 2014, p. 4). The sandbox teacher-as-DM takes on all of these roles. The acts of balancing all the DM roles is something of an art, which ties back to Dewey thinking about “art as experience,” a position that Eisner (1994) interpreted:

> Teaching can be done as badly as anything else. It can be wooden, mechanical, mindless, and wholly unimaginative. But when it is sensitive, intelligent, and creative-those qualities that confer upon it the status of an art-it should, in my view, not be regarded, as it so often is by some, as an expression of unfathomable talent or luck but as an example of humans exercising the highest levels of their intelligence. (p. 156)

These artistic DM roles are dynamic, involving minute-to-minute action, serious planning, developing expertise and choosing how to exercise it, and they are meaningful only when in concert with the adventurers (players). The DM uses a self- or more often other-written campaign, an adventure guide, which, in my experience, loses quality when the DM adheres to it too strictly. The relationship between the DM and the campaign writer is similar to the relationship between teachers and curriculum designers.

Curriculum Designers as Campaign Writers and Rules Creators

> The D&D rules help you and the other players have a good time, but the rules aren't in charge. You're the DM, and you are in charge of the game. That said, your goal isn't to slaughter the adventurers but to create a campaign world that revolves around their actions and decisions, and to keep your players coming back for more! If you're lucky, the events of your campaign will echo in the memories of your players long after the final game session is concluded. (Crawford, Perkins, & Wyatt, 2014, p. 4)

In my limited experiences as a DM, I personally have never written a campaign, and I generally follow the rules outlined by the game creators. In contrast, I have taught two courses that I was heavily involved in creating. I expect that the experiences are fairly analogous. We had to plan what we wanted to happen with (and to a lesser extent, to) our students. We had to map out learning goals that made sense and were meaningful. We had to (and still have to) create a curriculum guide (like the DM guide) that provided enough guidance for incoming teachers not involved in creating the adventure.

Final Thoughts: The Politics of Urgency and Taking the Game Less Seriously

In this dissertation, I have participated in what has been called "the politics of urgency" (e.g. Medd & Marvin, 2005). In education, Michelle Fine (2000) discussed how the politics of urgency has contributed to the consistent re-marginalization of those students for whom urgent action is argued necessary. The *politics of urgency* refers to how what might be labeled as urgent problems are nevertheless socially framed, and therefore politically framed. The politics of urgency is involved in framing problems and their resolutions, for example the choice to frame students not graduating from high school as "drop-out" or "push-out."

I have framed the problems of my dissertation in particular ways. From myths, to fantasies, to wicked problems – I have participated in the academic discourse of arguing to establish truths from which action should be taken. I think there are compelling reasons to take particular actions, for instance to work hard to reorganize schooling experiences around not only vertical disciplinary learning, but horizontal transdisciplinary learning. At the same time, I am cognizant of how any kind of reform movement likely involves what Derrick Bell (1980) called *interest convergence* – the idea that a coalition of support that results in reform will almost

certainly enact more faithfully some members' reform visions than others' (e.g. Apple, 1992a; 1992b; Romberg, 1992).

I have come to think that this tension between hesitancy and action is good. I find thinking about the ways that my actions are complicit in causing some injustices, yet my inactions are complicit in perpetuating others, to be very useful when I am making decisions. Nevertheless, I think the environment of educational policy and educational reform too easily moves toward identifying urgency and crisis. After all, much of politics is about change, and it is difficult to sustain arguments for things to stay the same.

I am not interested in stopping reform, however; I personally argue fairly consistently for educational reform. But, I think it is also important to wonder about the limitations of that reform. That is what I did in this dissertation. I studied a case of mathematics educational reform – creating two new undergraduate mathematics courses in quantitative literacy – in order to interrogate my own critical action in the name of reform. Although I look forward to learning how different readers of my dissertation dialogue differently with it, I want to conclude by stating that I think these courses are worthy to be sustained and even used as productive models for future reforms. I think quantitative literacy names an important and relevant reaction to the new ways mathematics and statistics have been used, are being used, and will be used to perpetrate injustices – and how they have been, are being, and will be used in projects of justice. I would recommend reform that considers quantitative literacy as an education goal that confronts modern realities, technological and social changes, and opens up transdisciplinary possibilities. Although I do not see these reforms as anything resembling a savior for the wicked problems we face both inside and outside of education, I nevertheless see reform for quantitative literacy to be a significant contribution to realizing new educational possibilities.

CHAPTER SEVEN:

MILLENNIALS, MATHEMATICS EDUCATION, AND THE METAMODERN AESTHETIC

My introduction and these parting thoughts bookend this dissertation. Together they illustrate how my positionalities weave throughout this dissertation. In my introduction, I am very explicitly discussing my own transformations and lived experiences through what I consider to be a partially non-fiction account informed by autoethnographic traditions. By giving very brief, retroactive accounts of experiences with my committee members, I purposefully played with the concept of a dissertation "defense." I ready myself for a dissertation defense that implies my committee members will attack me, despite the attacker-defender relationship not accurately reflecting any part of how I feel about those relationships, or at least what I hope they are. In a recent meeting with Higinio, we talked about our shared epistemological stance on relationships: that we know and become through and as relationships. In these parting thoughts, therefore, I want to enact my part of our relationships in a way that reflects how I perceive them: by openly discussing my "new," or at least up to now, unshared – except by Lynette - thinking.

My Positionality as a Metamodern Millennial Mathematics Education Scholar

This conclusion, therefore, feels to me like a funhouse mirror of the academic genre. The most notable difference between this chapter and my three body manuscripts is the relative absence of references. I think this absence is inevitable when grappling with emerging thinking; at the same time, I think it also reflects my purposefully chosen substance for this conclusion, as well as illustrates my identity as a metamodernist and a millennial.

