Journeys, Adventures, Bridges and Puzzles: A case study approach to understanding teachers’ conceptions of STEM

by

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ABSTRACT

Legislative changes and discussions about the United States falling further and further behind other nations in science, technology, engineering, and math (STEM) achievement are growing. As they grow, STEM instruction in elementary school has earned its place as a national area of interest in education. In the case of Ivory School District, teachers are being asked to radically change their daily practices by consistently implementing inquiry-based STEM experiences in their classrooms. As such, teachers are being asked to scale a divide between the district expectations and their knowledge and experience. Many fourth grade educators are teachers who have been trained as generalists and typically do not have specific background or experience in the philosophy, instructional strategies, or content associated with STEM. Using a prototype approach, this study aims to understand how such teachers conceptualize STEM instruction and the relationship between their experience and conceptions.

DEDICATION

Mom, this is our milestone. You told me once that your greatest accomplishments in life are me and Kyle; to date, this is mine, and it is without a doubt because of you. You are my strength and my inspiration. I will forever be grateful for your unconditional love, unyielding belief, and unwavering support. I carry them with me always. I love you.

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Introduction

Problem Statement

As a kindergarten through eighth (K-8) grade school district science, technology, engineering, and mathematics (STEM) director serving in a high needs, urban environment, I am tasked with leading change in the way that STEM teaching and learning occurs in Ivory Elementary School District. At the federal, state, and local levels, STEM and science education in particular are receiving increased attention. Similarly, science education is under new accountability in the forms of the Arizona Instruments to Measure Standards (AIMS) at the fourth and eighth grade levels in Arizona. As both the attention being paid to STEM grows and the accountability measures implemented for elementary STEM education increase, teachers are being asked to scale a dramatic divide between their knowledge and experience and the instructional outcomes they are tasked to generate. The potential enormity of the chasm between knowing and doing is so large that it sparked my interest in the conceptions elementary teachers have constructed of STEM education in the context of an urban, high needs school district.

Primarily trained as a social and biological scientist, I came to education via Teach for America (TFA) in 2007. I entered the corps immediately after completing my undergraduate degree in sociology, psychology, and medical science. I only intended to serve the required two years with TFA, and I was relieved when I was told that not only was I being placed in sunny Arizona, but that I would be teaching middle school science. I remember thinking to myself, “How hard can it be? They are still kids in middle school and the science at that level is no problem for me at all.” It did not take long for me to realize that I had grossly underestimated the challenge before me.

My days as a corps member were long. It took hours to plan and gather materials for lessons. It took even more time and energy to find ways to engage my students and even more time still to learn their backgrounds enough to make the learning relatable for them. Countless times, I was thankful for my strong science background. Even more often than that, though, I wondered how the majority of corps members were managing without any formal science or STEM training. I simply could not imagine how one would deal with all the challenges of teaching while trying to learn the content a few days ahead of delivering it to students.

As time progressed, I became more comfortable with and effective in my role as a science educator. Only a semester into my first year of teaching, an ASU preservice teacher was placed in our classroom and I was asked to mentor her. A semester after that, I was asked to mentor the incoming TFA corps members in my district and it was not long before I was mentoring and leading 24 middle school science teachers, the majority of whom did not have science background knowledge or experience.

As the other TFA members and I worked together, I became increasingly fascinated with how the teachers approached their daily work. Teachers progressed at different paces and drew upon different techniques and resources to assist them in their practice. Some approached activities collaboratively while others preferred to work in isolation, only reaching out when they felt truly overwhelmed. Efficacy, as measured by state standardized tests and district benchmark assessments, varied from teacher to teacher, but every teacher was doing his or her best to bring quality science instruction to the students. Furthermore, all the teachers approached their work with what seemed to be a solid notion of what *good science teaching* should look like.

When I left the classroom in 2011, I entered a similarly challenging situation but on a much larger scale. Now, instead of just 24 teachers, all with dedicated science time and some amount of science proficiency (as measured by the Arizona Educator Proficiency exam in middle school science), I was asked to reform the science instruction occurring in 17 middle school classrooms as well as to build and implement an elementary STEM program in 63 elementary school classrooms across the district. Initially, I did not appreciate the magnitude of this challenge. I had taken for granted my own STEM training as well as the extensive support I had received from TFA. I did not understand the history of the district or the culture of reading- and math-only instruction that had become so deeply embedded in Ivory Elementary School District. The more I learned, the less prepared I felt to do what had been asked of me. “How am I supposed to get teachers who don’t even know what STEM is to teach it?” I wondered.

The only reasonable plan of attack I could come up with was a Nike–like approach: just do it. Interestingly, I soon found that the teachers were either less aware than I was of what they did not know, knew more than I thought they did, or were faking it extremely well. In any case, slowly I began to observe a few fourth grade teachers take on the challenge of incorporating STEM instruction into their practices.

As teachers took on the task of bringing STEM to their students, I was surprised by the emotions that surfaced during the process. There was an air of trepidation in the teachers, which I initially attributed to their lack of knowledge and experience. I assumed that they were concerned because they lacked a conception of what was being asked of them and they felt lost. It only took a few weeks for my assumption to shift. Instead, I began to believe that their consternation was more likely a result of having a conception of STEM instruction that they felt they may or may not be able to achieve rather than the result of a lack of a conception. This notion perplexed me. “How exactly have they come to understand STEM instruction?” I wondered.

Informally, I worked to understand how teachers conceptualized STEM, and I asked them to explain their thinking and define what this type of instruction had come to mean to them. They struggled to articulate a precise definition, and they frequently spoke instead about what STEM was not or attempted to describe some vague characteristics it might contain.

As this struggle to define STEM continued, I could not help but liken STEM to an abstract noun. Take truth for example; most everyone is able to distinguish between what is and is not the truth. People can cite conditions or characteristics we use to determine if something is the truth or not. People can quickly categorize examples or occurrences as truth or not. There is an, albeit subconscious, thought process we use to deliver truth (Coleman & Kay, 1981). This conception—the one that both filters our receptive understanding and recognition of abstract nouns like truth and STEM as well as shapes our productive behaviors to deliver them—is the prototype we have created of it (Lakoff, 1987; Rosch, 1973, 1975).

Defined as the “best examples of a conceptual category” (Haas & Fischman, 2010, p. 534), the prototypes that fourth grade, generalist-trained educators have constructed of STEM instruction are the unit of analysis for this study. Through this work, it is my intent to gain access to what fourth grade, generalist-trained teachers’ mental models or conceptions of STEM instruction are. Using a prototype construction approach, this work will analyze interview and categorization task data through grounded theory to glean teachers’ conceptions of STEM instruction individually and collectively. In doing so, the following questions will be addressed:

1. What are generalist trained, fourth grade teachers’ prototypes of STEM instruction?
    a. What are the similarities and differences between and among fourth grade teachers’ prototypes of STEM instruction?
    b. What is the relationship between teachers’ experience and their prototypes of STEM?

Significance

With STEM instruction growing in importance on a federal, state, and local level, it is imperative that the education and research communities at large come to know the prototypes educators have constructed of STEM. These constructs serve as the fulcrum of policy implementation in that policy talk revolves around the prototype, and that policy talk is then leveraged into policy action (Tyak & Cuban, 1995).

A study that seeks to understand teachers' prototypes of elementary STEM instruction will be beneficial to several constituencies on the local, state, and federal level. Of these levels, local policy makers and support staff in the local education agencies (LEA) will likely be best served because they are presently tasked with the expansion and consistent implementation of elementary STEM education. At all levels, however, policy makers are concerned with the implementation of STEM education and the work of several scholars (Glass, 2008; Henig, 2008) has already established a consistent correlation between teachers' conceptual understandings of policy and its implementation. Thus, to expect implementation of STEM instruction without understanding teachers' presently held prototypes are akin to alchemy in that it is speculative. The knowledge that elementary teachers typically lack the formal training (defined as the knowledge and experience traditionally regarded as prerequisite for instructional implementation), the local, state, and national policy makers are potentially asking teachers to create something from nothing. To avoid this, we must determine what teachers have come to understand as their task. The ability to conceptualize the prototypes teachers hold for elementary STEM instruction will remove some of the uniformed anticipation as policy makers await implementation of the infamous and undefined elementary STEM instruction for which there is no benchmark.

In other words, to mandate effective elementary STEM instruction without addressing both teachers' present understandings and expectations for future practice is short sighted. Specifically, as a district STEM director charged with leading a change that challenges a decade of history, a lack of training, and contextual challenges, it is essential that I gain access to teachers' prototypes of STEM education. Such an understanding will allow me to better prepare for navigating the gap that exists between knowing and doing (DuFour, DuFour, Eaker, & Many, 2010) by designing a program that takes into account teachers' current reality. Additionally, it allows me to design more strategic support structures for teachers to enhance their STEM instruction for students specific to their context.

On a broader scale, the elementary instructional community will benefit from a study examining teachers' prototypes of elementary STEM instruction because other urban, high needs districts will soon be navigating the same knowing-doing gap, and they will hope to avoid elementary the alchemy involved in creating something from nothing as teachers are asked to implement STEM into their classrooms. Other educators in roles similar to my own will likely benefit from this study in that its findings will enhance their knowledge of how to better support teachers implement elementary STEM instruction, especially in its earliest phases.

The significance of this work lies in the implicit tension between policy and prototype. As the study title suggests, teachers possess three distinct metaphorical prototypes of STEM; the question still stand however, whether these prototypes will drive the policy implementation and ultimately the student outcomes we desire. To explore these ideas, this work has been arranged into four subsequent sections. The next section, a review of relevant literature, includes a discussion of the policy course that led to a widespread STEM focus in elementary schools across the nation. The literature review also examines the theoretical construct of prototypes and their derivations as well as the factors that influence prototype construction related to elementary STEM. In the following chapters, methods for data collection and analysis will be explained and findings as well as their implications will be discussed.

Chapter 2

Literature Review

Fourth Grade STEM

Interestingly, although both science, technology, engineering, and mathematics (STEM) and the application of prototypes are gaining popularity and relevance in education research, scant scholarly information is available on these two subjects at the elementary level. As such, literature for this study was expanded to include studies focusing explicitly on elementary science. The methodologies of elementary science most closely reflect the methodologies associated with recent STEM movements as well as literature on prototypes in fields other than education and in educational scenarios other than STEM. Additionally, literature included in the review was restricted to the elementary grades, which are most commonly defined as kindergarten through fifth grade, but they occasionally include kindergarten through eighth (K-8) grade. Literature addressing teachers focused primarily on fully credentialed teachers instead of preservice teachers, although works dealing with preservice educators who were frequently cited or informed other studies were also considered. Other factors were determined by the urban, high needs, low socioeconomic status (SES) context in which this study will take place and by various influential factors associated with these conditions. Finally, the literature review begins with policy related to STEM education. It is discussed first because policy has been the catalyst for the recent rise of STEM focus in education.

Policy Changes

Significant shifts in the amount of attention and emphasis placed on STEM education can be traced to shifts in policy. These shifts have occurred at both federal and state levels and have led to what many educators commonly describe as the swinging of the educational pendulum when it comes to science and STEM education. In this section, I will discuss the most relevant policies working as chronologically as possible to discuss both the policies themselves and their concurrent effects on elementary STEM education.

National Defense Education Act. The inclusion of math and science initiatives in United States policy as a reaction to social pressure and comparisons of student achievement can be traced back to the days of Sputnik and the Space Race. Originally introduced by President Eisenhower as a collection of math and science initiatives, the National Defense Education Act (NDEA) was a reaction born of fear that US scientists were falling behind their international peers, specifically the Soviets as they launched Sputnik in 1957 (Urban, 2010). Designed to increase the sophistication and efficacy of math and science education in the United States, the NDEA primarily targeted higher education but reached K-12 though its allocation of funds intended to support math and science curricula and instruction (Bandeh-Ahmadi, Bracken, de la Cruz, Flattau, & Sullivan, 2006). Signed into law on September 2, 1958 the NDEA opened the gates for policy and social action, including the establishment of NASA less than a month later, around the fields now noted as STEM (http://cshe.berkeley.edu/events/ndeaconference1998/background.htm).

No Child Left Behind. In 2001, the passage of the No Child Left Behind (NCLB) act prompted a slew of changes in the United States' (U.S.) education system. Among these, disaggregation of and accountability for student data at the subgroup level as well as measures of adequate yearly progress (AYP) have had sweeping effects on public kindergarten through twelfth grade (K-12) education.

AYP examines student achievement in reading and mathematics (science is tested at the fourth and eighth grade levels, but is excluded from the AYP calculations) on state standardized assessments, in a public forum with associated sanctions for failure to reach mandated achievement goals. As many schools have struggled to make AYP, schools have experienced increased pressure to perform not in tested areas per se, but in areas for which they are held accountable. Thus, focus for those schools struggling to reach the AYP bar have moved away from science, social studies, and other unaccountable subjects, and have instead moved toward reading and math.

Arizona Learns. Federal legislation is not alone it is mandates that states measure and make public student achievement. In Arizona, the Arizona Learns system utilizes measured student achievement (Arizona Instruments to Measure Standards, or AIMS, data) at the district, school, and subgroup levels, in a formula that accounts for growth as well as the number of students who fall into each of the four proficiency levels (*falls far below, approaches, meets, exceeds*) to determine the efficacy of a school. While the formula no longer includes federal measures of AYP, student growth and proficiency are linked on a policy level through NCLB.

Like NCLB, Arizona Learns labels are calculated from student achievement on high stakes assessments in reading and math alone. Also like NCLB, these labels are made public. Used to compare schools both within and across districts, these labels have significant implications for schools and districts in that they are a piece of information often used by parents to determine which school to enroll their students in, and they also serve as the catalyst for state school improvement processes. Both enrollment and school improvement are associated with losses in funding.

Race to the Top and Reactions to Low Student Achievement

Race to the Top. On July 24, 2009, the Obama administration announced the Race to the Top initiative that aimed to reward successful and innovative schools. Specifically, Race to the Top grant funding hinged on four specific areas: adopting standards and assessments that prepare students for college and the work force and to compete in a global economy; building data systems that measure student growth and success and inform teachers and principals about how they can improve instruction; recruiting, developing, rewarding and retaining effective teachers and principals, especially where they are needed most; and turning around the lowest-achieving schools (http://www.whitehouse.gov/the-press-office/fact-sheet-race-top).

Adoption of the Common Core State Standards. Low student achievement and inconsistency between standards from state to state were major catalysts for the creation the Common Core State Standards. Schools who adopted these standards did so partly because of motivation to increase student achievement and national competitiveness, but also because of stipulations laid out by the federal government under the Race to the Top initiative. During Phase One of the Race to the Top application process, states applying for funding were expected to sign onto the Common Core consortium and thereby an associated assessment consortium as well.

Arizona adopted the standards in 2010 with the expectation for full implementation by 2014. Because Arizona has lagged behind many other states in the reported rigor of their state standards as well as student achievement, many hoped that the adoption of the Common Core or Arizona 2010 Standards would not only meet the requirements of Race to the Top but would also help raise the bar for K-12 education across the state. While English language arts (ELAs) and mathematics are the only two subject areas that have detailed standards documented under this initiative, the expectation has been communicated that science, technology, engineering, social studies, and writing will be incorporated into ELAs and Math instruction.

Partnership for Assessment of Readiness for College and Careers. In conjunction with the new Common Core State Standards, a consortium of 24 states and the District of Columbia have come together to develop an assessment to measure student achievement under the Common Core State

Standards. Development of the assessment was funded by a $186 million grant through the federal Race to the Top initiative. The assessment addresses Common Core ELAs and mathematics standards in grades three through high school, and it is expected that the new assessment will be in place for the 2014-2015 school year (www.parcconline.org). While the Partnership for Assessment of Readiness for College and Careers (PARCC) tool will not measure science achievement, it is projected that much of the ELAs and mathematics assessments will be framed in science and social studies content (http://www.parcconline.org/3-8-assessments).

Reaction to Low Achievement: The Effect on Science

Legislative and policy changes at the federal, state, and local levels have resulted in significant but unintended consequences for public education. These consequences include, but are not limited to, highly achieving students demonstrating less significant academic gains and science, social studies, and their associated instructional methodologies being neglected in the classroom. Science education across all grade levels in Arizona schools, particularly in the elementary grades and in urban, high needs schools in which reading and mathematics achievement is low, has suffered. Many schools have gone as far as to restrict or even do away with science instruction in order to reallocate instructional minutes and resources to areas of focus on the AIMS test. While surely the intentions of the aforementioned federal and state legislative changes were never to shrink the focus on science or STEM education as a whole, poor achievement in assessed subject areas included in state and federal accountability calculations over the last several years indicates the legislations has had a detrimental effect on science.

Reevaluating reactions as low achievement in science surfaces. During the years leading up to this study, economic changes and pilot measures of student achievement in science, including AIMS and the Trends in International Math and Science Study (TIMSS) data have rekindled concern for U.S. students' learning. Available data indicates that U.S. students generally perform more poorly than their counterparts in other Western countries (http://nces.ed.gov/timss/) in science and math and that Arizona students in urban, high needs schools perform more poorly than their affluent Arizona peers (http://vitalsigns.changetheequation.org).

In their 2007 report on the state of STEM in the US, the U.S. Department of Labor argued that, "Our nation needs to increase the supply and quality of 'knowledge workers' whose specialized skills enable them to work productively within the STEM industries and occupations" (U.S. Department of Labor, 2007, p. 1). The repot went on to say that "Our nation's economic future depends upon improving the pipeline into the STEM fields" (p. 1). It also cited The National Science Foundation (2004) that claimed:

> There is broad consensus that the long-term key to continued U.S. competitiveness in an increasingly global economic environment is the adequacy of the supply and the quality of the workforce in the STEM fields. Scientific innovation has produced roughly half of all U.S. economic growth in the last 50 years. (p. 2)

The concern among educators is that “if current trends continue, more than 90 percent of all scientists and engineers in the world will live in Asia” (Business Roundtable, 2005, p. 2; US Department of Labor, 2007). Furthermore, the Executive Report of 2010 President’s Council of Advisors stated that, “throughout the 20th century, the U.S. education system drove much of our Nation’s economic growth and prosperity” (p. 5). This is undoubtedly a trend that will continue as:

> The success of the United States in the 21st century—its wealth and welfare—will depend on the ideas and skills of its population. . . . As the world becomes increasingly technological, the value of these national assets will be determined in no small measure by the effectiveness of science, technology, engineering and mathematics (STEM) education in the United States. STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection and national security. (p. 5)

Furthering the conversation about unintended consequences. In 2010, the attempted reauthorization of the Elementary and Secondary Schools Act (ESEA) sparked conversation around some of the unintended consequences of NCLB and added to growing debate on the role of education in our nation’s ability to compete in a global economy. Revisions of the ESEA document, which aimed to address these concerns, included a specific focus on college and career readiness as well as STEM education. In the released revisions addressing the

STEM focus for the reauthorization of ESEA, President Barack Obama stated that he was, “committed to moving our country from the middle to the top of the pack in science and over the next decade math education” (http://www.whitehouse.gov/the-press-office/remarks-president-education-innovate-campaign).

Race to the Top: phase three. While the ESEA has yet to be officially reauthorized, its implications have taken hold in K-12 education through Phase Three of Race to the Top and the financial incentives it places on the inclusion of elementary STEM in public education. Initially, many states interpreted the action steps necessary to obtain Race to the Top funding differently. As a result, there were variations among grant applications and many states were left without funding. After the initial awards were granted, commonalities began to emerge amongst successful states; many states that received grant funding had included a focus on STEM in their applications. By Phase Three of the Race to the Top initiative, STEM was explicitly stated as an area of interest under the grant (http://www2.ed.gov/programs/racetothetop/index.html).

Arizona, a Phase Two runner up in Race to the Top, was finally awarded grant monies after it met requirements laid out by the federal government; those requirements included the addition of a STEM focus. After this documented focus, Arizona announced its participation in the creation of and certain adoption of the Next Generation Science Standards.

Assisted in the creation and adoption of Next Generation Science Standards and the Associated Framework. While the PARCC Assessment and the Common Core State Standards do not directly address science and science education, a coalition of 26 states and numerous critical partners have joined forces to construct and put into practice the Next Generation Science Standards (NGSS). These standards are internationally benchmarked and developed around the research-based framework for K-12 science education to address rigor, cognitive development, critical thinking, and communication.

A product of a recognized need to both update outdated standards and address low student achievement in science, the NGSS are being created to assist in K-12 education efforts to ensure that U.S. students are able to compete in the global economy. According to NGSS:

> Science—and therefore science education—is central to the lives of all Americans, preparing them to be informed citizens in a democracy and knowledgeable consumers. It is also the case that if the nation is to compete and lead in the global economy and if American students are to be able to pursue expanding employment opportunities in science-related fields, all students must all have a solid K–12 science education that prepares them for college and careers. (Frequently Asked Questions, 2012)

The framework associated with the standards was also a collaborative effort that focused on the need for all students to receive a strong foundation in science, technology, and engineering as part of their K-12 educational experience. The framework is organized into three major components: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas in science. The framework aims to assist educators to integrate science, technology, and engineering into their daily practices to ensure that students are able to “participate in many major public policy issues of today, as well as to make informed everyday decisions” (National Research Council, 2012, p. 1). The reasoning behind this framework is that “science, engineering, and technology permeate every aspect of modern life” (National Research Council, 2012, p. 1).

This framework and the NGSS mark two dramatic shifts within the swing of the educational pendulum. First, these documents and their associated implementation signal a resurgence of attention and accountability on science and STEM in K-12 education. Second, the transition in verbiage from science to STEM indicates a philosophical shift in the content being taught as well as the manner in which the shift occurs.

The framework and NGSS both advocate for learning by doing, more rigorous content at all grade levels, and a multidisciplinary approach to teaching and learning. Although in line with Common Core Standards and their associated instructional philosophy, the NGSS marks a dramatic deviation from the direct science instruction that was inexplicitly advocated for by previous documents. Additionally, it serves as the inaugural expectation for STEM education in most elementary schools—one that to carry out requires the construction of a prototype for elementary STEM. The challenge of constructing the prototype lies in the fact that many elementary educators potentially lack the knowledge and experience commonly accepted as prerequisite for this work.

From Politics to Prototypes

The cycle of student performance and/or societal concerns and the associated reaction through standards and policy is obvious. There was a concern that students were not performing well in school. Policy was written and enacted to measure performance. Measures raised concern about reading and math achievement. Resources were redirected to support reading and math, but as a result other areas to inadvertently suffered. Measures showed this, and then the cycle began again.

Working form a social constructionist perspective, this cycle is not surprising. Haas and Fischman (2010) argued that, “public policy and the allocation of resources are closely related to the degree that an issue becomes a public concern” (p. 533). I agree with this line of reasoning in most cases; however, I posit that in instances in which the general level of knowledge of a particular issue or topic is low, then the converse can also be true for the general public. STEM, for example, embodies a case in which the stated application of this notion is true for policy makers and specific informed constituencies but demonstrates the inverse for the general public.

Here, the creation of policy preceded general concern and included widespread trepidation among elementary school systems and the teachers within them. As such, the K-12 education system is potentially early in the process of building its elementary STEM prototype and thus could be engaging in the educational alchemy of attempting to create instruction for which they lack a well developed and informed working concept: namely, a prototype.

Drawing on the work of the cognitive sciences and experientialist thought, prototypes play a critical role in the mental functioning of individuals. Prototypes are the mental constructions by individuals that most accurately represent the primary features of a concept or category (Boswell & Green, 1988; Haas & Fischman, 2010; Lakoff, 1987). A prototype can be thought of as the best example of a category and is central to human thought, specifically categorization (Lakoff, 1987; Rosch, 1975). Derived from schema (Lakoff, 1987) and refined through knowledge and experience (Boswell & Green, 1988), prototypes serve as benchmarks against which instances are compared and either categorized as examples or nonexamples of a concept (Barsalou, 1999).

During instances of reception, an individual receives information, often through experience, and attempts to categorize it. The process of categorization occurs as the individual determines the gradation of likeness between the stimuli and the prototype with the recognition that only in extremely rare cases will the input stimuli model a replica of the prototype. Rather, the stimuli will represent or resemble the prototype in the number and congruence of its characteristics (Barsalou, 1999; Lakoff, 1987). Herein lies the individual nature of prototypical cognition: the individual must determine the degree of semblance between the input stimuli and the prototype, which shapes membership or nonmembership to (example or nonexample of) the prototype category.

In cases of production, on the other hand, the individual utilizes the prototype as a frame upon which to assemble a new example, which then belongs to the prototype category (Lakoff, 1987). In this scenario, the use of the prototype is less clear, but the result remains that while the output is seldom a replica of the prototype, it shares characteristics and qualities of the prototype.

It is also important to note that prototypes, while often experienced as a gestalt, are not archetypal in nature; they are not constant nor are they universally understood (Lakoff, 1987; Haas & Fischman, 2010). Instead, prototypes are continuously refined as knowledge and experience are increased and schematic precursors evolve. Prototypes are, however, influenced by culture and context, which often leads to collective prototypes that are shared among people of similar backgrounds (Rosch, 1973, 1975).

Prototype Construction

Teacher knowledge: elementary STEM. As previously described, STEM has become an intense focal point in U.S. policy discussions in recent years. Concurrently, discussion as to what exactly STEM is as well as the expected approach for its implementation has also gained popularity as a topic of research and publication. Across these works, however, there is not a single widely accepted definition of STEM. Thus, for the purposes of this work, several definitions have been synthesized to reflect the broadest understanding of STEM in the elementary setting. Within the constraints of this study, STEM is defined as an interdisciplinary approach to teaching, learning and problem solving in which science, technology, engineering and math concepts are applied to real world issues through an inquiry or engineering design approach (http://www.sfaz.org/ stem; http://www.iteea.org/ Resources/PressRoom/ STEMDefinition.pdf). The concepts are in tandem to the focus with the thinking and problem solving highlighted by the discipline and learning occurs through discovery, critical thinking, argumentation, and developing connections (Morrison, 2006; Tsupros, Kohler, & Hallinen, 2009; http://stem.stkate.edu/basics/stem.php).

It is evident that STEM is both an interdisciplinary approach to the content; STEM focuses on the overlap of science, technology, engineering and math but also includes an expectation for the method of teaching and learning, which eludes to the need for teachers to possess both subject matter knowledge and pedagogical content knowledge. This division between subject matter knowledge and pedagogical content knowledge will be further explored in the subsequent sections.

The broad category of *teacher knowledge* can be broken down and understood in many ways; however, for the purposes of this study, the topic of teacher knowledge will be distilled into two major cross sections: content (or subject matter knowledge) and pedagogical knowledge, as established by the work of Fenstermacher (1994). These foundational areas are frequently cited in other works and have been developed and more widely understood through the use of Shulman's (1987) model that asserted teachers poses pedagogical content knowledge and subject matter knowledge. Both of these areas are developed in myriad ways and actively contribute to prototype development. When considering pedagogical content knowledge here, the examination of pertinent literature will be limited to the role of teacher preparation programs and teacher professional development, because they are within the realm of influence for a science specialist. Thus, teacher preparation program and professional development are most relevant to the questions posed in this study.

Pedagogical content knowledge. Pedagogical content knowledge (PCK) is the largest area of focus for teacher preparation programs. Most of these programs have been developed around teaching standards for beginning teachers that aim to address the question: “What knowledge is essential for teaching?” (Abell & Lederman, 2010, p. 1106).

While many states have adopted similar yet distinct versions of national standards, the standards for beginning teachers developed by the Interstate New Teacher Assessment and Support Council (InTASC) serve as the national foundation for beginning teacher licensure. These standards, most commonly known as the InTASC standards, “reflect the professional consensus of what beginning teachers should know and be able to do” (http://www.wresa.org/Pbl/The%20INTASC%20Standards%20overheads.htm). Within the InTASC document that outlines standards for beginning teachers, PCK is explicitly addressed as the first standard.

Standard one, entitled Content Pedagogy, outlines the expectation that beginning teachers understand the content, tools, and instructional approaches necessary to make content comprehensible for students. Outside of this standard, pedagogy and its direct relationship to content are not addressed. However, pedagogy is discussed in a sweeping sense throughout the document under the sections about multiple instructional strategies and motivation and management. The recurrence of this general notion is reflective of the focus for most teacher preparation programs and professional development experiences, with the focus being pedagogical development.

Teachers' application of PCK varies. Appleton (2002) argued that elementary teachers used activities that they believed to be functional as their primary application of PCK. Similarly, Roth et al. (2006) found that American teachers' primary evaluation of a potential lesson activity was their perception of its functionality. Interestingly, perceptions of functionality were often based on the observed or expected level of student participation for a given activity, but perceptions did not necessarily consider that participation was analogous to learning.

Inquiry-based model. While general discussion of teachers' PCK is valuable, it is not specific enough to meet the needs of this study. Additional consideration must be paid to the pedagogical strategies and methodologies associated with STEM, namely inquiry and problem-based approaches. While these approaches have been subject to some discrepancy in the literature, they are explicitly advocated for in the policy talk as well as the standards and frameworks driving the elementary STEM movement in the US (National Research Council, 2012). In the following sections, these two approaches are further explored.

Inquiry: What is it and why use it? It has been argued that, due to the complexity of science and its requirements, in order to develop content knowledge as well as knowledge for engaging in scientific practices and discourse, it is necessary for students to develop their knowledge differently than other subjects. Specifically, they need to learn by doing (Beyer & Davis, 2008). Reforms in science education highlight the need to promote scientific literacy among all students and suggest that students can become part of an informed citizenry by having the opportunity to learn science through inquiry (Beyer & Davis, 2008; National Research Council, 1996, 2000).

As evidenced by instructional shifts in both the Common Core Standards and the NGSS, it is clear that inquiry is an initiative at the forefront of many educational agendas. Thus, it becomes important to understand both what inquiry is as well as what it is not. As stated by Minner, Levy, and Century (2009) and supported by the vast amount of definitions of inquiry, the field of education has not yet reached consensus on exactly what inquiry-based instruction is. There is greater agreement in regard to what it is not. Therefore, we will begin the discussion of inquiry-based science instruction with what it is not, after which, we will move on to operationalize what inquiry-based instruction is for the purposes of this study. Inquiry-based instruction is not a “minimally guided, non-traditional instructional approach” (Atwood, Christopher, Combs, & Rowland, 2010, p. 65). It does not advocate for student engagement through teacher disengagement. It is not haphazard, and while it does require students to process information differently, it does not prevent students from processing information. Rather, inquiry-based instruction is a student-centered, investigative approach that relies on metacognition and critical thinking (such as comparison and contrast, making generalizations, etc.) to develop conceptual understandings of topics and to participate in discursive, evidence-based communities (Atwood et al., 2010; Beyer & Davis, 2008). In this way, teachers are expected to facilitate students' learning of scientific concepts by engaging in the activities and thinking processes of scientists (Furtak & Alonzo, 2010).

To define what inquiry-based instruction is, it is beneficial to examine its component parts as described by the literature. Based on the works of many researchers, I have found that there are five main components of inquiry-based instruction that run throughout the studies I reviewed. Furthermore, the research not only suggested that these components comprise the foundation of effective inquiry-based instruction, but that teachers must address each of them to successfully implement inquiry-based instruction associated with positive student achievement and conceptual development. These components are as follows:

- Data and Evidence: At the heart of scientific inquiry are data and evidence. In fact, "A key aspect of teaching science as inquiry, is one of allowing students extended time to really grapple with data and to make sense of their observations, using logic and reasoning" (Crawford, 2006, p. 618; Minner et al., 2009).
- Grappling: Students need to grapple with data in order to confront misconceptions and draw conclusions. This grappling, or time to struggle with data, misconceptions, questions and concepts, has been associated with higher levels of conceptual understanding (Minner et al., 2009) and short-term motivation (Palmer, 2009). Furthermore, grappling is a form of authentic, meaningful engagement with the science content. Through engagement,

Minner et al. (2009) argued that students were able to build conceptual understanding and form the basis of their working knowledge of science content. While engagement in this general sense is most certainly a component of inquiry, grappling as described across the literature is a more specific form of engagement that requires the learner to draw on higher cognitive processing skills to make meaning of the experience in conceptual terms. In this way, Longo (2010) also argued that grappling encourages students' creative processing.

- Ownership: In inquiry-based lessons, students are tasked with guiding their own experience. While this task varies in degree across open- versus guided-inquiry experiences (National Research Council, 2000), students must take ownership of their learning to ensure that the inquiry experience at hand progresses (Minner et al., 2009, p. 478). As a function of the student-centered nature of this inquiry ownership, teachers must be flexible. Not all students experience inquiry in the same way. The metacognitive questions and processes that guide students' thinking or that a teacher must provide to a specific student could vary greatly from one learner to another.
- Scientific habits of mind: Teachers support children as they draw upon scientific habits of mind (National Research Council, 2005, 2012; National Research Council, 2007; National Research

Council, 1996; National Research Council, 2000) to ask questions and test hypotheses. Through this process, children utilize natural curiosity and learn systematic inquiry techniques to question and explore topics relevant to them. Stohlberg (2008) asserted that this component of the inquiry process, among other components, helps to nurture the human sense of wonder.

- Communication: As a tool for either knowledge construction or explanation, language and communication are essential to inquiry-based science. Carlsen (2010) argued that, “Language is central to science. It is the medium through which claims are made and challenged, empirical methods and data are recorded, and the story of inquiry unfolds” (p. 67). In this way, language becomes the critical tool for communicating scientific findings, data and ideas. Communication serves to validate the scientific experience and understandings derived from it by sharing it.

While some researchers, like Dalton, Morocco, Tivnan, and Mead (1997), disagreed with the specific role of language in inquiry-based scientific teaching, learning, and practice, there is still consistency in the value placed on language and communication. The Dalton et al. (1997) study found that inquiry-based approaches to science teaching were more effective in modifying students’ content concepts than other approaches that simply incorporated a hands-on activity. Most significantly, however, the study found that in order for students to modify mental models associated with content concepts, the students must be provided time to discuss their experiences and findings as a class. Further supported by conceptual change theory (CCT), inquiry-based science instruction aids in students' creation of individual conceptual models congruent with public and or established conceptual models through discovery and discourse (Carlsen, 2010).

The challenges of inquiry-based science instruction*.* Utilizing an inquiry-based approach, the teacher guides the students toward a deep conceptual understanding of the content concepts. Unfortunately, this deeply conceptual understanding is highly desirable outcome hindered by challenges to the process. Roerig (2004) argued that the transition from theory to practice is a tough one for inquiry-based instruction. Teachers face many challenges in putting inquiry-based instruction into place in their classrooms. Typically, so implementing inquiry-based instruction effectively requires teachers to have a firm command of the content concepts themselves. Arguably, this situation becomes problematic in that most elementary school teachers are likely to lack a strong content background in science (Beyer & Davis, 2008; Furtak & Alonzo, 2010; Weiss, Banilower, McMahon, & Smith, 2001). The challenge of having inquiry-based instruction in the classroom is further exacerbated by the discrepancies between many teachers' beliefs about what inquiry-based science instruction is and what the scientifically and pedagogically accepted parameters for science education are (Crawford, 2006).

Furtak and Alonzo (2010) demonstrated the challenge associated with the likelihood that elementary teachers lack science content or background in inquiry-based instruction. Furtak and Alonzo (2010) asserted that the internalization of inquiry's requirement for teachers not to give students the answers has led to many teachers inadvertently withholding content knowledge from students (p. 426). Correspondingly, Smith (1996) argued that the phenomenon of withholding information might be attributed to what feels like the nebulous nature of inquiry-based instruction. He asserted that teachers more readily grasp what they believe they are not supposed to do during inquiry-based instruction, which leaves them to fixate on these types of issues while underdeveloping their positive mental models of the inquiry-based approach. In some cases, this can lead to an overemphasis on activities and behavior rather than on the underlying content concepts (Furtak & Alonzo, 2010). Carlsen (2010) believed that:

> Everyday experiences may be necessary for scientific concepts to develop, but they do not cause that development. Scientific ideas ascend from the abstract to the concrete (Rowlands, 2000; Rowlands, Graham, & Berry, 1999). In science there is always a need for formal instruction. (p. 59)

In order to truly develop a deep, conceptual understanding for students, teachers need first to recognize when it is appropriate to use inquiry-based instruction. Furthermore, they need to be skillful in their questioning strategies and guidance during inquiry-based instruction so as not to blur the lines between these two strategies. Such guidance ensures that students are engaging with the experience at a deep cognitive level and developing their own conceptual understandings.

Rigor matters. As a whole, the relationship between inquiry-based instruction and student mastery of concept standards has been inconclusive, yet Minner et al.’s (2009) findings determined that the level of cognitive rigor associated with an inquiry-based learning experience is positively correlated to student learning outcomes in science content (p. 487, 489). In addition, Minner et al.’s (2009) meta-analysis found that 55% of students whose treatment was coded as having a high level of inquiry saturation demonstrated statistically significantly improved performance as compared to their peers who experienced less rigorous or saturated treatment. This finding was further supported by the work of Dalton et al. (1997) and Kanter and Konstantopoulos (2009), who suggested that inquiry-based instruction is vastly different from recipe-style laboratory experiments in which students follow a predetermined set of steps. In their work, findings supported the notion that the cognition associated with an inquiry-based approach was correlated not merely manipulating materials, but with increases in students’ cognitive concepts as well. In fact, Kanter and Konstarntopoulos (2009) found that student achievement on high- and medium-level cognitive tasks increased over half a mean level shift but remained unaffected for low-level cognitive tasks (p. 871).

Problem and project-based model. Problem-based learning (PBL) has a long history in science education. PBL has been touted as able to provide students with meaningful learning scenarios within which to engage in constructing content knowledge at a deep level by allowing “students [to] assume the role of scientists,” (Drake & Long, 2009, p. 2). As a form of inquiry-based instruction, PBL presents students with a real life scenario or problem to solve before any direct instruction or content learning takes place. In this way, it is expected that students apply what they already know and engage in investigations to further what they need to know in order to solve the problem at hand (Gordon, Rogers, Comfort, Gavula, & McGee, 2001).

As a methodology in elementary science, the measured efficacy of problem-based instruction is inconclusive. First of all, there are few recent examples of empirical studies conducted in elementary grades using the problem-based approach. Second, many of the studies that do exist were not conducted in high needs areas, thus creating a skewed sample within the existing literature. One study by Kanter and Konstantopoulus (2009) asserted that there was reason to believe that PBL will have a beneficial outcome on student achievement, but the study does not provide empirical evidence for this claim.

In contrast to the inconclusive nature of findings involving inquiry-based PBL on academic achievement, there is evidence supporting other positive impacts of PBL on students. For instance, Drake and Long (2009) found that, when measured using the draw-a-scientist test, students who were part of an experimental group in which PBL was the instructional approach used in their classrooms held less stereotypical views of scientists than their control group peers (p. 11). In addition, students exposed to inquiry-based PBL in science have been found to be more engaged in learning, which is evidenced by time spent on a task (Drake & Long, 2009, p. 12), elaboration associated with answering higher order questions (Blanchard, Southerland, & Granger, 2008), and positive increases in attitudes toward science. However, Kanter and Konstantopoulus (2009) found decreases in the attitudes and intentions of minority students to go to college as well as decreases in their perceptions of the importance of science.

Subject matter knowledge. Subject matter knowledge (SMK) was described by Shulman's (1987) framework as the knowledge a teacher should or does pose regarding the content concepts of the subject he or she teaches. Early studies in the body of research focus almost entirely on the number of content courses taken as a measure of SMK. Later studies expanded their scope to include qualitative data to measure teachers' conceptual understanding of a given subject matter through his or her execution of a lesson. Such studies suggested that effective teaching requires the teacher to possess SMK that goes beyond the recitational level to deep ownership of complex content concepts (Jena, 1964).

Studies on SMK have been conducted in the domains of biology, earth and space science, chemistry, and physics. In general, these studies show that elementary preservice teachers have less SMK than their secondary counterparts and that their misconceptions tended to be similar to those of their students (Abell & Lederman, 2010; Martín del Pozo, 2001). Similarly, a study of elementary preservice teachers and parents found that they performed at approximately the same level as ninth grade students in the domain of chemistry but that secondary teachers performed slightly higher (Abell & Lederman, 2010).

The measurable relationship between teachers' background in science, especially when measured by the number of content area courses a teacher has taken, and efficacy is controversial. Abell (2007) reported that many studies have found no correlation between teacher science background and effective teaching. On the other hand, studies also report a strong positive correlation between a teacher's formal science background and effective teaching (Dreschler & Van Driel, 2008). It is possible that the incongruence of this data is reflective of how efficacy was measured and the breadth to which the notion of teaching was examined. Teaching is such a dynamic concept that to measure it as a singular whole is likely to yield different results than when taken in its entire form.