I use *metamodernism* to describe an aesthetic position reflecting an oscillation between modernism and postmodernism (Kadagishvili, 2015; Turner, 2011). Knudsen excellently summarized how I consider my metamodern aesthetic to "allow the possibility of staying

sympathetic to the poststructuralist deconstruction of subjectivity and the self…and yet still encourage genuine protagonists and creators" (Knudsen, 2013).

People can engage the metamodern aesthetic through combining "ironic detachment with sincere engagement" (MacDowell, 2014). I think MacDowell's words reflect many of my interactions with fellow millennials. I take *millennials* to include all people both alive and under the age of 20 at the start of the new millennium (which I take as the year 2000). Although I see generational labels as generally foolhardy, I also think it is important to explicitly counter the dominant cross-generational narratives. My experiences with elder generations, and the dominant narratives perpetrated by members of these generations about millennials, suggest to me that the *metamodern millennial* remains incomprehensible to them. Let me briefly explain what I mean.

Metamodern Millennials

I want to state that I do not think the metamodern millennial identity is an overarching identity descriptor for all millennials: our identities as humans are necessarily complex and plural. I also want to state that I expect many millennials would reject the metamodern label. I still opt to use the plural "we" here - instead of "I" – not to act as though I am a voice for more than one member of my generation, but to protect against a person reacting to what I write as an "exception."

The metamodernist aesthetic in poetry and architecture, Kadagishvili (2015) argued, is represented by the playfully serious juxtaposition of seemingly contradictory words or structures. He cited David Roester Wallece, Sir Geoffrey William Hill, Kay Ryan, and Michael Ryan as metamodern poets. They write the metamodern aesthetic through juxtaposing and oscillating between modernist structures, and symbolically and seriously deconstructing them as postmoderns. Kadagishvili (2015) gave the following juxtapositions as examples:

"enthusiasm/irony, hope/melancholy, naivety/knowingness, empathy/apathy, totality/fragmentation, unity/plurality, authenticity/pastiche, involved/detached, elitist/democratic…bright/plain, light/dark" (p. 561). Likewise, he discussed metamodern architecture, for example Peter Zumthor's 2011 pavilion for the Serpentine Gallery, made from "imposing black walls, an enclosed garden…designed for rest and speculation" (Kadagishvili, 2015, p. 563).

Metamodern poetry and architecture provide illustrative examples for the metamodern millennial. We are incongruous with both the structures of modernity and the deconstructive distancing of postmodernism. We are stressed about relaxation and take our playtime very seriously. We take lightly things elder generations took very heavily, such as job security. We take heavily things that elder generations took very lightly, such as microaggressions. We also both recognize and reject binaries and boundaries as real and fantasy. We can take seriously the importance of economics while playing with the need for capitalist hierarchical growth. We can follow leaders while simultaneously leading those who have that label. We are nostalgic for days past and pre-technological ages, but eager for future technological advances. As the generation of YOLO (you only live once), we expect and pursue unique lives. As the generation of FOMO (fear of missing out), we want to share in everyone else's lives.

Metamodern Millennials, Education, and Research

Ironically, I have not found age to be a salient idea in education scholarship – despite the fact that age is the most salient feature of schooling (cf. Donnison, 2007; Murgatroyd, 2010; Oblinger, 2003; Pardue & Morgan, 2008). The only reason people have to attend K-12 school is because of their age. From my perspective, the most closely held and commonsense idea people have about school is that children should be there. We, education scholars, distress over the

dropout rates (e.g. Astin, 1974; Christie, Jolievette, & Nelson, 2007; Guryan, 2004) and critically deconstruct how societal structures "pushout" students (e.g. DeRidder, 1991; Fine, 1991; Reddy & Sinha, 2010). Although different explanations for why students do not complete the prescribed schooling duration, they nevertheless all assume that leaving school early is bad.

I also think leaving school is bad, but only partially. Because society is structured hierarchically around credentials, leaving school (or completing alternative routes) has a limiting effect on a person's possibilities. The seriousness with which I take the role of mathematics as a gatekeeper (e.g. Moses & Cobb, 2001) lives alongside the irony with which I view the legitimacy of that gatekeeping role as fantasy - underscored, in my opinion, by all three of my body manuscripts. I find my existences as a metamodern millennial mathematics education scholar to be well reflected in my choice to take up a critical postmodern theoretical position (e.g. Stinson & Bullock, 2013; 2015) throughout this dissertation. Instead of returning to my three body manuscripts (let's be honest, they are long enough), I want to circle back to my epistemological stance, virtue epistemology (Craig, chapter two, this dissertation, p. 14). I do so in order to establish an argument for a new metaphor for in-person schooling.

Virtue Epistemology Revisited

My second chapter on methodology partially engaged with my feelings about what it means to *create* knowledge, as opposed to simply *know*. If knowledge is a manufactured product made by people, individually and collectively, then I argued that there are qualities to that manufacturing process that matter. I used virtue epistemology to describe those qualities in the research endeavor. At the same time, the methods themselves still matter. The methodological machinery matters to what researchers create and claim as knowledge. We have established methods for answering (or at least addressing) particular questions; we have analytical technique

for illuminating the realities that lay hidden within the data that emerge from those methods; we have dissemination processes – including peer review – that help refine our more raw knowledges.

Conceptualizing methods as machinery, however, causes me to imagine researchers using assembly lines. The production of knowledges in an audit-culture, neoliberal institutional environment resembles the mass production of writing in much the same way that large corporations mass produce material items. There are some phenomenally good aspects, from my perspective, of mass production. Most notably, mass production can democratize material goods, with people previously unable to have luxuries (cars, computers) now more readily accessing them. The way the internet, specifically google scholar, Wikipedia, and to a lesser extent networking sites like Researchgate.net and Academia.edu, allow the dissemination of research similarly democratizes access to the knowledges produced by academics. These changes to access also change the production processes themselves, though. From a neoliberal perspective, in order to satisfy the at-scale demand for academic knowledges, we must mass produce. Most (all?) of my committee members have commented about the transformation of the academic job precipitated by this shift.