Regarding the development of SMK, Arzi and White (2004) found that the best predictor of teacher SMK is the curriculum a teacher teaches. Arzi and White (2004) asserted that the curriculum serves as both an organizer and source of knowledge for the teacher. While there is not a congruent elementary study to explicitly support the generalization of this finding, it stands to reason that this observation would hold true given that elementary teachers typically have less formal science background than their secondary counterparts. Similarly, Hauslein (1989) and Hauslein, Good, & Cummins (1992) found that teachers' SMK is reshaped overtime as they gain teaching experience .

The finding of the relationship between SMK and teaching experience is critical in cases in independent school districts (ISD) in which teachers have not taught science in several years, if at all. Under the auspice of SMK development through curriculum usage, these teachers will likely present with a distinct deficit in SMK because they have not been exposed to the curriculum. Even in cases when the teacher may have some content background, he or she will likely not have had the opportunity to refine their understandings of SMK as they relate to teaching.

PCK and SMK Overlap. The challenge with PCK and SMK is that they are undeniably interwoven. For instance, in lesson delivery, when teaching is narrowed to focus on the delivery of content concepts from the teacher to the students, there is a positive correlation between a teacher's formal science background and their use of inquiry-based strategies including demonstration, discovery, use of student ideas to support deep conceptual development (Marshall, Horton, Igo & Switzer, 2009). When planning, Treagust (2010) argued that preservice teachers rely on SMK while they are planning but then use other strategies, largely PCK and pedagogical knowledge, PK during lesson execution. While this may speak to the need to utilize different skills in different parts of a lesson, it could also be reflective of many preservice elementary teachers' lack of content knowledge. In fact, Anderson (1979) believed that, "Lack of science content . . . made it virtually impossible for [teachers] to structure the information in lessons in ways preferred by science educators" (p. 226). This lack of SMK affects teachers' ability to adequately and accurately select and employ PCK, thus leaving one to deduce that while not mutually exclusive, the two are certainly codependent.

Teacher Experience

The compliment to teacher knowledge as asserted under prototype construction theory is teacher experience (Lakoff, 1987; Rosch, 1973, 1975). Here, experience is not standard and what may or may not be included in the experiences contributing to one's prototype is unclear. Therefore, we will consider the major factors that make the experience of being an elementary educator in the Ivory Elementary School District unique along with its context and its associated factors, student characteristics, and elementary teacher preparation or training.

Contextual information impacting STEM education in Arizona.

Aside from changes in federal and state legislation, there are a number of other factors that affect STEM education in Arizona. Demographically, Arizona schools serve a unique and changing population. In the last decade, Arizona has seen changes in the racial and ethnic composition in the state, the percentage of children considered economically disadvantaged, as well the amount of students who have limited English proficiency (LEP) or are considered English language learners (ELL). Table 1 includes the data regarding the demographic changes within Arizona.

Table 1

Demographic Changes in Arizona Population from 2000 to 2010

		2000	2010	Percent Change
Racial/Ethnic Category	Black	3.1%	4.1%	+1.0%
	American	5.0%	4.6%	-0.4%

	Indian/Native			
	Asian	1.8%	2.8%	+1.0%
	Hispanic/ Latino	25.3%	29.6%	+4.3%
	White	75.5%	59.8%	-15.7%
Economically Disadvantaged			15.3%	
English Language Learners (Language other than English Spoken at Home)		25.9%	27.1%	+1.2%

Note. Created from data provided by the U.S. Census Bureau retrieved from http://www.census.gov/prod/2003pubs/c2kbr-29.pdf, http://factfinder2.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t, and http://quickfacts.census.gov/qfd/states/04000.html

As one can determine by reviewing Table 1, the demographics of Arizona are changing. Neighborhoods are becoming more diverse and the needs of many communities are likely increasing. Increases in racial and ethnic diversity as well as the number of students who speak a language other than English at home reflect national and state trends (English-Language Learners, 2011). These increases, especially when combined with higher numbers of students and families who fall below the poverty line, pose significant challenges to educators' practices. More specifically, these demographic shifts further challenge teachers in their implementation of STEM instruction by limiting their ability to make it contextually, culturally, and chronologically relevant for students in the elementary grades. Research has shown that "All too often, teachers' knowledge of science and/or student diversity is insufficient to guide students from diverse backgrounds toward meaningful science learning" (Lee & Luykx as cited in Abell & Lederman, 2010, p. 171).

Science in Urban, High Needs Settings

Much of how individuals understand and come to develop prototypes is related to the context in which they receive information and engage in the prototype construction; therefore, it is necessary to explore the context in which our sample population has constructed their prototypes of STEM: urban, high needs environments.

Science has had a troubled history in urban and high needs schools and districts to a much greater extent than in suburban districts. For the purposes of this study, urban districts are those located in large cities. These districts also tend to be culturally and linguistically diverse and have a low SES (Lee & Luykx, 2010). The following outlines the connection between urban and high needs schools. There are achievement gaps associated with the three variables of linguistic diversity, low SES, and urban geography. While simply the presence of these characteristics does not categorize a school as high needs, demonstration of their associated achievement gaps does. Thus, high needs schools can be defined as those with large numbers of ELLs and low SES students who likely display below-grade-level achievement in at least one subject area at the student subgroup level.

Utilizing similar but inexplicit definitions of urban and high needs schools, Lee and Luykx (2010) argued that the previously mentioned variables are each associated with lower student achievement on standardized tests. They posited that while the achievement gap for minority students is gradually narrowing, there is a distinct difference in the student achievement of Black and Hispanic students when compared to their Caucasian peers. Additionally, while trend data on low SES students from national assessments is not available, it can be deduced from point-in-time data that students from low SES backgrounds score markedly lower than their more affluent counterparts (Lee & Luykx, 2010).

Not only do students in urban and high needs schools bring more challenges to the classroom than other students, but their teachers also report struggles in meeting the needs of these students. Many teachers report limitations on their ability to engage students in inquiry-based or hands-on learning. They attributed this to high-stakes testing pressures associated with teaching in schools with low student achievement in high-stakes subjects as well as lack of resources (Andersen, 2011). Additionally, differences in the experiences of students in urban, high needs settings as compared to those of their teachers make it difficult for teachers to draw on the funds of knowledge their students bring, which helps to make the learning relevant (Gonzalez, Moll, & Amanti, 2005).

Although teaching science in an urban, high needs school brings its own unique set of challenges, there are strategies teachers can use to mitigate these issues and make science learning more meaningful and comprehensible for students. Glynn and Winter (2004) cited contextual teaching and learning (CTL) as a means of highly contextualizing learning to present settings in order to bridge the gap for students of diverse backgrounds. Kanter and Konstantopoulos (2009) reported a statistically significant positive correlation between frequency of inquiry activities and student attitudes toward science with minority students.

Teachers who frequently supported students in explaining concepts to one another predicted increases in the value students place on science and their perceptions of its relevance.

Students

English language learners. As one of the factors comprising the high needs categorization of schools, student home language or their associated status as an ELL is critical to consider. In the *Handbook of Research on Science Education*, William Carlsen (2010) called language "more than just a social means to individual ends" (p. 58). He further asserted that, "Human knowledge is discursive in nature, reproduced through language and artifacts in social institutions like schools" (p. 65). As such, language, although inconsistently associated with science teaching, has been asserted as a critical skill for science learning. So much so that drawing on the work of Sutton (1998), Carlsen (2010) argued that, "research increasingly views language as more than just a social means to individual ends" (p. 58).

Lee and Luykx (2010) argued that students must be able to engage in the majority discourse in order to make sense of the learning. As they wrote:

> Regardless of the origin or nature of students' marginalization, academic success often depends on assimilation into mainstream norms. Thus, the educational success of immigrant or U.S.-born racial/ethnic minority students depends to a large degree on acquiring the standard language and shared culture of mainstream U.S. society. (Lee & Luykx, 2010, p. 173)

Discourse can be defined in Gee's (1999) terms as, "different ways of thinking, acting, interacting, valuing, feeling, believing, and using symbols, tools, and objects" (p. 13). The ability to engage in discourse in conjunction with ownership of the majority language allows students to make meaning of experiences or instruction in the social setting of the classroom (Carlsen, 2010; Kelly, 2010).

Carlsen (2010) carried on the line of argument regarding majority language in a chapter titled *Language and Science Learning in the Handbook of Research on Science Education*. He posited that science learning is, by nature, discursive. Even when using an inquiry-based approach, he argued that, "language is central to science. It is the medium through which claims are made and challenged, empirical methods and data are recorded, and the story of inquiry unfolds" (Carlsen, 2010, p. 67). This sentiment is further echoed by the work of Kelly (2010), who drew from the works of Gilbert, Boulter, and Elmer (2000) and stated that the use of language as a means of explaining scientific concepts and or phenomena is critical for understanding science.

Unfortunately, many students do not receive the language support necessary for them to fully and deeply engage in meaningful science experiences. For instance, Shaver, Cuevas, Lee, and Avalos (2007) reported less hands-on learning occurs under high-stakes testing pressures even when teachers know that a hands-on approach is better suited for the learning needs of ELL students. In districts like Ivory School District, this issue is only further amplified by the fact that the majority of students are second language learners or ELL students,

Teacher Training

Generalist trained teachers in elementary schools. In the US, a long-standing tradition of variability in teacher preparation and training programs has existed. Left up to each state, credentialing requirements, including education and certification standards, are inconsistent in both their conception as well as their enforcement. In Arizona, eight types of teacher certificates are available. Of these eight certificates, an elementary certificate enables a teacher to teach first through sixth grades and with special endorsements in content areas or early childhood, they are able to teach kindergarten or seventh through eighth grades.

Teachers who hold a K-8 certificate in the state of Arizona are typically trained as generalists. Individual with the certificate have graduated from teacher preparation programs that utilize a broad approach to teachers' training. Aside from three semester hours or 45 clock hours of structured English immersion (SEI) training as well as three semester hours or 45 clock hours of research-based phonics instruction, elementary teachers holding elementary certificates are not required to specialize in any area (Elementary Certificates, 2012).

The caveat to the certification, however, comes from federal NCLB legislation and the inception of highly qualified teacher statuses. Under NCLB, all students are required to be taught by a teacher who has been deemed by state guidelines to be highly qualified. In Arizona, this had little impact on teachers of first through fifth grade beyond the phonics and SEI requirements previously mentioned. In schools in which sixth, seventh, and eighth grade teachers teach specific subject areas, teachers are required to be highly qualified in any subject areas they teach that constitutes more than 50% of their instructional day. This highly qualified teacher (HQT) status is achieved by passing an Arizona Educator Proficiency Exam in a given subject area.

In the case of science, the high demand for but limited ability to fill science positions led to flexibility being built into the legislation. NCLB requirements on HQT status were revised to allow each state to adopt methods for highly qualifying teachers in broad science or subject specific science (Fact Sheet, 2004). In Arizona, teachers of grades seven through eight are required to pass an Arizona Educators’ Proficiency Assessment (AEPA) in middle grades science in order to be considered highly qualified as science teachers. First through sixth grade teachers are not required to take any AEPA subject area assessments nor are they required to have specific coursework in their college preparation programs beyond those required as baseline for graduation from their respective institutions.

In this way, the generalist training model for elementary educators is potentially problematic. Under such circumstances, elementary educators have little (if any) STEM background. Many have not had any exposure to STEM content, especially science, technology, and engineering, or STEM methodologies at the college level. Some programs like the iTeach program at Arizona State University (http://education.asu.edu/content/iteachaz) require all elementary educators to take a single semester methods course in which STEM instruction is addressed. This, however, does not take the place of STEM content courses. Without the content knowledge, the application of STEM pedagogical methods is not sufficient to ensure student learning. Furthermore, many teachers themselves lack the content, cultural, and experiential knowledge to make learning relevant for elementary aged students (Abell & Lederman, 2010; Carlsen, 2010; Jones & Carter, 2010; Lee & Luykx, 2010).

Teacher Attitudes and Beliefs

Little work has been done that directly measures elementary teachers' perceptions of STEM; however, a considerable body of knowledge has been constructed around teachers' belief systems. Belief systems are composed of attitudes and beliefs and serve as a perceptive filter for most teachers (Jones & Carter, 2010).

Jones and Carter (2010), drawing from the work of Keys and Bryan (2001), argued that, "virtually every aspect of teaching is influenced by the complex web of attitudes and beliefs that teachers hold" (p. 1067). While we cannot at this time directly assert a relationship between teacher attitudes and beliefs and teachers' prototypes of STEM, we are able to correlate teacher attitudes with PCK and SMK. In particular, teacher attitudes and beliefs are so strong that as early as 1977, studies found a connection between teacher attitudes and teacher knowledge (as cited in Campbell & Martines-Perez). Further research continued with later studies specifying that the number of science courses taken by a teacher positively correlated to the teacher's attitude toward teaching science using an inquiry-based approach (Jones & Carter, 2010). Therefore, it stands to reason that such an influential factor would have an effect on the prototypes teachers construct of STEM.

Chapter 3

Methods

Case Study

Teachers’ prototypes of STEM instruction are complex constructs that require deep analysis to understand. These constructs are significantly affected by teachers’ knowledge and experience (Barsalou, 1999; Lakoff, 1987). To capture the intricacies of teachers’ prototypes as well as the potential relationship between prototypes and experience, I will use a comparative case study to collect and analyze data. This will allow for a deep analysis of the data through repeated data collection and triangulation (Denzin & Lincoln, 2007, p. 120) and will provide insight to the prototypes that have been constructed by each of these groups. Overall, the research will all me to derive comparisons both within and across the groups being studied.

A case study approach, as Miles and Huberman (1994) established, will provide a more accurate view into the experiences and constructions of prototypes as related to science, technology, engineering, and mathematics (STEM) instruction for the selected groups. The approach takes into account “complex, situated, problematic relationships. They pull attention both to ordinary experience and also to the disciplines of knowledge, such as sociology” (Denzin & Lincoln, 2007, p. 126). Thus, the research requires analysis across multiple axes and through multiple interactions between the researcher and participant. Additionally, it has been found that research into scientific inquiry has been most successful when researchers work with teachers instead of simply studying them

(Crawford, 2006). Therefore, a combination of survey, interview, and categorization task data will be used as the primary methodologies in this study.

The unit of analysis for each of these methods are three independent cases: teachers with 0-3 years experience, teachers with 4-9 years experience, and teachers with more than 10 years of experience. Each case will be analyzed independently to determine the prototype constructed by the respective case. Each case will also be compared to the others. Finally, within each case, additional analysis will be conducted regarding teachers' knowledge and experience as related to training and coursework in order to discern the role of teacher training in prototype construction.

An implicit tension exists within this approach: the findings of the study will be highly contextualized, thereby limiting their generalizability; simultaneously, the study applies a broad enough purview to situate fourth grade teachers' prototypes of STEM instruction in the center of analysis. Such analysis allows generalizability to shroud the focus and create a space for this study's findings to potentially inform a larger, perhaps collective case study from which findings may be further generalized (Ragin & Becker, 1992).

Data Collection

The case study will use qualitative data from a combination of surveys, if-then questions, interviews, and a categorization task. The following subsections detail the purpose, rationale, design, sampling and protocol for each. Procedures for analysis are discussed in the subsequent section.

Survey

Purpose. Survey data will serve as Stage 1 of data collection, which fulfills two purposes within this study. First, the survey will serve as the tool for collecting basic teacher data including demographic data, years of experience, type of certification, and training. Second, surveys will be used to collect baseline information on teachers’ conceptions of STEM education through two if-then questions.

Rationale**.** As a tool for initial data collection, the survey was selected for two primary purposes. First, the survey is efficient. Second, this structure will allow me to collect the baseline data needed from multiple participants to construct the opening questions for the interview component of data collection.

Design. To access this information, the 10-item survey was composed of three major types of questions: demographic, professional history, and if-then. Demographic information elicited through the survey included name, sex, and age. Professional history includes years in education, years in the district, type of certificate, type of training, and whether teaching was a first career or not. The if-then questions were free response questions that asked participants to modify a scenario so that it transitioned from an example of STEM to a nonexample or vice versa.

Sampling and protocol. The survey instrument will be given to all fourth grade teachers in the Ivory School District. A link to the survey (full version of the survey and associated web link can be viewed in Appendix A) was e-mailed to each fourth grade teacher in Ivory Elementary School District along with a participant letter (Appendix B). The letter, which included instructions for completion and submission of the online survey as well as a URL address needed to access the survey instrument, was pasted into the body of the e-mail document to ensure easy access for participants. Any teachers who did not respond in one week received a follow up e-mail. Those who did not respond after the second e-mail attempt received a paper copy of the survey and a hard copy of the letter in district mail. If no response was received after the third attempt, it was considered that the individual declined to participate.

Timeline. Initial contact was made with all district fourth grade teachers the week of December 10, 2012. All completed surveys were obtained by December 21, 2012, at 4:00 p.m.

Interview

Purpose. The primary purpose of the interview was to gain access to participants' most conscious components of their STEM prototypes.

Rationale. The interview was designed to access the conscious components of the participants' prototypes. Teachers utilized their prototypes to construct their responses around their conceptions of STEM. Thus, an analysis of their interview responses provided insight into the teachers' prototypes.

Design. The interviews were semistructured and the initial questions were crafted from participants' survey responses. These initial questions varied from one participant to another and can be reviewed in Appendix D.

Sampling and protocol. From the completed surveys, I selected a random sample of 12 to 20 participants . These individuals were contacted via e-mail (or the preferred method of communication as noted by the participant in the survey) (Appendix C) and invited to schedule their interviews and categorization tasks as further participation in the study.

Each of the participants was interviewed separately in the environment of their choosing. Interviews were recorded and field notes were taken during the interview. As the interviews are semistructured in nature, any follow up or additional questions that were not part of the initial set were noted along with participants' responses. Interviews were transcribed and the transcription and field notes were then analyzed.

Timeline. Interview data was collected between December 26, 2012, and February 3, 2013. Interviews were conducted on the day and at the time of each teacher's choosing.

Categorization Task

Purpose. The categorization task was designed to gain access to the less conscious components of teachers' prototypes of STEM. This task functioned as the cognitive inverse of the interview. In this way, less conscious components of the prototype were illuminated through the unconscious categorization process and then further understood through the posttask interview.

Rationale. Prototypes and the categorization component of human thought and logic associated with them largely takes place on a subconscious level (Lakoff, 1987; Rosch, 1973, 1975). As such, completion of a task like this serves to illuminate the prototype by using it in an authentic manner to determine category membership or nonmembership because the prototype serves as the reference point against which experience is compared to make the determination between membership and nonmembership. The identification of an artifact as an example or nonexample in conjunction with analysis of the characteristics that led to such a determination provides insight to the prototype itself.

Design. The categorization task consisted of two major components: the categorization task itself and the posttask interview. During the categorization task, participants will be shown videos clips, still images, and phrases (referred to as artifacts in the rest of the study), which they will be asked to classify as an example or nonexample of STEM instruction. Although I recognize that this dichotomous design initially seems incongruent with experientialist thought, it is purposeful in its ability to access information specific to the prototype.

Although in its most comprehensive form, category membership occurs across a gradient, when the gradient is distilled, things do or do not belong. It is in this distinction that we unearth key components of the prototype. Ultimately, the scope of this work is concerned only with what the prototype is, not the degree of semblance between the prototype and the artifacts or the degree of influence of particular prototypical characteristics on an individuals' categorization.

The posttask interview was designed on the basis that an interviewee "brings in utterances stemming from a conceptual understanding of what is being talked about" (Larsson & Halldén, 2009, p. 624). During this phase of data collection, the unconscious usage of the STEM prototype makes its way toward consciousness as the interviewee explains how and why each artifact was sorted.

The posttask interview was unstructured in nature. The researcher asked probing and follow-up questions based solely on the responses and choices of each individual participant. During this phase, a standard question was used to open the interview. For examples, I asked "Tell me about how or why you identified these as examples and these as non-examples." I attempted not to lead with any questions or directions other than to explain the rationale for categorization of each artifact. However, additional questions were posed to obtain further information from each participant as the interview and debriefing process continued.

Sampling and protocol. All of the 12 participants who chose to participate in the study and completed the initial interview were asked to complete the categorization task. This was done one of three ways: immediately following the initial interview, during the same session, or at a later date. The point at which the categorization task was completed depended on the schedule and preference of each participant teacher.

To begin this segment of data collection, I read the categorization task instructions (Appendix D) to the each participant. The participant then had the opportunity to ask questions related to the protocol for the task. After all questions had been answered, the task began. As a self-paced task, the participant had control of the computer, which allowed him or her to advance through the categorization task, which included a PowerPoint slide show of images, videos, and text (Appendix E). The numbered artifacts were examined and categorized using a standard classification sheet (Appendix F) in which the artifact number was recorded in the example or nonexample column. After all artifacts had been classified, the participant was offered a break, following which the posttask interview debriefing took place.

I began the posttask interview debriefing by asking the grand tour question, which was “Tell me about how you classified each artifact as an example or nonexample of STEM.” Responses were recorded and field notes were taken to inform follow-up questions. All audio recordings from the posttask interview debriefing were also transcribed. Transcriptions, categorizations, and field notes were then analyzed using grounded theory.

Timeline. All categorization task data (completion of the task and the posttask interview debriefing) was completed between December 26, 2012, and February 3, 2013. Categorization task data for each participant was collected following the respective initial interview.

Participant Safeguards

In order to ensure the security and privacy of all participants in the study the following safeguards were put into place:

1. Any identifiable person or place, including the district and schools in which this study is taking place as well as the participating teachers, were given a pseudonym for use throughout the study.
2. Audio recordings used in this study were destroyed by March 1, 2013.
3. While audio recordings were used for analysis, they were be stored in a secure, locked location.

4. All information obtained as part of this study is fully confidential. None of the information collected as data or derived through analysis has been revealed to participant teachers' supervisors.

Data Analysis

Grounded theory. All data were analyzed using the grounded theory (GT) technique developed and explained by Denzin and Lincoln (1994, 2007, 2008) and Corbin and Strauss (1997). Here, GT serves as a “systematic, qualitative process used to generate a theory that explains, at a broad conceptual level, a process, an action, or interaction about a substantive topic" (Creswell, 2002, p. 439). To ground the theory in this study, coding occurred in three phases, each of which draw on open, axial, and selective coding to discern components or themes related to participant teachers' prototypes of STEM (Glaser & Strauss, 1967.

Operationally, open and axial coding are the processes by which themes or trends are identified, distilled, and then understood within the context of the data. Both open and axial coding utilize the researcher as a tool for analysis as he or she is tasked with first noting patterns within the data and then deciphering their significance. During open coding, the researcher identifies any themes or categories present within the data. This process is organic and iterative in nature. It begins by allowing themes to emerge as patterns within the data. At this point, it is not concerned with differences or similarities between trends, the number of occurrences of a given pattern, or the relationships between and among trends. Once all patterns have been identified, the researcher works to discern their meaning and marks the transition from trend to theme. Analysis of linguistic structure to answer the question: Who or what is this pattern referring to and what are its properties? The question guides the process of detecting the significance of the themes. At this point, occurrences of a pattern are combined to create the general category or theme.

Following open coding, axial coding occur. Axial coding serves to answer the question: What is the relationship between the various categories or themes? By answering this question, relationships, often causal or contextual in nature, emerge from the within the data. This emergence provides additional insight into the meaning of the themes by explaining each theme in terms of another. Finally, selective coding demarcates the final segment of GT analysis in which a central theme or category is used to explain the others. In this study, the central themes and categories were understood through metaphorical analysis of linguistic structures, This explanation represents the most narrow but most reliable understanding of the data as it is derived completely from the interrelationships presented in this specific case. Because the coding technique advocated by GT analysis is an iterative process, it will occur in multiple phases. These phases are detailed in the following sections.

Phase 1. The first phase of data analysis focuses on all if-then survey question responses collectively to inform the questions posed to all participants in the initial interview. During this phase, I open and axially coded all if-then question responses. From the categories and relationships generated through this process, specific questions designed to obtain further information about the prototype or prototype characteristics represented by the codes were crafted.

Phase 2. The next phase of data analysis was designed to discern the collective prototype of elementary STEM among participating teachers. Marked by open and axial coding of all available data, this segment of data analysis was done in conjunction with two other graduate students to ensure a rigorous and unbiased examination of the data. In this phase, all data, including a reexamination of if-then question responses, interviews, categorization task examples, and nonexamples as well as their associated explanations, were examined collectively to establish the initial set of codes from which I predicted the collective prototype would emerge. Following open coding, axial coding occurred.

As previously mentioned, Phase 2 of data analysis was conducted with a team. The team, made up of myself and two other graduate students, engaged in this work through two stages. The first stage of open coding was done individually. Each team member was provided with digital and hard copies of all instruments and their associated data and transcripts. I began the work session by reviewing the instruments and the purpose for the open coding phase and I instructed that this segment should be done independently. To begin, each team member generated his or her own coding scheme and paid close attention to the participants' generalized use of nouns, pronouns, and adjectives throughout the dialogue.

Stage two, axial coding, was done collectively. The team conferred and each member shared the codes he or she generated and the data associated with each. These codes were recorded, and the themes and concepts identified as well as the codes used to denote them were discussed. Through this discussion, codes and their associated data points were merged and rearranged until there was consensus regarding a central set of codes and themes that encompassed all data points.

Upon completion of Phase 2, I reviewed the data and continued to explore the collective prototype of elementary STEM through metaphorical analysis and the application of selective coding techniques to further develop this understanding.

Phase 3. The third phase of data analysis reexamined the data from each individual participant to discern their individual prototypes as related to the metaphorical representation of their prototype. To do this, I first reexamined the complete set of data for each individual participant and focused on the metaphors used during dialogue.

Analysis of metaphor was central to this phase of data analysis as the works of cognitive psychologists and educational researchers alike identify metaphor as a valid and robust tool in understanding the prototypes individuals hold for various conceptual categories (Fischman & Haas, 2012; Lakoff, 1987). Although other linguistic structures are noted as critical to discursive analysis of cognition, “the metaphor provides the basic pattern for the interplay where both the metonymy and the image schema are easily accommodated" (Díez Velasco, 2001, p. 61)"

According to Díez Velasco (2001), metaphor is underscored by image schema of each individual and these are composed of both structural elements and internal logic. Metaphorical analysis provided insight into these image schemas, which elucidated both the characteristics requisite of the prototype as well as the logic associated with the relationship between and among these components. It is this work that allowed me to identify valid of trends, themes, and concepts in the data. After each team member completed the first stage, we engaged in the second segment of data analysis: axial coding.

Metaphors were identified within and across the data. Ultimately, shared metaphors were used to form groups of teachers who share a dominant metaphor in their prototype of STEM. Once the dominant metaphor was identified for each teacher, member checking was conducted to increase theoretical sensitivity and reliability of the conclusions derived from GT analysis.

Phase 4. Finally, the selective coding protocol described by Glaser (1998), in which existing data and the associated codes are reexamined around a core theme or variable, is used to tell the story of STEM teaching and learning.

Chapter 4

Data and Evidence

General Context of ISD

A small, urban district located in inner city Phoenix, Ivory School District (ISD) is home to 10 schools and 7,432 students in kindergarten through eighth (K-8) grade. All 10 schools receive Title I funding and 100% of the total ISD student population qualifies for free and reduced lunch. The racial composition of the students in Ivory District as self reported by parents on student enrollment forms is provided in Figure 1.

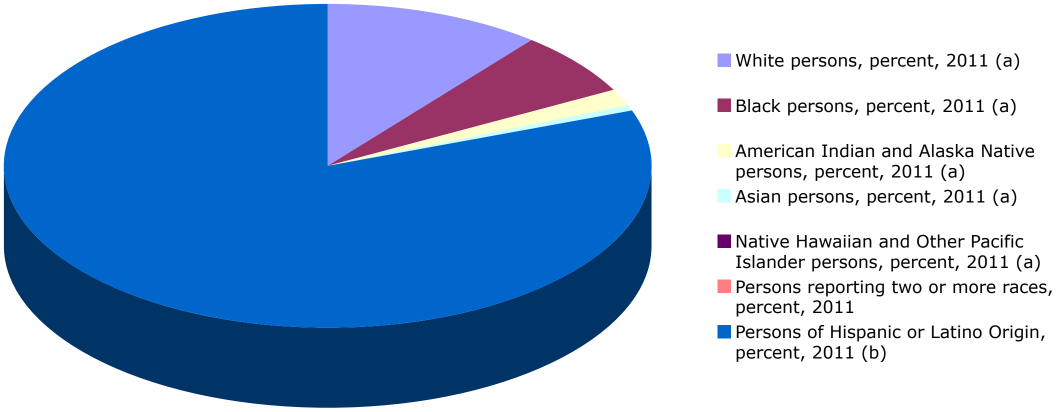


Figure 1. The racial composition of the student population at Ivory School District. Adapted from data collected through district enrollment reports.

For quite some time, ISD has been a high needs school district. ISD's status as a high needs school district is affected by the composition of their student population, and is the result of five major factors: the average socioeconomic status (SES) of ISD families is low, there is a high number of minority students, the schools has large numbers of second language learners, ISD experiences high student and teacher attrition rates, and the school reports historically low student achievement in measured areas when compared with more affluent Arizona districts. Demographic comparison of ISD to the state of Arizona and the nation can be seen in Figure 2 and Figure 3. In Figure 2, working from the outer circle to the inner circle, the racial breakdown of Arizona, the nation and ISD are shown. Likewise, in Figure 3, the home languages of Arizona, the nation and ISD are shown from left to right respectively.

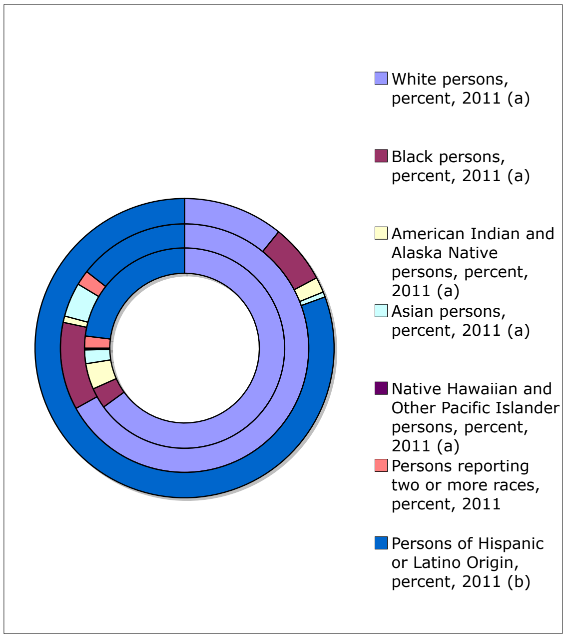


Figure 2. A comparison of the racial compositions of the state of Arizona, the United States, and Ivory School District. Adapted from data collected by the United States census, 2010.

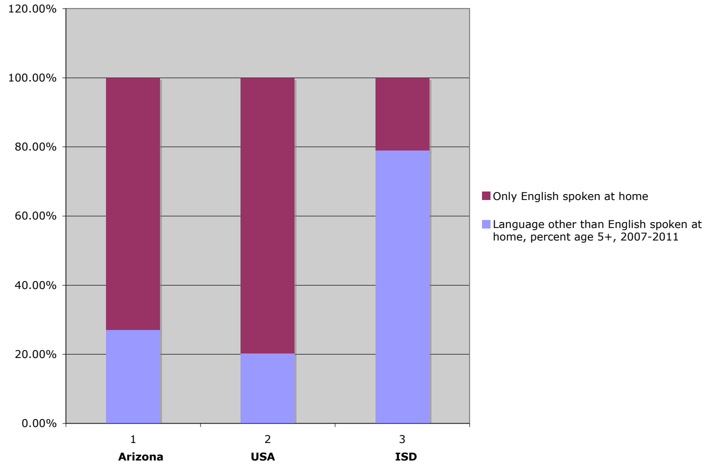


Figure 3. The frequency with which English versus other languages are spoken at home in Arizona, in the United States, and in Ivory School District. Adapted from data collected by the United States Census 2010.

As described by Lee and Lykux (2010) and González, Moll, and Amanti (2005), the effect of these factors is further exaggerated in that the racial composition of ISD educators is dissimilar to that of ISD students and families. Per an ISD human resources report, in ISD at the time this study was conducted, 43.5% of educators were Hispanic/Latino, 56.4% were White, 4.3% were Black, 2.4% were Asian/Pacific Islander, 0% were Native American, and 0% were other.

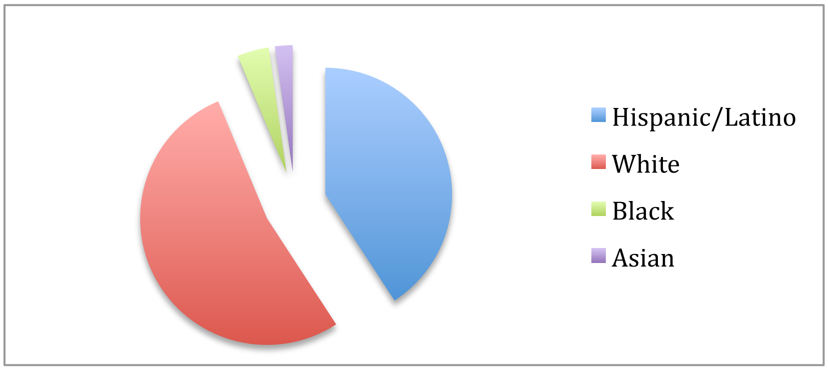


Figure 4. The Teacher Population of ISD According to Race. Data adapted from ISD human resources state compliance report.

Achievement in ISD

Like many other urban, high needs districts, ISD has struggled with student achievement. Measured by the Arizona Instrument to Measure Standards (AIMS) assessment, students in ISD consistently underachieve as compared to their more affluent peers. Table 2 shows the average percentage of students who earn passing scores on the AIMS test in the subject of reading and mathematics in ISD and Scottsdale Unified School District (SUSD), a nearby district with a more affluent demographic and the state average and in Arizona as a whole.

Table 2

AIMS Test Passage Rates for ISD, SUSD, and Arizona.

Subject	ISD	SUSD	AZ Average
Reading	62.3%	85.6%	69.7%
Math	51.5%	72.9%	50.5%

Note. Data retrieved from Arizona Department of Education.

Science achievement was not included in these percentages because the science assessment administered to students is not included in the calculation of school labels nor is it administered in all grade levels. The science AIMS assessment is only administered in fourth and eighth grades; however, as eighth grade is beyond the scope of this elementary study, only fourth grade data will be reviewed from this point forward.

In Table 3, science assessment data from the pilot version of the AIMS science test were isolated and compared to the state average across the previous four years. For clarity, the scores were aggregated into two categories from the four state-reported performance levels. The category of *passing* includes students who scored in the *meets* and *exceeds* categories. The *not passing* category includes student scores in the *approaches* and *falls far below* categories.

Table 3

Fourth Grade AIMS Data: Science and Math

Subject	Student achievement levels	2008-2009 district	2008-2009 state	2009-2010 district	2009-2010 state	2010-2011 district	2010-2011 state
Science	Passing	31%	57%	41%	61%	38%	60%
	Not passing	69%	43%	59%	39%	62%	40%

Notes. http://www.azed.gov/research-evaluation/aims-assessment-results/

Additionally, in 2009, Arizona fourth grade students scored an average of 138 on the National Assessment of Educational Progress (NAEP), which was 11 scale score points lower than the national average (http://www.azed.gov/ research-evaluation/aims-assessment-results/). Furthermore, comparative analysis of the AIMS and NAEP assessments suggest that proficiency on the AIMS is not equivalent to proficiency on the NAEP. Arizona ranks among the bottom 20% of all states when the levels of rigor on the state exams are compared to the level of rigor demonstrate by the NAEP assessment (Nation's Report Card, 2011).

Effects of historically low student achievement in ISD. Throughout this process, I have come to understand that the low student achievement in ISD has not only taken the obvious toll on students and their ability to experience educational success, but it has also had secondary effects. Nine of 10 schools are in various stages of school improvement under federal and state legislation (www.azed.gov).

The school improvement process, driven by low achievement in accountable areas (reading and mathematics), has fueled an intense focus on reading and math instruction. Evidenced by classroom schedules, resource purchases and professional development calendars, it is clear that a facet of this focus has been the shifting of resources and energy almost completely toward reading and math instruction and away from science, social studies, and other nontested and unaccountable subject areas. This is true of all grade levels but has been especially prevalent in the elementary grades. In fact, many teachers informally shared that ultimately, low achievement in accountable areas has resulted in many principals explicitly forbidding teachers to teach science or social studies in kindergarten through fifth grade in an effort to redirect resources, including instructional time, to reading and math.

As resources have become scarce for science instruction and as pressure to perform in reading and math has increased, most ISD schools have abandoned science instruction at the elementary levels altogether. In fact, through an informal conversation with district level administration, I learned that it has been over 10 years since science has been consistently taught in ISD’s elementary classrooms. In combination with high teacher turnover rates, this situation has led to a large number of the fourth grade teachers in ISD who have never taught science, let alone science, technology, engineering, and mathematics (STEM) to their elementary students.

Most recently, a combination of district leadership changes and state and national foci on STEM education has pushed ISD to recommit itself and all of its schools to science education for all ISD students. ISD’s participation in a pilot professional development program, the creation of a district math and science content specialist position, and, most recently, a Director of STEM and Innovation position, is evidence of the district’s commitment to STEM instruction for all students beginning in the fourth grade. As fourth and eighth grade levels are the tested, or benchmark, grades for science in Arizona, the bulk of the focus for this district initiative exists at these grade levels. According to the Asst. Supt. For Teaching and Learning, while resources and supports are in place for all ISD teachers to include STEM into classrooms, fourth, fifth, and eighth grade teachers have presently been prioritized at this point in the districts’ five year STEM plan.

The Fourth Grade Focus

To begin addressing the apparent gaps in science education in ISD and to transition to STEM, the district is interested in building capacity among K-8 teachers in all of the STEM content areas and pedagogy components. As one can imagine, this is a tremendous undertaking that requires a great deal of funding and time making it nearly impossible to address all the teachers at one time. As such, ISD has begun its work with a focus on fourth grade teachers and students.

Of 10 total schools, nine serve fourth grade. In total, 811 of the 7,432 students are currently enrolled in fourth grade. At this grade level, ISD's student population is comprised of 95% Hispanic or Latino, 3% Black, 0% Asian or Pacific Islander, 2% White, and 1% other students (see Figure 5). Of these individuals, 100% qualify for free or reduced lunch and 34% are presently classified as English Language Learners (see Figure 6) as measured by the Arizona English Language Learner Assessment (AZELLA). In addition, many of the fourth grade students in ISD are highly transient; an estimated 11.5% of students change schools (either within our outside of the district) each year.

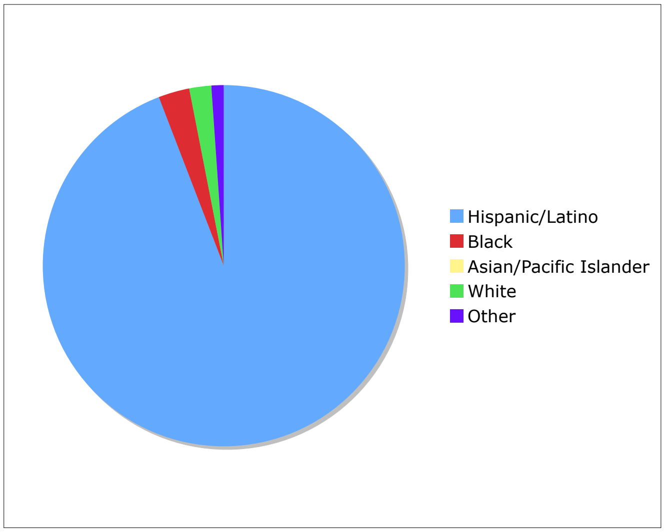


Figure 5. The student population of ISD according to race. Data adapted from ISD student information system report.

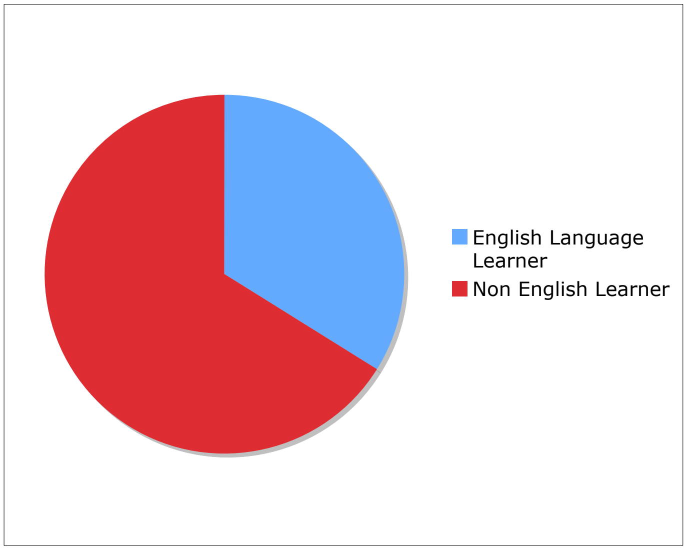


Figure 6. The distribution of English Language Learners and non-English language learners in ISD. Data adapted from ISD student information system report.