Research as an Imaginative Act

I want to also revisit my thinking about research as a creative act. I chose creative because I think it reflect how we conceptualize research with *results*. The results are an artifact in themselves, something researchers create to share with other people in a variety of ways: manuscripts, conference presentations, books, curricula, professional development, and others. As I mentioned in my conclusion (Craig, chapter six, this dissertation, p. 112), I also feel that democratic education is incomplete without seriously considering fantasy. I think the analysis of

realities is incomplete without considering fantasies alongside. Insofar as research is also concerned formally with realities, I think it is similarly incomplete without seriously considering fantasies.

The Metamodern Aesthetic in this Dissertation

This dissertation is one of the most serious things I have ever done. The nearly countless hours spent with my data, revisiting my students through our videos and their work, constituted an intellectual and emotional labor unlike anything else I have tried. Despite, or perhaps because of this seriousness, throughout my dissertation I juxtapose the serious with the playful. Nowhere better are these juxtapositions evident than in my conclusion where I considered "the educational game we *play* so *seriously*" (Craig, chapter six, this dissertation, p. 118, emphasis added**)**. There are other times where seemingly ironic or detached playfulness comes into my dissertation. I told my positionality as a story and talked about my committee members as characters in that story; I wondered whether we have positioned people to believe in numeracy as an educational savior by framing it as a myth; I thought about how one of my most treasured ideas, quantitative reasoning, may be involved in a sort of fantasy; and I explored how the QL courses at focus in this dissertation may be involved in dehumanizing education by portraying them as objects from the Harry Potter universe.

I think it would be a reasonable response to reading these juxtapositions as a lack of serious engagement. In contrast, I feel the most serious when I am making the most playful juxtapositions. Thinking about the courses into which I have poured part of my own soul as a horcrux sometimes gives me shudders. At the same time, I think these courses represent important – and very *real* - possibilities for mathematic education.

Researchers as Artisan Crafters

To return to my fantasy gaming metaphors from the previous chapter, I want to finish my dissertation with some comments on future research. It feels serendipitous to conclude my dissertation under this sub-header. *Researchers as artisan crafters*. In gaming, artisan crafters are at the top of their profession. They can make items of such a high quality, of such phenomenal uniqueness, that they are legendary. In those games, usually only one person gets to use that legendary item. It makes me think about questions like: What if this dissertation is the last piece of academic writing that I ever do? How will I feel? Who knows how my perspective will change. Right now, at least, I think I would feel fine – despite my current intentions to pursue academia.

I heard once that the average published research paper has less than three citations. I do not know whether that is true, but whatever the number is, it seems certain to decline. What will happen when the average published research paper has less than one citation? What about when the majority of them have no citations? What about when the majority of them have never been read (besides maybe by reviewers)? I finish my dissertation by proposing another way for researchers to respond to our current environment. Write less. Take full drafts and throw them out. Focus more on your students, your colleagues, your friends and relationships, and on yourself. Do something else that sustains you and makes you feel whole (I am writing a fantasy novel and creating a board game). For me, that meant embracing the facts that I love fantasy books and gaming, and understanding how as my academic and those identities are part of the same whole, so they can be together in my writing. In the digital age, the legendary thing you create is *recyclable*, *multi-locational*, and *re-watchable* (Craig, Appendix F, p. 162). Artisan research offers a perspective on toiling with ourselves by not being afraid to grapple, and

struggle, and love, and hate, and be, and become, with your thoughts, your truths, your realities, and your fantasies. The legendary items you create through your artisan crafting are unique, unreplicable, partially unwritten, partially unsaid, and unfinished.

So, I hope you simultaneously write (and create) as though you may never write again. Please, do not discard the fantasy thoughts you have about the possibilities for education as unrealistic. I will try to join you there.

APPENDICES

APPENDIX A:

Research Participant Information and Consent Form (Phase One)

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision.

Study Title: Transformative Learning through Quantitative Literacy: The Emotionality of Interrogating and Reimagining Frames of Reference
Researcher and Title: Jeffrey Craig, Ph.D. Candidate
Department and Institution: Program in Mathematics Education, Michigan State University
Address and Contact Information: 122 North Kedzie Hall, 354 Farm Lane, Michigan State University, East Lansing, MI 48824; Lynette Guzman, guzmanly@msu.edu
Project Chair: Dr. Beth Herbel-Eisenmann, bhe@msu.edu

You are invited to participate in a research study about students' experience in an innovative undergraduate mathematics classroom. The purpose of this study is to better understand students' thinking and feeling related to the content in this innovative mathematics classroom. You have been selected as a possible participant in this study because you are enrolled in MTH 101, Quantitative Literacy I. You must be at least 18 years old to participate. The estimated time commitment for participation in the seven weeks this course runs.

In this study you will be asked to consent to having your classroom activities and reflections collected and analyzed. All activities will be coordinated through the scheduled classroom time. No additional activities beyond the curriculum are involved in participation in this study. The researcher will collect all artifacts from our classroom activities. You will not directly benefit from your participation in this study. There are no foreseeable risks associated with participation in this study; however, there is a risk of potential discomfort if you do not agree with the interpretation of data made by the researcher. In addition, you may experience discomfort as a result of knowing that you may be portrayed on videotape in educational environments, such as classrooms and research conferences. The researcher will seek to minimize these potential discomforts by preserving your anonymity in written publications and minimizing attention to individuals in publically shown video clips.

The results of this study may be published or presented at professional meetings and educational settings, but the identities of all research participants will not be shared with others without written permission. Every effort will also be made to protect the confidentiality of the information provided. All materials will be kept in a secure and locked location and only the researcher will have access to the data. Pseudonyms will be used to disguise personal identifiers in any written reports, publications, and presentations.

Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. You may choose not to answer specific questions or to stop participating at any time. Whether you choose to participate or not will have

no effect on your grade or evaluation in any related teacher education courses. Your instructor will not know whether you have chosen to participate until the course is fully completed. Your instructor will not know if you choose to revoke your consent during the course. If you choose to withdraw from the study, the information that can be identified as yours will not be kept as part of the study and will not be analyzed. No cost will be incurred to you based on your participation in the study.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact Lynette Guzman (guzmanly@msu.edu; 122 North Kedzie Hall, 354 Farm Lane, MSU, East Lansing, MI 48824).

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355- 2180, Fax 517-432- 4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Dr. Rm 207, East Lansing, MI 48824.

Thank you for your consideration and assistance.

Best regards,

Jeffrey Craig
Ph.D. Candidate, Michigan State University
Program in Mathematics Education

Beth Herbel-Eisenmann, Ph.D.
Associate Professor, Michigan State University
Department of Teacher Education

Research Participant Information and Consent Form

Study Title: Transformative Learning through Quantitative Literacy: The Emotionality of Interrogating and Reimagining Frames of Reference
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Project Chair: Dr. Beth Herbel-Eisenmann, bhe@msu.edu

_____

Participant's Name (Please Print)

Initial all (items 1-4) that apply:

1. _____ I give permission for data to be used from written transcripts of discussion and classroom artifacts for educational and research purposes.

2. _____ I give permission for my audio/video recordings to be used for educational purposes in classroom settings.

3. _____ I give permission for my audio/video recordings to be used for educational purposes that will appear online.

4. _____ I give permission for my audio/video recordings to be used in professional publications and presentations.

Please Check:

____ I CONSENT TO TAKE PART IN THE RESEARCH STUDY.

____ I **DO NOT** CONSENT TO TAKE PART IN THE RESEARCH STUDY.

My signature below indicates that the consent gatherer has answered all of my questions to my satisfaction and that I consent to take part in this study. In addition, I have been given a copy of this form to keep.

_____ _____

Consent Gatherer Signature Date **Participant Signature Date**

APPENDIX B:

Description of Study Script

My name is Lynette Guzmán, and I am a doctoral candidate in the Program in Mathematics Education at MSU. I am presenting details about a research participation opportunity based on the dissertation work of your instructor, Jeffrey Craig. You have been selected as a possible participant in this study because you are enrolled in Jeff's section of MTH 101 this summer semester.

Your participation in this project is entirely voluntary. Your grade will not be affected in any way. You will not be asked to do anything additional to the course curriculum if you choose to participate. I am presenting the project to you because Jeff will not know whether you have chosen to participate in his study until ***after*** the course completes and grades are finalized.

Jeff wants to know about your experiences in this innovative mathematics course. He is particularly interested in what your emotional experiences are: how you relate to the content and whether it is interesting and impactful to you. All students in the course obtain their participation points by completing daily course check-ins. This feedback will be used to improve the course experience and teaching. The feedback, as well as your course work, and a video-recording of the classroom space, will be used to inform Jeff's study of your experiences in the course.

No cost will be incurred to you based on your participation in the study. After the course completes and grades are finalized, Jeff may reach out to you for follow-up interviews. At that time, a further project description and consent form will be provided. This phase of the project, and this consent form, are only for what happens as part of the course.

Attached is a consent form that further explains the details of this study. Again, participation in this research project is completely voluntary. Whether you choose to participate or not will have no effect on your grade or evaluation in any related teacher education courses. Additionally, this project does not intend to evaluate your performance or your teacher preparation program.

If you are interested in participating in this study, please review the attached consent form and return it to me. The principal investigator, Dr. Beth Herbel-Eisenmann, is an associate professor of teacher education here at MSU. She will secure your consent forms and Jeff will not gain access to them until the course completes and grades are finalized. You may either me or Dr. Herbel-Eisenmann with any questions or concerns, and our contact information is on the document you're keeping.

Jeff really appreciates your time and consideration!

Best regards,
Lynette Guzman on behalf of Jeffrey Craig

APPENDIX C:

Research Participant Information and Consent Form (Phase Two)

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision.

Study Title: Transformative Learning through Quantitative Literacy: The Emotionality of Interrogating and Reimagining Frames of Reference
Researcher and Title: Jeffrey Craig, Ph.D. Candidate
Department and Institution: Program in Mathematics Education, Michigan State University
Address and Contact Information: 122 North Kedzie Hall, 354 Farm Lane, Michigan State University, East Lansing, MI 48824; Jeffrey Craig, craigjef@msu.edu
Project Chair: Dr. Beth Herbel-Eisenmann, bhe@msu.edu

You are invited to participate in a research study about students' experience in an innovative undergraduate mathematics classroom. The purpose of this study is to better understand students' thinking and feeling related to the content in this innovative mathematics classroom. You have been selected as a possible participant in this study because you were enrolled in MTH 101, Quantitative Literacy I. You must be at least 18 years old to participate. The estimated time commitment for participation is 6 scheduled hours between August 1, 2016 and February 1, 2017.

In this study you will be asked to consent to having your follow-up interviews. All activities will be coordinated on the Michigan State campus accommodating your schedule. The researcher will collect all artifacts from our follow-up interviews. You will not directly benefit from your participation in this study. There are no foreseeable risks associated with participation in this study; however, there is a risk of potential discomfort if you do not agree with the interpretation of data made by the researcher. In addition, you may experience discomfort as a result of knowing that you may be portrayed on videotape in educational environments, such as classrooms and research conferences. The researcher will seek to minimize these potential discomforts by preserving your anonymity in written publications and minimizing attention to individuals in publically shown video clips.

The results of this study may be published or presented at professional meetings and educational settings, but the identities of all research participants will not be shared with others without written permission. Every effort will also be made to protect the confidentiality of the information provided. All materials will be kept in a secure and locked location and only the researcher will have access to the data. Pseudonyms will be used to disguise personal identifiers in any written reports, publications, and presentations.

Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. You may choose not to answer specific questions or to stop participating at any time. Whether you choose to participate or not will have

no effect on your grade or evaluation in any related teacher education courses. If you choose to withdraw from the study, the information from this phase of the study that can be identified as yours will not be kept as part of the study and will not be analyzed. You may withdraw from only this phase of the research project or from both this phase and the previous phase.

No cost will be incurred to you based on your participation in the study. All of the activity materials required for the research will be provided. You will be provided meals at on-campus meetings and Amazon gift cards as compensation for your participation in the study. You will be compensated $10 for each follow-up interview, potentially up to 3 follow-up interviews for a total of $30 in Amazon gift cards.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact Jeffrey Craig (craigjef@msu.edu; 122 North Kedzie Hall, 354 Farm Lane, MSU, East Lansing, MI 48824).

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355- 2180, Fax 517-432- 4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Dr. Rm 207, East Lansing, MI 48824.

Thank you for your consideration and assistance.

Best regards,

Jeffrey Craig
Ph.D. Candidate, Michigan State University
Program in Mathematics Education

Beth Herbel-Eisenmann, Ph.D.
Associate Professor, Michigan State University
Department of Teacher Education

Research Participant Information and Consent Form

Study Title: Transformative Learning through Quantitative Literacy: The Emotionality of Interrogating and Reimagining Frames of Reference
Researcher and Title: Jeffrey Craig, Ph.D. Candidate
Department and Institution: Program in Mathematics Education, Michigan State University
Address and Contact Information: 122 North Kedzie Hall, 354 Farm Lane, Michigan State University, East Lansing, MI 48824; Lynette Guzman, guzmanly@msu.edu
Project Chair: Dr. Beth Herbel-Eisenmann, bhe@msu.edu

_____

Participant's Name (Please Print)

Initial all (items 1-4) that apply:

1. _____ I give permission for data to be used from written transcripts of follow-up interviews for educational and research purposes.

2. _____ I give permission for my audio/video recordings to be used for educational purposes in classroom settings.

3. _____ I give permission for my audio/video recordings to be used for educational purposes that will appear online.

4. _____ I give permission for my audio/video recordings to be used in professional publications and presentations.

Please Check:

____ I CONSENT TO TAKE PART IN THE RESEARCH STUDY.

____ I **DO NOT** CONSENT TO TAKE PART IN THE RESEARCH STUDY.

My signature below indicates that the researcher has answered all of my questions to my satisfaction and that I consent to take part in this study. In addition, I have been given a copy of this form to keep.

_____ _____

Researcher Signature **Date** **Participant Signature** **Date**

APPENDIX D:

Interview Guide

1. What is your overall perspective of your experiences in our course?

2. What are your thoughts on the role of mathematics, statistics, and quantitative literacy in the world?

3. [Course Feedback Artifacts]: Do any classroom activities stand out to you as particular important?

4. Do any activities stand out as content about which you felt strongly?

5. Why do you think you felt strongly about this content?

6. What do you know about this content? Can you recall prior interactions you have had with this content either inside or outside of school?

7. Do you think aspects of your identity might be related to how you think and feel about this content?

8. What else do you wonder about this content?

9. What are some ideas and assumptions related to this content?

10. Do you think what you learned or felt during the class has changed the way you think about, or act in, the world?

APPENDIX E:

Not True or False, but Good or Bad: Wicked Problems Curriculum

Abstract

Across places and disciplines, people and scholars are working on problems that are messy, global, connected, complex, and unavoidable. This paper makes the case for these problems being included in and central to curriculum. These *wicked problems* are in contrast to curricula that center tame problems that are self-contained and solvable. This mismatch between disciplinary activity and school curricula provided the impetus for the author to think about education for wicked problems. In this paper, I develop an argument for a *Wicked Problems Curriculum* by connecting to complexity theory, transdisciplinary inquiry, curriculum integration, and open democratic education. After developing aspects of a Wicked Problems Curriculum, I report on an innovative undergraduate course in quantitative literacy.

Introduction to Wicked Problems and Curriculum

> This is the first human generation in which the majority will live in crowded cities, whose actions will flood low-lying islands and whose rate of resource use exceeds 2.5 times the production capacity of the planet (Melkert and Vox, 2008). Well-founded projections suggest that future supplies of the air we need to breathe, the water to drink and the food to eat are in doubt. (Schneider et al., 2007 as cited in Brown, Deane, Harris, & Russell, 2010, p. 3).

This excerpt is the first paragraph of a book, *Tackling Wicked Problems* (Brown, Harris, & Russell, 2010), which works to unite people across disciplines to confront the global problems that affect us all. In the book, scholars argued that this particular class of problems required something radically different from disciplinary inquiry. The *transdisciplinary imagination* implies the fusion of knowledges across and outside of disciplinary boundaries. Whereas

interdisciplinary maintains the disciplinary knowledge borders and looks to invoke or combine multiple disciplines, transdisciplinary approaches create knowledge that "is more than the sum of its disciplinary components" (Lawrence, 2010, p. 19). Transdisciplinarity needs imagination to cross the disciplinary boundaries within which we typically work and learn. The *wicked problems* that are at the center of transdisciplinary inquiry require imaginative approaches because they cannot be (at least, have not been) solved by any disciplinary techniques. Wicked problems are in contrast to *tame problems*:

> It seems as though some problems are tame, such as factoring a quadratic equation, traversing a maze, and solving the tower of Hanoi puzzle. But problems of importance… are invariably 'wicked.' (Coyne, 2005, pp. 5-6)

This second quotation is from the introduction of a paper on wicked problems in design theory. Coyne (2005) briefly defined wicked problems by contrasting them with tame problems. That he chose the three ideas he did: factoring, navigating a maze, and the tower of Hanoi, is an indictment of mathematics education. Those three ideas are canonical to mathematics education curricula. That Coyne used these three examples subtly criticizes the prevalence of tame problems in mathematics education at a time when the public and many scholars and scientists are alarmed by the global challenges facing us.

The juxtaposition of these two quotations poses a question of education (specifically of mathematics education): is there a mismatch between tame curricula and wicked problems? This manuscript is a response to that question, and has two parts. In the first part, I unify several different theories and perspectives around the concept of a *Wicked Problems Curriculum.* In particular, I bring together curriculum integration, transdisciplinary inquiry, complexity theory, and open democratic education. All of these ideas strengthen the case for wicked problems being relevant to curricula. Taken together, they support the idea of designing and implementing a

Wicked Problems Curriculum in a course in quantitative literacy and shape my primary question of concern:

- How might a QL curriculum support the consideration of Wicked Problems?

I describe an empirical report on a mathematics course in quantitative literacy. This innovative course was designed around context-based modules and a course-long project. In the months after the course completed, I searched for language to describe my experiences design and teaching the course, and the potential I saw realized in my students' work in the course. When I encountered *wicked problems* (Rittel & Weber, 1973/1984), the framework resonated with my experiences. As a result, I use the ten characteristics of wicked problems as a conceptual framework from which I enacted a theory-based coding scheme. I report some of the exemplar instances of each of the characteristics as a case study in engaging a Wicked Problems Curriculum. I also detail some of how our planned curriculum outside the projects also aligned with a Wicked Problems Curriculum.

Characteristics of a Wicked Problems Curriculum

Wicked problems facing the world regarding sustainability are staggering in scope, and elusive. Further, evidence increasingly suggests that addressing sustainability questions necessarily involves addressing myriad social injustices and complex economic relationships (Peterson, 2016). Nearly two decades ago, education for wicked problems was "taken seriously by no one, even if they are included with some regularity in official curriculum documents" (Parker, Ninomiya, & Cogan, 1999, p. 119). Serious consideration of these wicked problems as justifiable school curriculum remains uncommon. Indeed, the national effort to create and adopt the Common Core State Standards for Mathematics (National Governor's Association, 2010) was explicitly focused on raising achievement for existing assessments. The complexity of

wicked problems points to the impossibility of a unilateral (even at the country level) resolution and the necessity of collective, global action. Despite the apparent scope and potential urgency of these wicked problems, curriculum discussions remain much the same as they were when:

> Chief among these marginalized goals is civic education of a global kind---education for shared problem solving on messy international problems and, thereby, the cultivation of a global perspective on such problems. (Parker, Ninomiya, & Cogan, 1999, p. 119)

In the following sections, I outline how I see a Wicked Problems Curriculum as co-emergent with ideas in complexity theory, transdisciplinary inquiry, and open democratic education.

Wicked problems are ill-structured, complex, and unsolvable; according to Rittel and Webber (1973/1984) there are at least ten characteristics of wicked problems:

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rules.
3. Solutions to wicked problems are not true or false, but good or bad.
4. There is no immediate and no ultimate test of a solution to a wicked problem.
5. Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of possible solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The planner has no right to be wrong.

Wicked problems have been conceptualized within many fields, including: environmental studies (e.g. Kreuter, De Rosa, Howze, & Baldwin, 2004; Van Bueren, Klijn, & Koppenjan, 2003), political science and public policy (e.g. Head, 2008), public health (e.g. Blackman et al., 2006), public risk and defense (e.g. Ritchey, 2001), and economics (e.g. Batie, 2008). The move to consider work in their fields as wicked problems generally emerged alongside recognition of

non-quantifiable complexity. Ritchey (2001) claimed, "if you work with long-term social, commercial, or organizational planning – or any type of policy planning that impacts *people* – then you've got *wicked problems* (p. 1). The presence of wicked problems can be signified by a sense of *reactivity*, where after attempting resolution, the problem transforms and "fight[s] back when you try to do something" (Ritchey, 2001, p. 1).

Across these disciplines, many scholars engage *networks* for attempts at resolution (Van Bueren, Klijn, & Koppenjan, 2003; Roberts, 2000). According to Weber & Khademian (2008), "networks have assumed a place of prominence…as the foremost means to organize to address complex problems" (p. 334). Wicked problems are suggestive of a particular kind of network, specifically *complex* networks where an immense amount of individual actors (usually people) are making many decisions that are interrelated and uncertain. The dominant and traditional methods of quantifying uncertainty which have been historically central to the field of statistics are challenged by particular forms of uncertainty. Two particular forms of uncertainty resist quantification or prediction, "*agnostic uncertainty* (conscious, self-reflective actions among competing actors) and *non-specified uncertainty* (for instance, uncertainties concerning what types of scientific and technological discoveries will be made in the future)" (Ritchey, 2001, p. 7).

Complexity Theory

As these challenges emerge, statisticians and mathematicians have responded with new theories and methodologies, sometimes clustered as *complexity science* or *complexity theory*. "many of the factors involved are not meaningfully quantifiable, since they contain strong social, political, and cognitive dimensions" (Ritchey, 2001, p. 7). Complexity science emerged as a way to describe the objects of study during developments in artificial intelligence, cybernetics, and

considering collective behavior. Weaver (1948) produced a seminal piece that sketched the emergence of complexity science. He described three different types of problems: problems of simplicity, problems of disorganized complexity, and problems of organized complexity. *Problems of simplicity* generally involve a relatively small number of interacting parts, and many, if not all, variables can be controlled: such as constructing a functioning radio or turbine; *problems of disorganized complexity* involve a distributed uncertainty, or randomness, that is at the center of traditional statistical techniques involving the law of large numbers and normal distributions.

In contrast, *problems of organized complexity* involve an interconnectedness that sabotages any claims of randomness. Questions in genetics, nature, neuroscience, and social interaction, for example, have *reactivity* similar to addressing wicked problems. The elements of these systems (genes, organisms, neurons, and people) necessarily interact and affect each other. In fact, these systems are notable precisely because they have a "*sizable number of factors which are interrelated into an organic whole*" (Weaver, 1948, p. 5, emphasis in original). The difference between problems of disorganized complexity and organized complexity has more recently been reframed as the difference between complicated and complex, respectively (Davis & Simmt, 2003, p. 140).