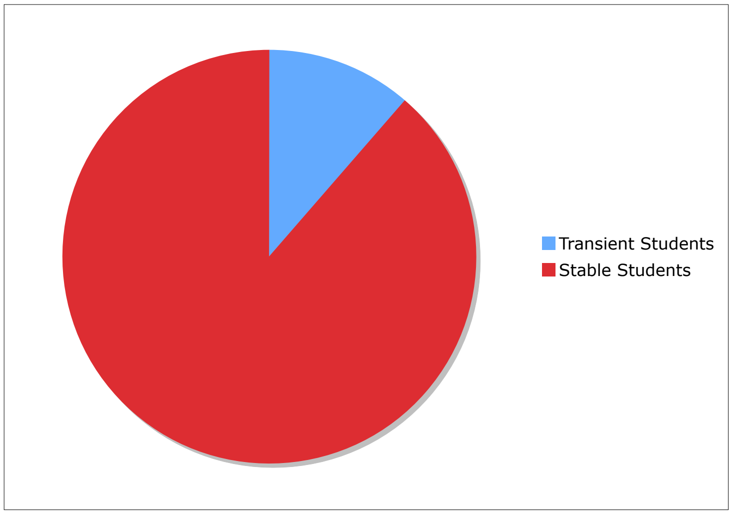


Figure 7. The distribution of transient students and stable students in ISD. Data adapted from ISD student information system report.

Additionally, ISD human resources reports also revealed that across ISD, there are 36 fourth grade teachers, 7 male and 29 female, all charged with the task of preparing students to succeed in reading, writing, math, and most recently, science. At the time this study was conducted, among the districts' fourth grade teachers (per internal human resources report), 31% were Hispanic or Latino, 0% were Black 0% were Asian or Pacific Islander, 66.3% were White, and 2.7% identified as other. Of these teachers, 72% obtained their certification through traditional teacher preparation programs while the other 28% obtained their certification through alternative programs. Among these 36 teachers, experience levels varied with 4 having taught three years or less, 6 having taught 4 to 5 years, 7 having taught 5 to 10 years, 16 having taught 10 to 15 years, and 3 having taught 15 to 20 years. Of all 36 teachers, none possess specific background in a STEM field or STEM content beyond the standard science and mathematics methodology course required in generalist teacher preparation programs.

Data

In the following sections, data from the surveys, interviews, and categorization tasks will be presented along with narrative describing the model used to discern various themes and relationships characteristic of teachers' prototypes. Methods are summarized and data obtained and the understood through Grounded Theory analysis is presented. This information was derived from analysis of authentic written and verbal dialogue; therefore, quotes from participants will be presented in their original forms. To protect the identities of the interviewees, their names have been replaced with pseudonyms or numbers and demographic information that could be used to identify specific participants has been removed.

Presentation of data is reflective of significant findings and inverts phases 2-4 of the analytic process to more clearly and completely explain the prototypes participant teachers hold of STEM. To begin, Phase 1 of the analytic process and data collection is reviewed and findings of the survey data are presented. Specifically if-then segments are reviewed in combination with how themes discerned from them as well as the research literature was used to generate the initial interview questions. Next, I continue the discussion of data analysis and findings with Phase 4. Findings of Phase 4 are then used to contextualize and explain data collected in Phases 2 and 3.

To summarize the data collection and analysis process, Phase 1 collected basic information about participant teachers, including demographic and experiential information through a survey. It also prompted teachers to respond to two open ended, if-then questions, responses from which were analyzed using Grounded Theory to reveal preliminary themes in participant teachers' prototypes of STEM. Phase 2 was broken into two stages; interviews and categorization tasks. The interviews sought to elicit conscious and productive components of teachers' prototypes by asking them to respond to direct questions. The categorization task on the other hand functions in the inverse, putting participants in a scenario in which they must receive information (the artifacts) and then categorize it. The process participants use to do this is relatively unconscious so following the categorization of all artifacts, participants are asked to reflect on and then explain how each artifact was categorized as well as under what conditions it would have been placed in the other group. The task here is not concerned with consistency of categorization for each specific artifact and data collection showed little to no congruence in the example/nonexample categorization of most artifacts for participant teachers. The value of this exercise lies in the activation of the unconscious prototype through the categorization and then the discussion that ensues to surface some of the components of the prototype used to make the categorizations. Transcripts from the interviews and categorization tasks were dissected and digested to discern themes within them. These themes were then triangulated to present the observable components of the collective prototypes present in this participant group. Next, Phase 3 reexamined the themes presented to unearth the relationships between them. Finally, in Phase 4, all data sets were reexamined to identify and understand metaphors presented in the discourse of participant teachers. These metaphors were then analyzed to determine whether they were representative of STEM as a whole or of one of its component parts of characteristics. Those that represented STEM as a whole were then selectively coded and utilized as an additional tool for data analysis by filtering the open and axial codes through the lens of a selective code—in this case, a dominant metaphor.

Data Analysis: Phase 1

All of the district's fourth grade teachers were given a basic survey (Appendix A). Of the 36 teachers to whom the survey was distributed, 17 were completed and returned within the data collection window. Five were completed online via Survey Monkey and 12 were completed and returned in hard copy form. Many of the returned surveys did not include responses to all of the questions resulting in variation in the total number of respondents by question.

Data from the survey instrument was exported to an Excel document, and demographic information was amalgamated and responses from the two if-then questions were isolated. Demographic information from the respondents is represented in Figure 8-14 below.

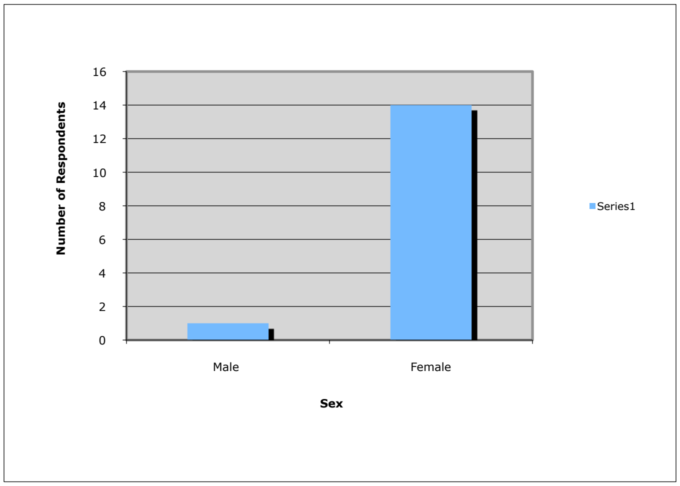


Figure 8. Gender of Survey Respondents.

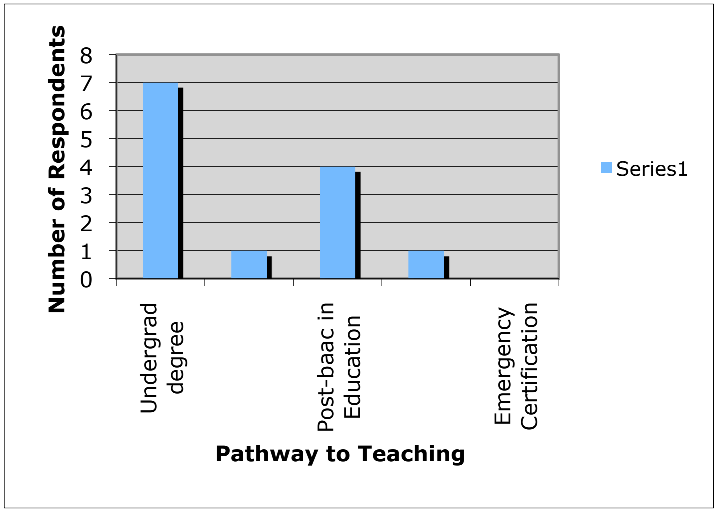


Figure 9. Pathway to Teaching for Survey Respondents.

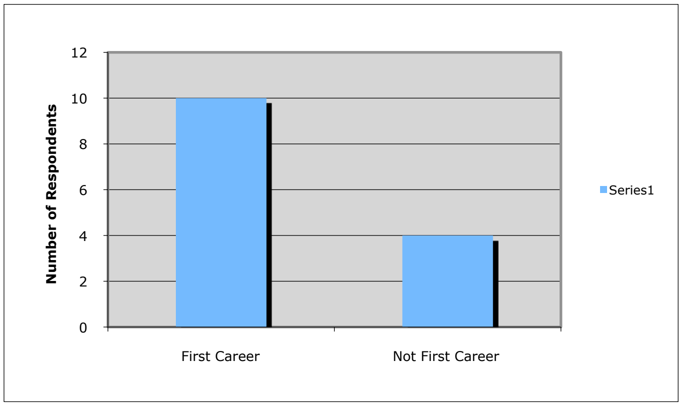


Figure 10. Number of First Career and Nonfirst Career Survey Respondents.

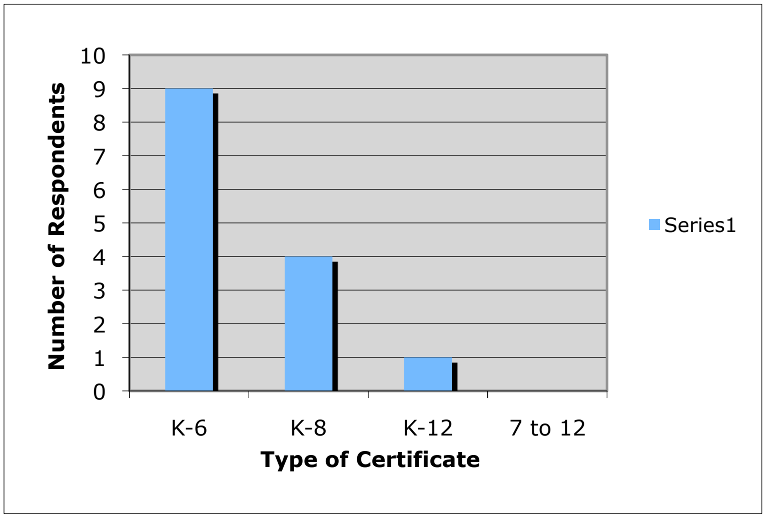


Figure 11. Types of Certificates Held by Survey Respondents.

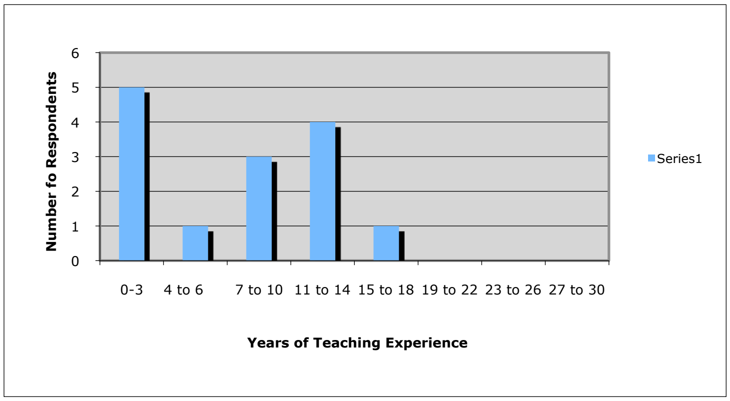


Figure 12. Years of Teaching Experience for Survey Respondents.

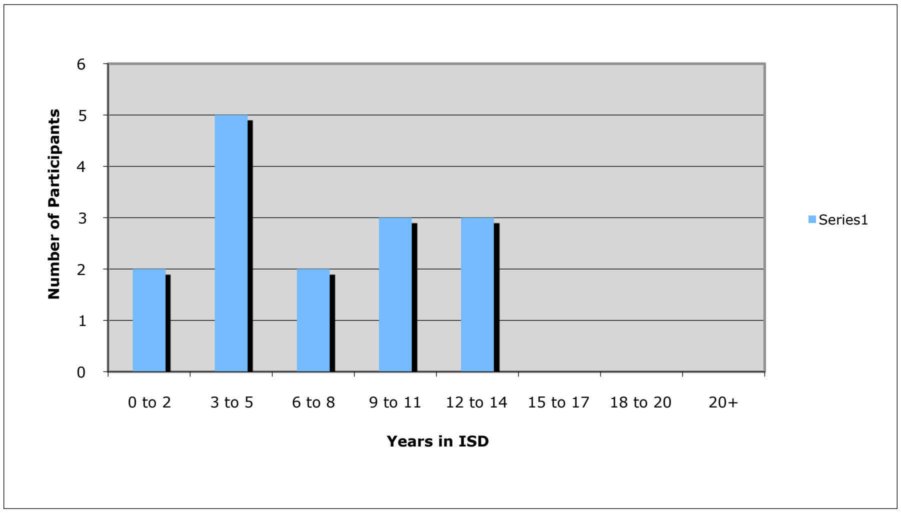


Figure 13. Years in ISD for Survey Respondents.

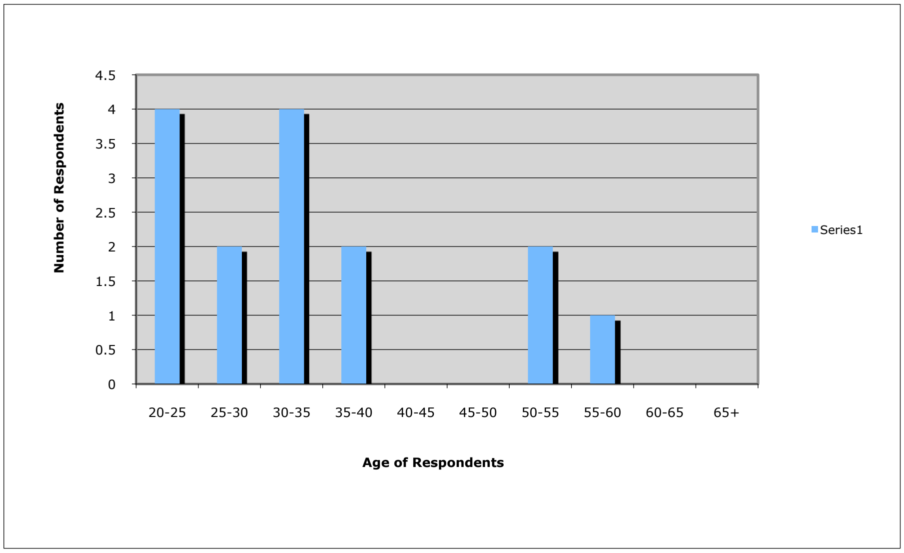


Figure 14. Age of Survey Respondents.

In addition to the demographic information provided in the surveys, I learned that many of the participants in this case study represented teams within the schools. Three of the participants (Participants 3, 5, and 6) are on a team together at Moss School. Participants 2 and 11 make up the fourth grade team at Iris School and two others, Participants 4 and 10, make up the fourth grade team at Eucalyptus School.

If-then Questions. If-then responses were coded to identify themes or components potentially central to the collective prototype of ISD teachers. Through this process, the following themes emerged:

1. Ownership
2. Integration
3. Role of Technology
4. Grappling
5. STEM is real
6. STEM is generative
7. STEM is immersive

Each of these themes will be further discussed in the following subsections including discussion and explanation of how these themes influenced the creation of initial interview questions.

Ownership. The notion of ownership was immediately apparent in respondent's if-then answers. Responses included the term *teacher* and associated pronouns such as *I* and *we*, as well as the term *student* and the pronouns *they* and *them*. The use of these terms indicates two dominant subjects in this area, one often controlling the other. Many teachers referenced what they would *have students do.* For instance, Participant 1, a fourth grade teacher with seven years experience reported, "I would have students make predictions about what a hurricane is" (Participant 1) while another said that she would, "have students view [a] clip of [a] hurricane and identify what misconceptions where discovered or what new information was gained" (Participant 6). Examples like these in which teachers combine use of personal pronouns (I) and *have students,* demonstrates ownership that lies with the teacher. Conversely, a smaller number of teachers used language indicative of student ownership of STEM. Phrases such as, “they are constructing their own ideas of hurricanes” (Participant 6) and “they will come up with ideas of why [hurricanes] happen” (Participant 3) in which the student subject is followed by active verbs and possessive adjectives are indicative of student ownership as a component of STEM.

Integration. The second theme that emerged from the if-then data was that of integration. Early examination illuminated tendencies of integration in learning or integration in application within this category. Teachers whose responses included phrasing such as, “this would be an opportunity for students to learn ecosystems, weather patterns, global warming, etc.” (Participant 4) in Question 9 and “If subject areas were not overlapping like science/chemistry, culinary and math (proportions). If the lines of a particular subject within STEM are not connected to another subject . . . these lessons would not exemplify STEM” (Participant 1) in Question 10 demonstrate the notion of integration in learning. Here, teachers refer to the blending, or overlapping, of subjects during the STEM experience for the purpose of student learning. Integration in application was reflected in responses like that of Participant 5, who stated she would use a STEM activity to teach students a new science concept as well as to encourage their application of mathematics concepts by evaluating the mathematical certainty of that science concept. Likewise, Participants 1 and 6 spoke to integrating application of new learning by asking students to produce outcomes in several areas (letters, slideshows, creating tools, completing mathematical work, etc.) that use skills in multiple content areas to achieve the task at hand.

Role of technology. Unlike the previous two components, the role of technology did not emerge as a binary theme. Here, teachers typically spoke to technology as a tool. When addressed as a tool, teachers spoke to technology they would use most often, and in 5 out of 9 instances they referred to videos or clips of videos. When not referencing videos, teachers also referred to devices such as lap top computers, iPads, Promethian or other interactive boards and document cameras.

Grappling. The theme of grappling emerged as teachers explained notions of how students would engage in the process of new learning. This theme was marked by student-centered nouns paired with active verbs such as *investigate* and *discover*. This combination of terms shed light on the transformational nature of such processes by addressing new learning as an indirect process that often results from directly challenging or confronting and then correcting students' misconceptions. Participants 2 and 6 spoke to identification and confrontation of students' misconceptions as a critical component of the learning process. Participant 6 went so far as to explicitly state that by doing so, students are able to achieve a "change in schema" through the identification of "something new learned."

STEM is real. Of survey respondents, 30% indicated that STEM is real. In other words, their responses demonstrated a propensity to believe that only experiences grounded in plausible scenarios can be categorized as STEM. More specifically, teachers spoke to the notion that such ideas would contribute to or increase students' abilities to understand and empathize with those faced with such scenarios. In fact, of the participants who referenced, the *real* nature of STEM, 100% used language similar to that of Participant 4 who stated, "students immersed in this study can appreciate devastation hurricanes can cause" or similar to Participant 5 who argued that "students can collaborate and come up with solutions to the problems that a certain area is having after the hurricane." Statements such as these speak to a belief that the value of STEM experiences is potentially two-fold; STEM experiences influence what students learn and what they are able to do because they have learned it.

STEM is generative and STEM is immersive. The final two themes extracted from the if-then data did not appear as frequently as the others but presented more clearly in the instances in which they did occur. The notion that STEM is generative emerged through teacher explanations of what students could "come up with." For instance, Participant 4 told me that students would "come up with solutions to the problems" while Participant 3 reported that students would "come up with ideas of why [hurricanes] happen . . . . Then they recreate a hurricane or come up with a newscast for a hurricane and use technology to record and publish." Through these expressions, teachers' prototypes seem to include a product, which is most often concrete and tangible like those previously mentioned but occasionally abstract as described by Participant 6 who argued, " [students] are constructing their own ideas." In either case, learning is not the sole outcome. Rather, students produce or generate a product that is typically indicative of their learning and they do this by engaging in a dynamic process of hypothesizing, synthesizing and evaluating information/data in context.

The notion that STEM is immersive was even less frequently noted than the notion that STEM is generative; however, it was the most explicit of the themes observed. Participant 4, a Hispanic male teaching fourth grade for the third year, specifically stated, “[STEM] would be an opportunity for student to learn ecosystems, weather patterns, global warming, etc. Students immersed in this study can appreciate devastation hurricanes can cause.” Perhaps related to the notion of integration, STEM is immersive indicates a facet of the prototype that calls for students to be exposed to the STEM content and context through multiple avenues.

Interviews

Initial interview questions. Initial interview questions were crafted to extract information related to themes that emerged in the literature and those that were identified as characteristics coded in the if-then section of the surveys. Initial interview questions can be seen in Appendix C. Throughout this section, the purpose of each question and the background related to its creation will be discussed and the interview process will be explained. Then, information on the data collected through the interviews themselves will be presented after metaphorical analysis of teacher discourse is explained and applied.