Complexity science and theory is interested in this organized complexity, in terms of their *emergence* and *self-organization*. *Emergence* refers to "instances when coherent collectives arise through the co-specifying activities of individuals" (Davis & Simmt, 2003, p. 140) and can be illustrated by considering the emergence of culture, the emergence of ideas, or the emergence of species. *Self-organization* refers to the idea that this emergence is not visible through analyzing the interactions of individual elements; a complex system is neither reducible to nor

predictable from observing or understanding its constituents' behavior. As complex systems differ from their not-complex counterparts, approaches to understand them likewise changes. The common, dominant approaches wherein the boundaries of exploration and inquiry are drawn fairly rigidly coincide generally with the formulation of the problems relevant to a *discipline*. Foucault (1975/1977) historicized discipline as a formation that constructs and constrains individuality to direct it toward a narrowly defined set of phenomena. Complex wicked problems involve a multiplicity of phenomena, however, as well as their interrelations. The non-linearity of the related phenomena disrupts attempts to understand causality in classical ways. For example, recent work in epigenetics (see Holliday, 2006), further complexifies the longstanding questions about the relationships between nature (genetics) and nurture (environment). This *transphenomenal* character of wicked problems expresses how these problems relate across and through multiple disciplines as an organic network (Davis, 2008).

Transdisciplinarity

Studying complex wicked problems, therefore, poses a challenge to disciplinary approaches to knowledge; in response, *transdisciplinary* approaches "step outside the limiting frames and methods of phenomenon-specific disciplines" (Davis, 2008, p. 55). The transdisciplinary approach mirrors the collective nature of complex problems and values not only the multiplicity of knowledges from different disciplines, but also their fusions (Lawrence, 2008). These fusions help differentiate transdisciplinarity from interdisciplinarity, where multiple disciplines give rise to a new discipline (i.e. biochemistry) with its own new boundaries of inquiry. Transdisciplinarity, in contrast, redraws the boundaries of inquiry (to the extent possible) around the problem itself, to ask what disciplines and their fusions can contribute to addressing and resolving a problem, rather than whether a problem belongs inside a discipline.

For wicked problems where boundaries are elusive (or impossible) to draw, the inquiry is, therefore, necessarily inclusive. All knowledges are relevant and applicable to resolving wicked problems, and transdisciplinarity "is created by including the personal, the local and the strategic, as well as specialized contributions to knowledge" (Brown et al., 2010, p. 4). This lack of boundaries is conducive to a *transdisciplinary imagination* (Brown, Harris, & Russell, 2010). In the transdisciplinary imagination are attempts "to generate fundamentally new conceptual frameworks, hypotheses, theories, models, and methodological applications that *transcend* their disciplinary origins" (Hall et al., 2012, p. 416, emphasis in original). The openness with which transdisciplinary inquiry is practiced poses challenges to education in much the same ways that complexity and wicked problems do.

My central question about possible curriculum design leads to several more. Open inquiry seems to run counter to the role of curriculum as directing inquiry. In particular, open transdisciplinary inquiry challenges both the disciplinary formulation of curriculum domains (mathematics, history, language, physics, etc.) and the specialization of curricula within those domains (mathematics into algebra, geometry, trigonometry, calculus, etc.). Put another way, "how can freedom, diversity, autonomy and choice be exercised within centrally-prescribed curricula" (Morrison, 2008, p. 20)?

Democratic Education and Curriculum Integration

Many scholars have theorized about democratic education (e.g. Freire, 1970; Gutmann, 1999; Apple, 2014; Beane, 2016). Although these scholars, and others, have generated detailed and deep theories about education in a democracy that include attending to students' roles as participating in democratically organized classrooms (e.g. Dewey), the importance of the teacher relinquishing an authoritarian position in the classroom (e.g. Giroux, 1984), and the institutional

principles necessary to support democratic education (e.g. Gutmann, 1993; 1999). Considering all these issues is essential to fully theorizing and faithfully implementing democratic education. This paper focuses, however, on curriculum. How do wicked problems fit with democratic education?

First is the proposition that curricula are non-neutral relative to democracy. Westheimer and Kahne (2004) found that behind the easy support generated around attempting democratic education were at least three distinct goals. The three types of citizens imagined as goals for democratic education- personally responsible, participatory, and justice oriented – were not mutually exclusive, yet many educators and democratic education programs foreground one over the others. For example, a program centered on the personally responsible citizen, by emphasizing individual action over collective good or solidarity, may generate obedience without critical reflection (Westheimer & Kahne, 2004). Ultimately, their work demonstrated how democratic education is itself political in the sense that there is disagreement on what its goals are. Specifically, they did not focus how democratic education might be arrived at, instead focusing on "the varied conceptions of the destination itself" (Westheimer & Kahne, 2004, p. 239). Some mathematics educators have similarly concluded that mathematics curriculum is not apolitical, following general trends in the sociopolitical perspective in education.

If the curricular choices are political, which choices align with democratic educational goals? Specifically, are there general characteristics of a curriculum oriented toward democracy? One claim is that for a curriculum to be organized around democratic education, it must attend to authentic, meaningful problems. Freire (1974) insisted that this is foundational to the endeavor:

> Democracy and democratic education are founded on faith in [people], on the belief that they not only can but should discuss the problems of their country, of their continent, their world, their work, the problems of democracy itself. (Freire, 1974, pp. 33-34)

According to Freire, democratic education involves a curriculum designed around problems, and not centrally around disciplines. Beane (1997) echoed this perspective when representing the longstanding tradition of curriculum integration. *Curriculum integration* does not mean reorganizing existing lesson plans in each discipline according to a shared timeline. Curriculum integration scholars argue that the idea traces back at least to Dewey and Kilpatrick (Vars, 1991). The curriculum integration perspective mirrors the idea that wicked problems are complex and transdisciplinary. Drake (1998) argued that curriculum integration also better represents an education appropriate for contemporary society.

> The world we live in is changing, and education must change with it. If we live in an interconnected and interdependent world, it only makes sense that knowledge be presented as interconnected and interdependent. (Drake, 1998, p. 24)

Beane (1997) defined curriculum integration as a longstanding educational tradition, and its core ideas seem reflected in complexity theory and education, and transdisciplinary education:

> Curriculum integration is a curriculum design that is concerned with enhancing possibilities for personal and social integration through the organization of curriculum around significant problems and issues, collaboratively identified by educators and young people, without regard for subject-area boundaries. (Beane, 1997, p. 2)

Beane (1997) noted my third concern regarding curriculum and democratic education – the role of students as co-designers of the curriculum. For students to participate in authentic democratic education, they need to be active participants in the deliberation and construction of ideas: problems, formulations, and solutions. The effectiveness of democratic education is contingent on the commitment that students have to the problems being addressed. The

curriculum must involve “questions and concerns that have personal and social significance” (Beane, 1997, p. 3).

Wicked problems are well-aligned curricular subjects for democratic education. I have also argued that wicked problems mirror shifts in the complexity of problems given our increasing interconnectedness and effects on the world, and the transdisciplinary approach to circumscribing inquiry relative to an open, complex problem as opposed to disciplinary boundaries. Thus far, I have hoped to sketch an argument for wicked problems being meaningful curricular material. In the second half of this paper, I describe an innovative course in quantitative literacy that was developed for the general undergraduate education curriculum at Michigan State University. My study of the course includes a focus on student projects in a mathematics classroom focused on quantitative literacy, where I retroactively found their topics and projects to involve wicked problems. To introduce the projects, I first describe the course in broad terms and then the results of my theory-based coding to trace each of the characteristics of wicked problems as they emerged in my students’ course projects.

APPENDIX F:

Digital Knowledge Material on the Internet

I claim that a primary "material" of the internet is knowledge, which I boringly call *digital knowledge material* (DKM). Through writing blogs, sharing posts, making videos, taking photos, and leaving comments – among other things – DKM is (mostly) democratically and freely available. DKM is mass produced through the internet because every person can more readily be a producer. As opposed to meeting massive demand by mass producing, an alternative perspective on how the marketplace of ideas functions on the internet is through the democratization of creation. YouTube is a great example of this. People, without any credentialing process, have created incredible DKM. The beauty of DKM on the internet is illustrated by what I describe as the three primary differences between it and physical material goods. Those three features are: its durable *recyclability*, its complex *re-watchability*, and its powerful *multilocationality*.

Recyclability of DKM. By *recyclability*, I mean that regardless of how many people have watched a YouTube video, the knowledge material does not deteriorate (though it changes over time and space, and based on who watches it). This recyclability of knowledge relies specifically on how the DKM maintains fidelity (though it takes a plurality of forms as it co-exists with people).

Re-watchability of DKM. With *re-watchability*, I refer to the ability of a single person to return to DKM they had previously engaged, re-watch it, and have a different experience. I use re-watch specifically to fit with the colloquial use of re-watchability in reference to TV shows (mostly through Netflix and Hulu) and viral videos on YouTube.

Multilocationality of DKM. The *multilocationality* of DKM denotes how it can simultaneously exist across multiple spaces at the same time. My use of multilocationality is meant to translate the concept of "multilocation" from Greek philosophy, mythologies, and the occult – which is the "alleged psychic or miraculous ability wherein an individual or object is located (or appears to be located) in two distinct places at the same time" (Nickell, 1993, as cited on Wikipedia, 2017, para. 1).

The Effects of DKM on Co-Constructing Knowledges

I claim that DKM has revolutionized knowledge generation. That knowledges are co-constructed socially, with reciprocal cultural and political influences, is a tenet in the socio-cultural, socio-political, and situative perspectives on learning (e.g. Gee, 1990/1996/2007; Greeno, 1998). The premise is that knowledges are produced and learned both during, and as, social practices that are embedded within, and mutually constitutive of, social, cultural, and political environments. Those environments radically shifted with the emergence of the internet because DKM has different properties than non-digital knowledge material.

The recyclability of DKM affects the time-sensitive stakes of learning and knowledge production. Potentially, the urgency of creating knowledges to address problems is shifted into a set of collective co-constructions of knowledge through re-watchability. Making "new" knowledges is less salient, when "old" knowledges can be revisited, with an unstable fidelity. The multilocationality of DKM also dissolves some of the historical spatial boundaries that excluded many from the knowledge production process, though access issues seem to still exist.

With digital natives in school. How does the prevalence of a (possibly) radically different form of knowledge production affect school with people who are digital natives" (e.g. Bennett, Maton, & Kervin, 2008)? Murgatroyd (2010) provided some insight:

> This generation will understand the power of social networks, cloud based computing and technology and will absorb such technologies to facilitate work and social transactions, change work practices and engage in global conversations (Palfrey, 2008; Tapscott, 2008). They will have these skills despite their school systems, which currently seem unable to engage these technologies in the pursuit of learning, knowledge and understanding. Indeed, many school systems are outlawing social networking technologies, seeing them (sometimes with good reason) as distractions. (p. 261)

If school is meant to prepare students for life after it, his thoughts have serious implications for education. School will be perpetually outdated, in an age of social practices and knowledges that are *deictic* – meaning perpetually and meaningfully changing. If tomorrow will be qualitatively different from today, preparation seems to become a fantasy. In a search for alternative perspectives on school and education, therefore, we might be well served by thinking about fantasies. In particular, I use the metaphor of education as game to frame two further metaphors for educational philosophies.

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