While not included in the official transcripts, each interview began with an off the record segment in which participants often asked questions about the intention of this study, my educational background, etc. Engaging in this informal dialogue provided an opportunity to establish rapport between the interviewee and I. After this informal segment came to a close, the interviewee was asked if he or she was officially ready to begin and the recording commenced.

Questions 1 through 10 comprise the first set of questions crafted strictly with the research literature and if-then data in mind. Questions 1 and 2 were designed to be grand tour questions (http://www.gifted.uconn.edu/siegle/research/qualitative/qualitativeinstructornotes.html), which would allow the interviewee to set the direction of the interview. The information provided by the interviewee in response to these questions afforded me insight into their level of knowledge and familiarity, and in many cases their comfort, with STEM. This insight helped me to organize the presentation of subsequent questions. Questions 3 and 4 aligned with the notion of ownership in STEM. This theme emerged in the if-then questions of the initial survey as well as the literature by Miner et. al. (2009). By challenging participants to not only describe the role of the teacher and student but also to compare and contrast that with the role of teachers and students in non-STEM instruction, Questions 3 and 4 sought to glean insight into control and influence in the STEM experience.

Like Questions 3 and 4, Question 5 is designed to solicit information related to the theme of ownership. In addition, it aligns to the idea of grappling as presented by Minner, Levy, and Century (2009) and Longo (2010). Similar to the if-then survey questions, the notion of grappling was anticipated to emerge through descriptions of students confronting misconceptions, making meaning of data, struggling, etc.

Questions 6 and 7 were more narrow in their focus and sought to garner a clearer gauge as to how technology factored into teachers' prototypes of STEM. Unlike the other questions that were generated after similarity between the literature and if-then data emerged, these questions arose from the apparent dissonance between trends in the if-then segment of the surveys and those in the literature. Literature, including an explicit set of technology standards (azed.gov/standards) tends to address technology as a content area that students need to learn on a conceptual level. Conversely, the theme extrapolated from the if-then responses was much more indicative of a viewpoint that technology is a tool. Moreover, student learning reflects this purpose as a tool in that technology is often a support to learn other content concepts but within the confines of this case, is never discussed as the topic of learning itself.

Questions 8 and 9 were designed to obtain more data around the theme of integration. There appeared to be a great degree of congruence between the patterns identified in the if-then segment of the survey codes and the literature. Both demonstrate a propensity toward integration in that STEM subjects should be learned and presented together, potentially in combination with other content areas as well. These questions should elicit additional data around the role this notion plays in the larger, more general prototype of STEM.

Question 10 was the final question of the original set crafted from the literature and if-then data alone. Derived from findings in the works of Furtak and

Alonzo (2010) and Carlsen (2010), this question asked teachers to speak to the ways in which they determined success in a STEM scenario. The development of Questions 10 drew on the assertions of Furtak and Alonzo (2010), who posited a connection between pedagogical content knowledge (PCK) and subject matter knowledge (SMK) and their association of success with observable student behaviors as opposed to conceptual development. The question sought to glimpse the role that each plays in teachers' prototypes and potentially a connection to their levels of PCK and SMK.

Additional interview questions. Questions 11 through13 were added to the set of questions after the first two interviews revealed that PCK and SMK were influential in teachers' prototypes as they continuously presented during dialogue and were addressed as follow-up questions. In an effort to be consistent and thorough with each interview, the questions were added to the formal question set and were revisited with Phase 1 and Phase 2 in a second iteration of the data collection and analysis process.

Question 14 was added following the third interview when early analysis of transcripts and teacher dialogue demonstrated a difference in value assignment for STEM relative to students of various socioeconomic backgrounds. Review of the literature by Jones and Carter (2010) supported that teacher beliefs are often correlated with context and knowledge. This question sought to understand more about the teachers' beliefs toward STEM. Those beliefs can then be disaggregated by levels of knowledge and experience.

Data Analysis: Phase Three and Four

In Phases 3 and 4, I analyzed and interpreted data from the interviews, categorization task examples, and categorization task nonexamples using grounded theory (GT) methodology as explained in the works of Creswell (2002), Glasser and Strauss (1967), and Corbin and Strauss (1998). By engaging the data in multiple iterations of data review and analysis, I sought to identify themes and metaphors central to the prototype of each individual, thus informing the collective prototype for ISD fourth grade teachers as a group.

To do this, I first analyzed all transcripts for use of metaphors in participants' speech (Phase 3). These metaphors provide insight to the reasoning processes participants use when conceptualizing STEM (Fischman & Haas; 2012; Lakoff, 1987). They reflect conscious and unconscious components of the participants' prototypes, and due to their systematic structure, expressions from one domain of the metaphor are often used to talk about corresponding concepts or themes in the general metaphor (Lakoff and Johnson, 1980), which provides additional insight to the relationships among the themes discussed within the metaphor.

Metaphors were constructed in accordance with Grounded Theory (GT) techniques, using multiple iterations and my own theoretical sensitivity to identify and discern the meaning of each metaphor. The works of Rosch (1973; 1975) and Lakoff (1987) were highly influential in this process. Their analysis of structural and situational metaphors framed the analysis of participant transcripts.

Across the transcripts of all case study participants, several metaphors presented with varying frequency that will be briefly explained in the following sections. Of those initially identified and represented below, only four were determined to encompass the whole of STEM whereas the others represented facets of STEM and were then understood to be themes within the larger metaphor and will be discussed with the other major and minor themes.

This process led to the identification of nine total metaphors within participant teachers' discourse. Of those, I determined four to be descriptions of components of STEM and not STEM in its entire, holistic form. These have been extracted and reconceptualized as themes and will be discussed in final segment of this chapter. Four others did embody STEM as a whole; STEM is an adventure, STEM is a journey, STEM is a puzzle and STEM is a bridge. One additional metaphor was related to STEM in the contrast it provides for teachers. This metaphor, nonSTEM teaching and learning is a nutritionist, marks the comparison against which teachers have come to understand what STEM Is not.

Once metaphors were identified, I set out to understand them in the broader context of participants' discourse. At this point, I discovered that throughout this process, the most significant finding occurred in Phase 4 of data analysis and is that of the amorphous prototype. The amorphous prototype is embodied by six participants and is marked by a lack of dominant metaphor in the discourse of participants when describing or discussing STEM.

While bearing in mind the amorphous prototype, the four metaphors that describe STEM and the one that describes nonSTEM were then used as a tool for data analysis (Lakoff and Johnson, 1980). Through selective coding, the dominant metaphors were identified and then used to further understand the participants' prototypes. The metaphor became the lens through which the aforementioned themes and less dominant metaphors were understood.

We will begin discussion of metaphors through the nonSTEM teaching and learning is nutrition. It is not surprising that teachers are more readily able to describe and identify what STEM is not. Related to the same body of research from which the categorization task was born, individuals typically construct an understanding of a counter example or nonexample in the process of coming to know and constructing the exemplar prototype.

Knowledge is Nourishment. The metaphor of knowledge is nourishment presented in the discourse of 11 of the 12 participants. The significance of the metaphor to ISD participants' prototype of STEM is not in the direct usage itself. Rather, the usage of this metaphor in STEM compared to non-STEM situations is reflective of the activity and passivity associated with each.

The universality of this metaphor for this participant group presented in that 11 participants utilized the metaphor to express a concept that, much like the nourishment provided by food is critical for physical growth or growth in stature, the nourishment provided by knowledge is essential to intellectual and academic growth.

The variation, however, is reflected when the usage of the metaphor to compare and contrast STEM and non-STEM is examined within or between participant transcripts. For instance, Participant 7 argued that "[students] have to really feed [inquiry]. I can give you a question. But it's not until you have the students' input on what they really know before you can move forward." In this way, she and others illustrated the metaphor that knowledge is nourishment to be actively consumed. Conversely, they used the knowledge is nourishment metaphor to explain the passive nature of students acquiring knowledge in traditional or non-STEM situations. Another teacher, Participant 11, explained:

> I'm noticing with the STEM, you are collecting data and you have to analyze the data versus I'm giving you everything. So it's more what a student can do for themselves, versus the teacher baby feeding them, and I think that's a big thing.

Participant 3 drew the following comparison:

> So, in a non-STEM classroom, it would be a lot of plug and chug for math, and here is your list of science facts, and you are going to be tested in the exact same way that I gave you the information, you just need to regurgitate it back. And I think in STEM, it’s more how you interpret things. Just going through a process of learning.

STEM Might be Many Things (The Amorphous Prototype). The notion of the amorphous prototype is marked by a lack of dominant metaphor in the discourse of participant teachers. When dominant is understood as used two or more times that of other metaphors, six participants did not demonstrate a dominant metaphor in the triangulated data set.

For these participants, their conceptions of STEM are still under developed. Like the other participants, they speak clearly and consistently to the knowledge is nutrition metaphor but significantly less clearly and consistently about STEM.

STEM is a Puzzle. The metaphor STEM is a puzzle presented directly in the interview with Participant 12 who, when asked to describe the role of the teacher in STEM, explained:

> T: In a STEM experience, they are the leader. You facilitate the learning, you give them the pieces, and it's more inquiry based and exploratory to where you give them a little bit and they kind of put the pieces. Or maybe it's better to put it that way, you give the, the pieces and they put the puzzle together on their own.

By drawing this comparison, she and the other participants illustrated their conception that unlike total inquiry experiences, in which all learning occurs through student discovery, in STEM the teacher provides components of the learning and the students discover how they all fit or function together. This comparison asserts integration through application rather than new learning.

STEM is a Bridge. The idea that STEM is connected is not the same as it being integrated. Here, the idea is that STEM and the skills students develop by engaging in it are linked to life beyond the classroom. The construct of connectedness develops in parallel with the idea that STEM is real. The reality of STEM seems to be what connects it to life outside the school day.

For many participants, technology had a great deal to do with this metaphor. The pervasive nature of technology in the 21st century and the effort to bring technology into the classroom through STEM is viewed as a link between what occurs in class and outside. Participants 3, 5, 6, 7, 8, 10, 11, and 12 explicitly spoke to this. Participant 7 explained that she believed this link to be critical. Even though she admitted to being fearful of technology, she must “get over it” for her students. She explained:

> T: [Technology] does impact our learning because, if I'm scared of it, I'm also limiting our students. I think with STEM, they don't want the kids to feel that fear. So, with the teachers, if we don't want that telephone—I mean, I can text, but it'd take me an hour versus you talking like five minutes, and my fingers are fat. With the texting, if I don't use that technology or mention that technology, I'm limiting my kids going globally with it, so I think even though as a person, I think as a teacher it's very important you get over that fear because you are limiting your students ability to progress as well. So, they are going to leave my room, like what's texting, what's the app, what's the polling. And I'm like, I don't know, I don't have it. Even if I don't feel comfortable in personal use, I need to apply it in the regular. And the same thing with the kids—even if they don't feel comfortable at home because maybe their parents are religious or their viewpoints are different, if they are applying it in school, at least they are having that chance to be heard.

STEM is an Adventure. The metaphor that STEM is an adventure is largely characterized by the unexpected nature of the ultimate destination and student control of the learning experience. For STEM to be an adventure, one must accept and even embrace a certain amount of uncertainty both in the final destination as well as the route by which one will arrive there. The act of determining where to go and how to get there is an active process, indicated by physically active verbs in phrases such as “where we will go,” and “where students will take you.” Likewise, the physical activity and uncertain nature of the STEM adventure is fun and exciting for students and teachers alike.

STEM is a Journey. Varying only slightly in its characteristics compared to the metaphor that STEM is an adventure, STEM is a journey is writ with reference to pathways, exploration, routes, avenues and excitement. The difference lies in the lack of question and consistent presentation of the destination. Unlike the metaphor that STEM is an adventure, STEM is a journey asserts that all students and teachers will or should end their voyage at a predetermined destination. They will likely arrive at that destination in different ways, but ultimately the destination is the same for all learners.

Data Analysis: Phase Four

After the metaphors were identified, they along with themes were examined against one another to determine the dominant metaphor of each participant. This was discerned by the frequency of its presentation within the triad of interview, categorization task example, and categorization task nonexample data understanding that dominant metaphors were those with two or more times the usage of other metaphors. Additionally, member checking with each participant served to confirm or challenge what I had determined to be his or her dominant metaphor. 100% of participant teachers confirmed their dominant metaphor which was then used to group participants. Those participants with like dominant metaphors were grouped together and became a separate unit of analysis or a smaller case within the larger case of this study.

Their dominant metaphors were used as a tool to better understand the themes presented in the amalgamated data of metaphorically similar participants. In other words, the data was selectively coded, which transitioned the metaphor from a theme to the lens through which the themes and other, less assertive, metaphors could be understood and interpreted.

A cross examination of themes and metaphors based upon dominant metaphor assisted in the development of a more comprehensive understanding of the teachers' prototypes. These prototypes represent, in part, the set of characteristics and their associated relationships in the context that ISD participant teachers use to productively and receptively categorize STEM (Rosch, 1973; 1975). Each dominant prototype will be presented in the following subsections as a *profile*. Through each profile, I will explain the themes and metaphors present in each groups' discourse as understood and conceptualized through the dominant metaphor. To do this, I will use first person retell of the analytic process as well as occasionally utilizing the voice of participant teachers directly to illustrate their conceptions and prototypes as accurately and completely as possible.

Through this process, five distinct groups of varying numbers of participant teachers surfaced. In this section, these metaphors will be presented and explained in order from the most (that of the nonexample) to the least dominant presentation within the group as a whole. At this point of the study, it cannot be stated that a hierarchy in terms of accuracy, importance or reliability exists between the metaphors. Rather they are understood and presented in order of frequency and scope. The metaphor that education or knowledge is nutrition is presented first as it is broadest in scope, encompassing all teachers who used this metaphor to contrast their conceptions of STEM. Next, the amorphous prototype, encompassing six teachers (Participants 3, 5, 6, 8, 9, and 11) is described. Within this group, none of the participant teachers utilized a distinctly dominant metaphor in their discourse indicating the amorphous prototype. Next, STEM is a journey and STEM is a puzzle were both well solidified but only applied to two teachers each. Finally, STEM is an adventure and STEM is a bridge, both inclusive of a single teacher each are described.

STEM Might be Many Things (The amorphous prototype). Participants 3, 5, 6, 8, 9, and 11 did not utilize a dominant metaphor in their discourse and collectively represent the negative case (Wicks, 2010) at this point of data analysis. At first glance, these participants were very dissimilar. Participants 3, 5, and 6 made up a team at Moss School but vary greatly in their characteristics and experience. Participant 3 was a 23-year-old White female who entered teaching through an alternative certification program and had been teaching for two years. Participant 5 was a 35-year-old Indian female for whom teaching is a second career, and she had been teaching for 7 years. Participant 6 was a 23-year-old, traditionally trained teacher in her first year of teaching. Participants 8, 9, and 11 all taught at different schools and possess varying demographic characteristics.

Further examination of the characteristics of this group did reveal a common trend that could be associated with their inconsistent use of metaphors.

The shared pattern between all six of these participants was that they all overtly recognized gaps in their own knowledge. Statements around participants' limited knowledge and experience included passing to examples of the struggles involving lack of content knowledge. For example, Participant 3 acknowledged limited knowledge when she wondered aloud, "Especially just starting off, I feel like, I mean if it's really going to be true STEM, where you are integrating math into it, how? How do you do that?" Whereas Participant 8 struggled with content knowledge in a lesson:

> M: You've mentioned kids using or connecting previous background knowledge. Tell me more about background knowledge.
>
> T: Well we certainly, we brought up pictures of the wind turbine and asked, have any of you seen those? And that was a big thing, we saw them going out to California because you know you see them going out to Los Angeles, so they could relate to that. You know as far as doing a table, obviously, that does take a lot of background knowledge. I'm trying to see what else we did. They weren't real familiar with wind energy, and to be honest, I'm not real familiar with wind energy either, so we had to go through all the parts of wind energy and how its produced, but of course they have to ask me, how does it get produced and I say, I don't know exactly, I just know there's this giant Hoover Dam and somehow there's this electricity and that's really sad that I don't know that. You know I again, I would say, "have you ever seen this giant dam when you are going to Las Vegas?" "Yeah, yeah, we drive, you know- drove over it."

The issues of limited knowledge also involved a teacher's passionate call to fill these gaps:

> T: I don't feel I have experience myself, except for the table. I feel we facilitated an inquiry-based learning and the kids were really into the engineering process and going through it, and talking about it, and discovering it. However, I don't feel, I as myself had really engaged students in the sense of it. Maybe it is the lack of knowledge? Or the time restraint we talked about?
>
> M: If you think that's relevant, I do want to discuss that.
>
> T: I'm not saying, oh if I didn't have that, I would do that. There's just so many other variables of what you need to do and what your expectations are. Ideally, I would want to do it to get our kids at that higher level. For them, it would make them much more successful in the future and its one thing that we need to maybe rethink. We want to change how we approach education and move out of what we have been doing for years, and years, and years. Especially with the technology integration, because it's the reality that it has to be integrated with everything. We have to get out of our comfort zone: fork out money, get it out there to the kids. Again, we are doing a disservice to them and again we need professional development to make sure that we deliver this correctly, so we just don't throw everything at them and just do it half way, half assed. We have to do it.

Teachers in this group demonstrated an awareness of their lack of knowledge as well as the challenges that it caused. Within in the group, 21% of instances coded as barriers to STEM fell within the subcategory of teacher knowledge. They included PCK and SMK as well as logistics such as how to manage time.

All teachers within this group spoke to time and teacher knowledge in conjunction with one another. They appeared have an observable positive correlation when viewed as barriers, because time accounted for 14% of the occurrences coded as barriers within this group. This relationship was well illustrated in discussion with Participant 7. She was very clear in articulating this connection when she said:

> So that's what I'm telling you, I don't think I have enough time to sit and really go through the experiment or what I am thinking of the task and give that knowledge to the kids. Because once I give it to them, they run with it. But until I know what my level is, it's not working. For me, that's the hardest part. There's not enough time that I'm having to analyze my own self, my own probing to get it up to their level."

Teachers used examples like this to consistently articulate that this lack of knowledge often necessitates additional time in planning STEM experiences and preparing for their students.

The negative case presented by Participants 4 and 10 further substantiated this trend. Neither Participant 4 nor Participant 10 spoke to teacher knowledge as a barrier (Participant 4 stated it was necessary but did not elaborate enough to code it as a barrier), and neither spoke to time as a barrier.

Granted, both Participants 4 and 10 have a more flexible student schedule than the other participants in this sample as they only teach math and science and have two hours in which to do so. This structural difference in their school day may have an effect on the lack of tension between these two themes, but trend data demonstrated that time is more challenging when teachers do not feel they have the necessary SMK and PCK.

STEM is a Journey. Participants 4 and 10 both utilized STEM is a journey as their dominant metaphors. Participants 4 and 10 make up the fourth grade teaching team at Eucalyptus School and have taught together for three years. Both are traditionally trained teachers who graduated from the same institution although several years apart. Neither of them have formal background in STEM content, but both participated in a pilot professional development program sponsored by ISD and Arizona State University in the 2011-2012 school year. Additionally, they were recently accepted to a STEM professional development program sponsored by Northern Arizona University and Arizona Public Services that will begin in the spring of 2013. They represent the participants with the highest PCK and SMK as measured by experience and professional development.

During the member-checking phase of metaphor analysis, Participant 10 said, “[STEM is] definitely a journey. A very challenging, very rewarding journey.” She and her teammate, Participant 4 used the metaphor STEM is a journey throughout their dialogue. Operationally, a journey is any travel from one point to another marked by progression to the next phase and typically requiring extended periods of time (dictionary.com; websters.com). Working from this understanding, the STEM journey presented by Participants 4 and 10 followed suit. Marked by a clear destination, an openness and value for variation in pathways, and a belief that extended periods of time are essential to the process, these participants used spatial metaphors to describe the learning process. They discussed a starting point, a destination, and where students would go.

For Participants 4 and 10, the destination toward which they were pioneering, as well as the point of embarkation each time they engaged their students in STEM, was clear. The destination was a content concept derived from the science or mathematics standards and referred to in the discourse with the pronoun *there*. When asked where *there* is and how to determine where Participant 4 and his class are going, he told me that he has to “find that standard and connect to that, and find those things that they need to know for math or science.” Participant 10 similarly explained:

> Because if the whole point of, like, having the standards and the STEM go together is that you are teaching in these new creative ways that expands on the student's thinking and builds their own knowledge, but you are still getting across your goals, because when it comes down to it, everyone is going to have to be tested on the same standards.

Likewise, there is clarity around the point from which the journey does and should begin. Within the metaphor STEM is a journey, the point of embarkation should be the students’ background knowledge. According to Participant 4:

> You know, I'm not going to get up there and tell them, this is a simple machine, this is a pulley, this is a lever, you know. I think they need to see it, they need to, I need to draw them what they know already, their experiences. Then we discuss that part of it, and we tell them. I think we go from there. I think whenever when they are drawing from their own knowledge of what they think they know from, about the subject. I think from there is where I really get into the lesson or you know, wherever we are going for the day. I think that helps. We start with that knowledge of what they know, and we connect.

In this example, extracted from the interview with Participant 4, he consistently engaged the metaphor that STEM is a journey as he discussed students' background knowledge as being "from there," along with the usage of the verb "go" when he refers to "wherever we are going for that day," which indicates physical movement toward another destination.

Teachers who conceptualize STEM as a journey will not directly tell their students how to arrive at the specified learning destination. This is in large part due to the teacher's belief that there is value in the variation in the route each student will use to arrive at the destination. Describing the role of the students, Participant 4 told me:

> So, it's how to get there, it's just having them practice, having them explore more, having them do things like we are doing with these kits and now with the science fair projects. They are answering their own questions with their curiosity: letting them explore.

Through this experience, teachers are likely allowing students to bolster college- and career-ready skills (Conley, 2007).

The trend of student ownership in which teachers foster the facilitation of student skills holds true for both Participants 4 and 10 as well. They demonstrated the greatest collective propensity to believe STEM supports students in cultivating the attitudes and beliefs necessary to be career and college ready (Conley, 2007). In her interview, Participant 10 explained:

> The experience is lots of hands-on stuff and lots of perseverance. I had a discussion with my class the other day when we did our very first STEM activity. It was building the paper tables with the cardboard, and I had kids that before they'd tried were like, “I hate science,” “I can't do it,” “I don't know,” “I give up, it's not possible,” “Miss Summers, this is a trick, you can't even do this.” They were just done and they didn't have any interest. I went home frustrated just being like “I can't believe it, I love it, this is such good stuff” and now they've gotten to a point where they've just learned, you know, part of being a scientist and an engineer is failure and that you learn from those things and you can improve from those things. So, when a student first walks into the class, they are going to be, like, holy crap this is a lot of work to it, because it's not just a simple multiple choice or it's not just a simple underlining a word in the text to find the answer. The process is a lot for these classes, but they learn that it is possible to do these things. It builds a lot of confidence as they go through the entire process.

The participant acknowledges that the process takes time, but also acknowledges that time is not a barrier. Both participants speak to how fortunate they believe they are to have two hours allocated to STEM in their schedules. Participant 10 explained at length:

> I'm spoiled in the sense that I just teach math and science I get to choose how long I'm going to spend on science and math each day. There are some things that I could let the kids work on, like when we build the cars for electricity I could let them work on for like five days and they would just still be working on them. I wish, sometimes I feel that there would be a little more time, but luckily for me, I'm allowed to be flexible with how long I tackle things, so I can make sure that the kids really understand it before I go on.

Along similar lines, Participant 4 said, “When you give [the students] that opportunity, they are going to take advantage of it and, you know, just give them the time to do it; they'll surprise you with what they can come up with.”

As Participants 4 and 10 explained their thoughts on STEM, they, like all the other participants, spoke to a process and a product involved in STEM. Unlike the others, however, they did so without noting tension between the two. Participant 10’s explanation demonstrates this notion:

> M: So you said, you know, to make sure they get it. What's “it”?
>
> T: “It” is being able to get the concept, and I also really want the kids to be able to come up with the solution to whatever problem I have, because, like, when I said about building the confidence, if I only gave them one

hour to work on their cars or if I only gave them, you know, two days to work on these things, I feel like their working on it but they don't get the confidence because they haven't finished the thing until we move on to the next activity. And if they don't have those successes, it's harder to maintain all of the interests and motivation in it. So that stuff is definitely important to me: for the students to be able to come to a point where they feel they've been successful. I can drill them and ask them all about things, and they can challenge me and they can prove to me their reasoning and how they solved the problem.

M: So you talked about, you know, owning a concept and then solving or coming up with a solution for a task. Can the kids gain conceptual understanding, even if they don't ultimately solve the problem?

T: Sometimes yes, it depends on the activity, so for the cars, we did those right before Christmas break and I gave them some time every day for about three days and I had about half the cars and about half the cars not done, in the sense that they were able to roll and move. But other kids were able to, when they held it, it was able to move but just because of the weight of the car didn't work. I would still consider that success in my book, because they were still able to do it and the students, when they had to take apart their cars to return their electricity stuff, they were, like, yeah, I got my wheel going. Like, they don't even think about really I was supposed to have the car going. As long as, you know, my goal was to be able to make the complete circuit. So, if they were able to do that, whether

> they got the car to move or not, if they got the motor working, well their wheel didn't work because it was a bottle cap, well sorry that part didn't work, but they were able to show me that they could at least use the electricity component correctly.

Here, process and product fulfill two distinct roles. Process drives the learning, but product fosters the attitudes and beliefs that have come to be valued by these participants. The roles of process and product also appear to be connected to the teachers' view that STEM supports language development in that the process is continuously noted as the specific component within the STEM prototype that fosters this development:

> M: So, you talked about a couple of times, the things that they say and when they verbalize. So, talk to me about the role of language in this whole scenario.
>
> T: The role of language is actually very interesting with these kids because they are all ELD [English language development]. I have a lot of students in here who parents signed them out of the English language program before they even passed the test, and those students are building a lot of confidence. They are able to get out the same words that everybody else is getting and they are learning a lot of the vocabulary that everybody else is learning. Wherein, sometimes I feel like other classes they don't, they always feel like they are one step behind, but since everything is new and in the STEM world everybody is learning it together, they learn the words and sometimes I'll push them to say the correct words. So, like, with our

> magnetism, I keep referencing it because we just finished it; they kept saying the word, “oh the magnets stick together” or “are they sticking, is that sticky?” They are like “no, no,” and they are like “what's that word?” “Oh it attracts.” They are just learning the correct verbiage for those things, but it's also just, they are more willing to discuss things in the STEM world so that just in general brings up the ability to have a lot of the language aspects into things because they are interested in it and it brings it out of them.

In addition to their strong belief that STEM supports language development, the Eucalyptus teachers expressed an additional facet of the language component of their prototypes in that they believed the only challenge limited language may pose to STEM is in the assessment of learning. The combination that STEM supports language development and the bolstering of college- and career-ready skills within the journey of STEM also led to Participants 4 and 10 viewing STEM as an equalizer.

STEM is a Puzzle. Participants 2 and 12 were both second career teachers who had previously worked in the private sector. Participant 2 worked in banking for over 15 years and Participant 12 worked as an accountant for five years before they began their teacher preparation programs. Since graduating, they had taught for seven and three years respectively. Participant 2 had been a structured English immersion teacher for the prior three years, while Participant 12 had only taught fluent English-speaking students (as measured by the Arizona English Language Learner Assessment). These two participants presented the dominant metaphor of STEM is a puzzle. In addition, Participant 5, the only other second career teacher in the group also presented a strong tendency to speak to STEM as a puzzle even though this was not her foremost metaphor.

This metaphor was second in numerical prominence to STEM is a journey with 42 noted occurrences of the metaphor throughout the data. Operationally, this metaphor is marked by discussion of connection, pieces, and student decisions. Background knowledge also appears to play a significant role within this metaphor, as does integration.

Participant 12 posited the comparison between STEM and puzzles explicitly when asked to explain the role of the students:

> In a STEM experience, [the students] are the leader. You facilitate the learning, you give them the pieces, and it's more inquiry based and exploratory to where you give them a little bit and they kind of put the pieces. Or maybe it's better to put it that way, you give the, the pieces and they put the puzzle together on their own.

This comparison continued when both she and Participant 2 referenced pieces throughout their discourse. The pieces they spoke of varied with the context of the question and ranged in reference from physical materials to learning experiences for students. For example, Participant 12 spoke to both student experiences and academic content areas as pieces when she explained:

> With STEM, the teacher basically brings the raw foundation to the student, the foundational information, and then the pieces that they want them to grow with in STEM. So, you have to give them what to start with and then

> the student basically takes and runs with it from there. In a traditional classroom, most of the time you are just giving them information, you are just showing them how to do it, and there isn't a whole lot of room for other thinking. Where with STEM, if you are facilitating the learning and they are in the driver's seat, there are more opportunities for students to see other things and make connections that maybe you wouldn't have presented to them.

For Participants 2 and 12, the connections between skills and content areas students experience in STEM mirrors the real world, thus increasing its value. Participant 12 said:

> Then it will depend on what you are teaching. It is the culminating of seeing the connection between science technology and math and engineering and all of those pieces incorporate just about everything in this world. They are all interconnected in some way and just about every single thing that you teach through STEM is going to be connected in some way and once they've seen that connection, and that piece is going to build upon itself and every interaction that they have in life is going to be more enriched and more meaningful because they are going to see the connection between things.

Here, like a puzzle, the pieces are more valuable when assembled. They are more meaningful.

To reach this point, Participants 2 and 12 expressed a need for students to possess background knowledge related to their anticipated learning experiences. Within this theme, the metaphor presented two different ways. The first is related to the academic background knowledge. Both of these participants held a deficit view of students' background knowledge and believed that it was one of the functions of the teacher to supplement this gap. In an exchange of dialogue regarding how Participant 2 classified an artifact as an example, she realized her own views on student background knowledge:

> M: I'm going to back up there for a second. You said "here's how I might change it for the next time and go through that process." What do you mean by that process?
>
> T: The process of thinking, of analyzing what worked and what didn't work, how did theirs work, how did mine work, and what model of rocket worked the best for the goal we were trying to achieve. So what do I need to change on mine? Do I need to rebuild the whole thing; do I need to modify just one piece of it? That type of stuff.
>
> M: Is that necessary for something to be considered a STEM example?
>
> T: No
>
> M: It's not?
>
> T: No, I don't think so. And that's one piece that made me think of it as STEM—number 5, I put as STEM—was the fact that they are creating their own musical instruments. Because the rest of it to me is reading and writing and presenting a report, but to create their own musical instruments, they are going to have to use some mathematical design for the measurements. I assume they are going to try to do them to scale, so

> there are going to be some mathematical qualities there. Also, the science of how musical instruments work, how does sound come, that type of thing. The engineering piece—how you get all the pieces together and what pieces you use for that. And the one piece in there is what made me put the yes as opposed to the no.
>
> M: How do they know all that?
>
> T: Good question. I am going to have to get some technology and do some research.
>
> M: Hey, I'm doing something right when you tell me good question.
>
> T: Yeah, good question. I guess I kind of assumed on this, too, that they would have had some exposure that was tied into this piece.

Here, her reference to pieces and connectivity continues the metaphor of a puzzle, and she asserts that background knowledge is an essential piece necessary to assemble the entire experience. There is also an assertion that students already possess this background knowledge. In the event that they do not, both she and Participant 12 expressed a belief that the teacher must provide it to the students and that without it, they are likely unable to fully engage in the STEM learning.

The second form of background knowledge presented in the context of the STEM is a puzzle metaphor is experiential knowledge. Best exemplified by Participant 12's dialogue, she spoke to the exposure students have had and how like the other pieces of the STEM puzzle, should connect:

> M: Is all background knowledge academic?

> T: No.
>
> M: Tell me more about that.
>
> T: Well you got lifestyle, there's the real world, kids are exposed to things on their own; they discover things on their own outside of the classroom and that knowledge is also incorporated in how they view things and how they interact. Especially with STEM, you are going to get students where you are doing some kind of lesson and because of something that they experienced outside of the classroom, they can use that and can possibly connect that to something that they are doing in the classroom.

The theme of tools also seemed to be related to background knowledge in the prototypes of Participants 2 and 12. Both spoke to technology as a tool; one that is frequently used to provide background knowledge to students. Participant 2 said the following:

> Well, in today's world, technology is limited, so it's really hard to incorporate that. The technology is more whatever is in the classroom at the time, which in my classroom, I mean I am very fortunate. I love my Prometheon; I love my doc camera; that versus a couple of years ago if I wanted to show the kids something I would have to walk around with my laptop, "this is what it looks like," from desk to desk to desk. A huge improvement there—and to be able to show videos and video clips and those things large enough for the kids to see it. They don't really interact with it. They don't have laptops. They can't search things out on their own. They can't do that type of stuff.

During the STEM is a puzzle experience, process and product surfaced, and like their presentation in the metaphor STEM is a journey, they did so without tension. Uniquely, the process seems to be more limited in nature for these two participants and much more reflective of the concept of grappling. When asked to clarify what she meant by process, Participant 2 explained:

> the process of thinking, of analyzing what worked and what didn't work, how did theirs work, how did mine work, and what model of rocket worked the best for the goal we were trying to achieve. So what do I need to change on mine? Do I need to rebuild the whole thing, do I need to modify just one piece of it? That type of stuff.

This is congruent with the trial and error nature of the literal process involved in constructing a puzzle.

Physical activity is also a significant theme in this metaphor. Student verbs included build, construct, assemble, and put together. The use of such words underscore the essential nature of physicality in the STEM experience. This was particularly evident within the categorization task because Participants 2 and 12 classified all artifacts lacking physical student activity as nonexamples.

STEM is an Adventure. Participant 1 was the sole individual to present STEM is an adventure as a dominant metaphor. He was a male who had taught fourth grade between six and eight years, and he was working toward a master's degree in physical education at the time of the study.

Unlike the metaphor STEM is a journey, in which the destination is predetermined, when STEM is presented as an adventure, the destination in

STEM appears to be unknown. When I approached Participant 1 to member check this metaphor, he told me, “I would say an adventure because the end result and the path may not always be the same for each student or even for the teacher.” In his interview, he gave the example:

> I had kids ask me a question the other day about the body. We weren’t even focusing on that. We were talking about something else until their questioning led to something else that was important, so I went down that path of questioning to a certain point to answer their question because they were interested in it. It was valuable because they wanted to know.

This explanation and phrases like “you never know where you are going to end up” highlight the uncertain nature of the destination for Participant 1.

In STEM as an adventure, the teacher takes on the role of the guide and the students take on the role of explorers. In this way, student choice and interest are critical components of Participant 1’s prototype, yet student interest begins to compete with clear learning targets and the content concepts outlined in state standards documents. In a later noteworthy example, Participant 1 referenced learning objectives and the content students were expected to master; however, in the previous example, student interest was permitted to deviate the learning from the predetermined goal.

It is possible that the metaphor of STEM as an adventure is connected to the tension between product and process in that Participant 1 viewed engaging student interest as a means of encouraging fun and excitement, which is a necessary component of the STEM is an adventure metaphor. The metaphor itself asserts that the experience only remains an adventure as long as the adventurer is engaged and experiencing excitement from the occurrence. If the predetermined learning goal, set by the teacher, fails to cultivate the desired affective reaction from the students, then deviation to learning outcomes driven solely by student interest may be viewed as necessary to maintain the spirit of adventure.

This affective theme of fun and excitement was regularly revisited in Participant 1's dialogue as he used direct and indirect statements to communicate the significance of the affective component of his prototype. During the categorization task component of the data collection, he utilized visual affective cues to influence his categorization choice. Considering Artifact 2, he said, "One kid just looked to be very excited and so. They are working together, and so they are probably using information. Probably sharing what they know or how they could do something together." He also indirectly visualized affective cues by contrasting the adventure of STEM to traditional teaching.

M: So you said it's cut and dry for the kids.

T: Yeah, it gets kind of boring.

M: How?

T: One, because it's not usually as engaging. Not every kid likes to read stuff out of a book. They are not all textual. A lot of kids are visual learners. And, so, to be able to read something and physically be able to do it, or create something, kinda stays with the kid longer. Or they are able to retain some of that better than strictly reading something or taking a test

> on it. And that's pretty much how things in traditional teaching methods—you read, you take a test—it gets boring for kids.

Also, within the context of this metaphor, Participant 1 spoke to the process and product involved in STEM. Unlike participants who utilized other metaphors, 100% of his utterances of process and product presented tension between the roles of process and product. One is not consistently noted as more important than the other, and unlike the presentation of process and product in the metaphor of STEM is a journey in which one supports the other and the two also have separate, valuable outcomes, here the two seem to be at odds.

> T: So, if the student thinks differently that the teacher? The student would have to somehow be able to verbalize what they did and have reasoning behind why they did it. They can't just be "because I wanted to." They have to show some support or some reasoning behind why "I went this way instead of the way the teacher directed the class." If they went over here, the opposite direction of what the teacher was thinking and totally missed the point of what the context was, well then they didn't understand the objective and the content that supposed to be focused on or what the focus was. So, that would be, you would have to scratch that apparently and do that over with that student—a little more one-on-one.

STEM is a Bridge. Participant 7, a sixth year teacher, presented the metaphor STEM is a bridge as the dominant metaphor within her discourse. Early in her interview, she discussed the comparison:

> What I was stating earlier was that I kinda hate how we isolated all the curriculums and they aren't bridged together. And I feel like STEM is trying to bridge it all together, but what I'm finding that I hate in my classroom is that we'll do reading and it's all these outside texts on these topics that don't really correlate with the curriculum. Then you have these content topics that would be great to be covered in your reading block so that it all kind of comes together so you are actually correlating the reading with the STEM so that they have more of a vocabulary, building a bridge between the actual text and then being able to digest it trough the experiment.

Within this comparison, the metaphor first appeared to be limited to within the learning, and thus very similar, if not a replica, of the STEM is a puzzle presentation. Soon after, however, this comparison not only expanded but shifted focus from connectivity of concepts to connecting location: the classroom and the real world. Interestingly, who is included in this metaphor is unclear within Participant 7’s dialogue. She spoke primarily to her experiences as a teacher of STEM, and only occasionally used the pronoun *we* to refer to herself and her students as a group. Available data were too limited to discern whether or not this metaphor consistently extended to the students or if it was limited in its scope to the teacher.

The metaphor is characterized by the connection between the classroom experience and the real world. It seeks primarily to bringing the learning out and secondarily to bringing the world into the classroom. Participant 7 gave an example:

> Plants. Say there's something new discovered on the plants. Say we saw that video about the algae and how they are trying to use it for different energy resources. Okay, in the past that would just be an algae plant video to me. I would look at it and be like, um okay, algae, interesting. I wouldn't ever think about it again. But then, because they are also asking those questions that you are asking, how does this impact my world, or how would this be used, it makes you kind of think, and when they are adding in the possibility of the experiment, and they are like, oh, I just used that vocabulary term I used when we started talking about algae. So it's those connections for me that I'm starting to pull in myself. Oh, we just used algae. Oh, look, I see algae on the pool. Like, I'm starting myself and I don't think as a person I was very conscious myself about it. And I think right now we are trying to make the kids think about their thinking versus I just have one answer and this is the answer and I have a strategy, but I can't tell you my strategy. So, because we are forced to think about it, it is kind of changing it a lot.

Here she explained STEM as the bridge that connected classroom (in this case professional development) learning (the video on algae energy) to the real world by wondering about the algae that she was now aware of in the pool. Previously, these had existed as two separate realms. The breadth of this metaphor is limited, but its repeated presentation demonstrated significance for this participant.

Data Analysis: Phase Two

Circling back to Phase Two of data analysis, I will now explain the various components of participant teachers' prototypes within and beyond the scope of their dominant metaphors. Doing this is critical as many of the teachers, even those who presented a clearly dominant metaphor do not have well solidified prototype of STEM. As such, they tend to speak through multiple metaphors and without metaphors at all. Complete understanding of their prototypes can only be garnered when accounting for all discourse and thus the themes presented in transcript analysis are reviewed and explained here.

Stage 1. The first stage of the second phase of the model is the open coding phase and seeks to answer the question, "What themes, patterns or categories are present in this data?" The study answers the question by identifying and then triangulating themes from the interview data, categorization task examples, and categorization task nonexamples.

First, each data set was coded separately then reexamined as a collective. As coding transpired, memos were kept to record patterns, categories, and evidence from transcripts related to what ultimately became the final set of coded themes. Each of these themes were then triangulated by cross referencing the number of occurrences for each theme along with notes on the general presentation for a given data set with each of the other data sets. By identifying the themes present in all three sets of data, this process discerned the *major themes*. (Appendices 9, 10, and 11 represent the frequencies of themes in the interviews, categorization task examples, and categorization task nonexamples, respectively.)

Major Themes. What follows is an explanation with concurrent evidence for each of the identified major themes. The major themes are grappling, background knowledge, action, challenges tradition, creativity, fun and excitement, inquiry, integration, conceptually driven, requires tools, processes and products, supports language development, challenge and rigor, and ownership. They are discussed in relationship to the frequency with which the theme presented in the data, which the least common themes discussed later.

Grappling. More expansive than initially expected, the theme of grappling presented in the data collected from 11 out of 12 participants. Contrary to the literature, the theme was not limited to the context of grappling with data collected through scientific testing (National Research Council, 2007, 2012). Rather, this theme was marked by any metacognitive confrontation resulting in a new construction or reconstruction of an idea. While the theme was partially composed of data collected from scientific testing, this theme is more inclusive and often marked by feelings of frustration or disequilibrium for students. The following is a dialogue with Participant 5 that incorporates the them of grappling:

> Teacher (T): Have them analyzing things. Probing them for justifications. Generalizing things so.
>
> Meghan (M): So then, tell me, describe to me, what if I'm a student engaging in STEM, what's that experience like for me?
>
> T: I hope it would be kind of, somewhat at a disequilibrium. Like what are you doing, solving, figuring things out. Hopefully that disequilibrium will engage them because they want to know what's going on, because some

> kids, that's what they thrive on. They like that. It makes them more engaged.

Background knowledge. Presented as the most dominant theme within the data, 100% of participants spoke to background knowledge on behalf of the students. This theme emerged with a binary nature as participants spoke to both academic background knowledge and experiential background knowledge (see Figure 15). Academic background knowledge can be defined as knowledge that students already know about the content they are being expected to learn more about (Marzano, 2004). Meanwhile, a child’s *experiential background* “is his knowledge of common objects gained through direct concrete experiences.” (Schmidt, 1978, p. 2)

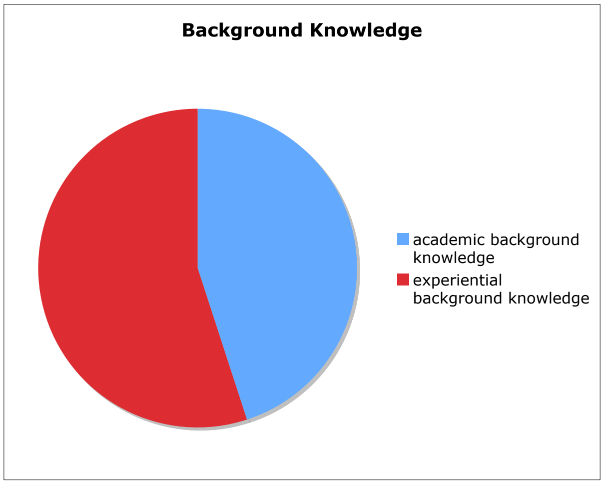


Figure 15. Occurrences of theme background knowledge by type. Data adapted from triangulated themes.

Of the two types of background knowledge, it remains unclear if one is any more important than the other in the prototype of teachers. It is clear, however, that teachers tend to have a more positive view of students’ experiential background knowledge than their academic background knowledge. Of the respondents, 100% spoke to students' academic background knowledge in deficit terms. For instance, in an interview dialogue, I explored the topic with Participant 9:

> M: No, it's valuable information. It's interesting. So you are talking a lot about students making decisions and having input and, you know, as that being a part of STEM, talk to me about background knowledge. Student background knowledge: how does that fit into the whole picture?
>
> T: I don't think they have enough. Some kids come to, I think from the younger grades, to where we're at. I don't think the younger grades, the you know, kinder, first, second, third, I don't think they're teaching like the way, by the time they get to us, the way we want them to learn. I don't think they have any, and some do, but it also has to do with the community that we are in. They don't have, I mean, they are not exposed to a lot . . . maybe the previous teachers didn't expose them to any of it. So it has to be, if we are going to go towards the STEM route, we have to do it from kinder up to, you know, when they leave. I don't think, it doesn't work the way we are doing it. I don't think it works here. They come to fourth grade, it's like, oh yeah, you are going to be tested on science, it's like, you have to teach science, but first, second, third didn't teach anything, once they go to fifth, whether the fifth grade teacher wants to teach it. And then what? They go to middle school and then, then they are exposed to it again. So they don't have a true understanding of everything,

> you know? I think what I'm trying to say is by the time they get to the fourth grade, all they've ever done is reading and math. That's all they've ever done and maybe writing, but it's like they haven't really done anything else because it's reading, math, reading, math for the test. It's all they get tested on and writing kind of gets pushed to the side because there's not enough time. That's what I would want to see that if we are going to go with the STEM, if we want to get our kids to be more, I don't know, better thinkers, we need to expose it to them from when they are really young.

Participant 9 is not alone in this deficit view of students' background knowledge. The other 11 participants echoed her thoughts on the lack of academic background students possess. Unlike her, however, 33% of respondents expressed that this lack of academic background was not detrimental to the students when engaging in STEM.

To the contrary, most teachers expressed an opposing view of students' experiential background knowledge, as evidenced by 10 out of 12 teachers using verbiage that reflected a positive view of students' experiential background knowledge. Participant 5 articulated a belief that, "every student has something, but you may need to click into something. If [teachers] just throw out a word to them and the word may not mean anything to them." Likewise, Participant 11 explained that "their prior knowledge can come from any variety of things" and then went on to cite examples such as TV, books, camping, and culture as sources for obtaining experiential background knowledge.

Additionally, 5 out of the 12 participants spoke to an obligation for the teacher to determine what background knowledge their students brought to the experience and also spoke to the importance of utilizing it to enhance their learning. Participant 3 articulated that by doing so, the students are able to “take away more since they were connected to the prior knowledge, instead of just information thrown at them with no connections made.”

Action. The idea of action as a component of ISD teachers’ prototypes of STEM was illuminated throughout data collection, but it was especially evident during the categorization task. Ultimately, 100% of artifacts depicting or discussing students being active or physically constructing or creating something were categorized as examples of STEM by 50% or more of the participants. Interview responses support this, such as the response of Participant 1, who described the comparison in the following words:

> it gives the kid, the students are a little more engaged. Because they are allowed, I mean you can create models, you can do hands-on activities with it. Whereas paper and pencil stuff is what is typically done in the classroom for math or for writing type activities.

The over attribution of student activity as engagement is supported by the findings of Appleton (2010) and Roth et al. (2006) who both argued that over attribution can be one of the most common pitfalls of inquiry based instruction.

Challenges tradition. Throughout the data collection process, teachers spoke to the challenges STEM poses to tradition. Most often, these ideas were expressed when asked to compare and contrast STEM to non-STEM and when asked to explain the roles and experiences of teachers and students. The presentation of this theme, illuminated through the contrast of the role of the teacher and types of activities or actions students participate in during STEM learning experiences is congruent with the literature, which argues that individuals are often able to conceptualize a counterexample before an example of inquiry (Furtak & Alonzo, 2010; Smith, 1996).

Of the 12 participants in this study, 100% demonstrated a propensity to assert that STEM challenges tradition. Challenging tradition occurs in three main ways: through the role of the teacher, the role of the student, and through the types of activity that occurs within the classroom. Of the 83 total coded occurrences, the percentage by category is shown in Figure 16.

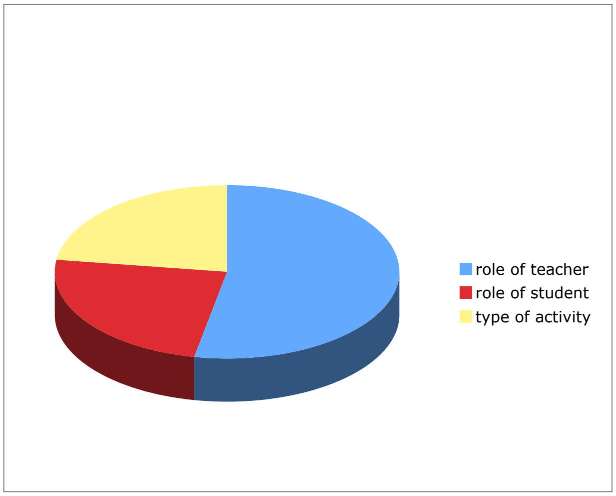


Figure 16. Challenges to tradition by type. Data adapted from triangulated themes.

Role of teacher. The traditional role of the teacher as the owner and dispenser of information is directly challenged by the role of a teacher in STEM according to the conceptualizations of the teachers in this study. Like Participant

4, 100% of the teachers involved in the study agreed that they were facilitators in a STEM experience. Participant 4 elaborated:

> They have to step away from the teaching part of it. I think that we have to become more of a guiding facilitator as we are doing this and not so much telling them what they are going to learn but how it's more them discovering for themselves and asking what if and the questions that they ask themselves.

This process can be a challenge though, and it can even evoke some fear for teachers. Participants 4, 5, 7, and 9 speak to the idea that moving away from the typical and often comfortable role of teacher is likely difficult. Participant 4 predicted that this transition:

> will be difficult for teachers. Like I said, teachers are going to be, I believe teachers are more concrete. They want to know, what am I doing and I don't see that here. They see a noisy classroom, like no, that's not what I want in my class.

Similarly, Participant 7 observed: “I’m seeing difficulties on the teachers’ part by getting over that fear base.”

Type of activity or action. The next challenge posed to tradition is in the form of the activities or actions students are likely to partake in or perform. For many of the teachers, this meant that students would not be reading or completing worksheets because they believed these to be exemplary of tradition. In the event that they did these types of work, it would only be as a beginning or starting point for the less traditional work that is to follow.

During discussion on integration and the types of work students should expect to engage in during a STEM experience, Participant 1 explained the idea of activity.

> T: Using food objects or a different size ball and getting kids to determine what it's made of, what's in it, like a balloon versus a, uh, a balloon with helium versus a balloon with just air and which one weighs more. That kind of thing.
>
> M: Okay. And so what's the purpose of that?
>
> T: Uh, I think it's for, to expand their real world experiences and to get them critically thinking outside of what traditional teaching has been.
>
> M: Okay. Is that any different or how does it compare to non-STEM.
>
> T: It's different in that the traditional method is typically like let's do writing and you just do writing and so you spend however long doing your writing section. Then you go to reading and you do you reading block. And then you go to math. But you may not go back and cover something that you did in your reading section. You just focus strictly on math. Whereas STEM allows you to overlap subject areas.

Creativity. Creativity is a theme that was less associated with teaches' prototypes themselves and more so as an ability or skill developed by engaging in STEM. Referred to directly and through metaphor as thinking outside of the box, creativity was only noted as a theme in the data presented by 3 out of the 12 participants. It did, however, appear in all three data sets. When asked why she would offer STEM experiences to her students, Participant 12 explained:

> To do that, one it's more engaging. Two, there's more rich, knowledge and learning going on. Also with the kids, with the engagement and the critical thinking piece, their minds are starting to develop in a way that they think outside of the box and they see the real world connection and the connection between all of those things as opposed to singling out one item at a time, as opposed to math one plus one is two.

Her thoughts were echoed by Participant 1, who made the connection between creativity and the traditional role of the teacher as he explained:

> I mean, you come in the class one day and you have all these things, are you, like, we are going to do this and they kind of look at you with this blank face “you can’t do that.” Somebody surprises you can creates something on what you were trying to work on, it’s like it is possible. So the unexpected nature of being creative, I think, plays a big part and allows the kids, the students, to be creative on their own as well so that they are not stuck within the framework of what the teacher came up with. They can go outside of it and think on their own as to how to do something”

Participant One went on to explain how creativity was a factor in his decisions to categorize the rocket artifact as an example:

> That looks like each student was able to create their own rocket with, it looks like cardboard and either paper or plastic bottles. And so, they had their own creativity in part of the design or the building of it by themselves. Since they’re outside, they may actually be testing them.

Fun and excitement. One of the less frequent but nonetheless major themes was fun and excitement. The propensity for teaches to include fun or excitement as a part of their prototype was demonstrated by five participants. Reacting to Participant 9's explanation of the student and teacher experiences in STEM, I told her it sounded like a lot of work. She affirmed and when I asked why she would want to do this, she told me:

> Because it's fun. It's fun for me. I think it'd be fun. It'd be more planning as far as unit planning, so long-term planning. It'd be more of let me sit down for hours and plan this lesson. It'd be more materials, but I think when it's all said and done, it'd be a lot of fun. Once I do the planning, they do all the work."

In Participant 8's words, "But [the students] love it. They absolutely love it. And it's fun for us too because it's a day of exploration and that's what the whole Common Core theme is."

Inquiry. According to 7 out of 12 participants, STEM should allow the students to participate in inquiry by discovering and make meaning of various experiences. Congruent with the findings of Appleton (2010) and Carlsen (2010), students did this by following a process and using information to typically solve a problem or challenge. Throughout the data analysis, participants referred to the process of STEM, which appears to be reflective of this idea of inquiry and the products associated with it. As explained by Participant 3, this is often a divergence from traditional or non-STEM instruction.

M: As you think of that, how does that compare to non-STEM instruction?

> T: To me, STEM is more investigative and discovery based, not so much like here is a list of facts for science, memorize them, and then like type them in a Word document. That's not exactly using science and technology together. So, it would be different because it's more like inquiry based as opposed to what most people normally think about when they think of science or think of technology, or think of, I don't even think teachers think of engineering in school.
>
> M: Okay. So inquiry based, what does that mean?
>
> T: When we entered our STEM trainings, we were posed a problem and given some guidance, but it was really up to us to come up with our own solution to problems or think through the process. You gave us the engineering process and we kind of worked through that, and with that we learned about different scientific things.

Integration. Noted as a key factor in the prototypes of 100% of this case study's participants, the theme of integration presented in two dominant ways: integration in learning and integration in application.

Both affected participants' categorization task decisions in that artifacts they believed to be isolated lessons, which focused only on one content area, were quickly categorized as nonexamples of STEM. Dialogue around these decisions revealed that integration both between the four STEM content areas and among other disciplines such as reading, writing, and language were required for the teachers in this case. Participant 2 told me:

> In my perspective, if you do a science lesson, and you do a technology lesson, and then you do an engineering lesson, and then you so a math lesson, that's not necessarily STEM because there's got to be a correlation between those two. You have to see how those things are related. So if you teach them in isolation, then to me there is no reason to lump them together in the acronym STEM.

Integration is also more than including skills or learning from multiple disciplines in the same lesson or segment of time. Participant 1 illustrated this idea during the categorization task when he put

> [the artifact] as a nonexample because one, they read. Two, they calculate the distance they traveled but they didn't do anything with it. They drew a picture of a ship they would have explored on. None of those things connect anyway. They didn't use the distance they traveled to connect anything. They didn't use the reading. Yeah they probably read in the story that they used a ship, but there is no real connection between any of those things.

Here, he explained not only the need for skills and learning from multiple disciplines to be present in a lesson, but for them to also be codependent. If each could be isolated and function on its own, this is not integration. Integration requires a codependence in the way the information is used or learned.

Conceptually driven. The idea that STEM and the associated experiences should be driving toward specific content concepts is a recurring theme in the transcripts from 7 out of 12 participants' data sets. In all cases, the belief that

STEM learning should be driven by content concepts was extremely explicit. Significant variation, however, arose when digging deeper into how or from where the content concepts are selected. In this regard, presentation ranged from direct connection to state standards document to student interest to what the teacher believes to be necessary for student as a life skill. In the case of Moss School's teachers, along with two other teachers the standards should determine the goal or objective for a STEM experience.

When explaining how she would manage the challenge of time to accommodate STEM learning in her own classroom, Participant 5 spoke to the standards in all content areas as a driver for planning and lesson execution. Here is the dialogue:

> M: So think about your day specifically. What would have to change about the way that you engage in your work so that you have the time to do this?
>
> T: I would have to just chunk an hour, an hour and a half time, where I am just doing STEM. But knowing I am integrating what I am doing in math with it. And integrating maybe even reading standards with it so the kids are . . . cause and effect, it's in there so I make sure it is all fit in and I get more bang for my buck, you know what I mean? So I am doing what I need to do, because of my restraint on time, you just have to manage it very carefully, you can't just throw things together—I'm going to do this, this week and this, this week. There has to be some curriculum timeline planned out to make sure that if you went through this, you hit all these standards and make sure that kids are prepared and know what they need

> to know for that grade level. But this is how you are going to be approaching it and this kind of instruction. So, I guess a big chunk of time where I know. It's just my own knowledge of knowing what I'm going to be doing, I'd go okay, but it's just not there yet. I don't know how to do it.

Other participants spoke to objectives, and I learned through informal conversation with the Assistant Supterindendent of Teaching and Learning that the concept of objectives had been a focus of professional development and should be directly linked to standards. Of objectives, Participant 3 said: “In any lesson I think you start with an objective or a question that the kids need to be able to answer. So I think that would be the final goal piece. Did you figure it out?”

Conversely, Participant 11 explained that, “I think kids should know things.” Her thinking is representative of two other participants as well in that she believed there were some things students should just know and it is the obligation of the teacher to provide this knowledge. However, these things may or may not be connected to standards or student data. When discussing how she would choose to engage her fourth grade students in a lesson on plants, she divulged:

> I think it's just something that they need to know: this is what a plant looks like. If you ask them, how does this grow, a lot of times they have no clue. Does it grow on a plant, does it grow underground, does it grow on a tree and the sad thing is, in today's society a lot of the kids don't have any clue. I grew up on a farm. I know that potatoes have to be dug up; I know that

> turnips have to be pulled up; I know that radishes are pulled up. I know that green beans grown on a plant. I know what kind of things grow in trees because I grew up touching and feeling and knowing all of those things. But I think kids today, you all buy in the grocery store. Let me give you a parallel to that, because I thought for many years and you can't laugh at me, I thought for many years my mother would say go get a can of green beans from the smoke house. Well to me a can of green beans was a jar because my mom canned all the stuff. And so I didn't even realize for many years that they came in cans. Because she did canning and I thought that that jar was a can. Not that I didn't know the difference between a can and a jar, I thought that everyone bought them in jars. I thought they came in jars, because we canned all our fruits and vegetables.

Requires tools. Initially, the theme that STEM requires tools emerged as separate categories reflecting the usage of questions, language, and technology within the context of STEM. After repeated examination of these patterns, it was evident that all three of these are used as tools within the STEM experience. Defined here as anything used to make doing work easier, tools of STEM as a concept was often presented through discourse that described STEM as something one does rather than something one learns. Generally, the tools were utilized to make completing this work more simple and less frustrating.

This theme presented with the largest range of occurrences within the participant group. Participant 6 only referred to necessary tools one time while

Participants 3 and 7 did so on 16 occasions. A breakdown of the 102 total observed instances for this theme is relatively even, with 39 for using technology as a tool, 27 representing language as a tool, and 36 indicating questions as tools.

Questions. Questions were discussed as tools used by both teachers and students, but the theme was presented much more frequently as a teacher tool. In all, 83% of the instances coded as *questions are tools* were indicative of questions as tools used by teachers. In this way, participants explained that the teachers must ask questions to help the students to continue moving through their inquiry experiences and to further their thinking around STEM concepts and the problem solving process.

Language. The idea that language is a tool surfaces as participants speak to the ways in which students must communicate in order to create plans, explain results, and share ideas. While participants expressed the possibility of achieving these tasks through more visual means, 58% articulated a belief that language is a valuable tool for communication and growth. Participant 5 explained that a great deal of STEM requires communication and collaboration to grow and be successful. She said:

> So you have to be able to talk and work with each other, articulate your ideas and then plan something out. You are going to have to write it out, either visually or writing in words. So you are going to have to present your data somehow or collect your data, so they are going to be writing in

> that way. It's kind of keeping track of everything and communicating your ideas.

Technology. Used both productively and receptively, technology is spoken of as a tool throughout the interviews and represents 39 of the 102 total occurrences in which participants spoke to technology as a tool. Participants most frequently cited technology as a tool for knowledge consumption that is particularly valuable for filling gaps in background knowledge and for doing research. Productively, technology is most frequently described as a tool for communicating what students have learned. Additionally, teachers articulated a viewpoint that, for this tool to be used most effectively, it should be in the hands of the students. Participant 2 told me:

> They don’t really interact with it. They don’t have laptops. They can’t search things out on their own. They can’t do that type of stuff. We don’t have time allotted for that. They don’t use video cameras to observe nature, to make connections between things. We don’t have tools for them to go out and measure certain things and do experiments. We don’t have things like that for them. It’s so limited, the things we have for them to work with.

Participant 3 echoed these beliefs when she said, “You know, it needs to be an essential piece. If your kids are doing an experiment or if they are working through a project, they need to have the technology right there with them.

Processes and products. Implicit within the theme of process and product is the relationship between the two components. The process should result in the creation of a product and both the process and the product are part of the learning involved in STEM. Participant 10 reasoned, “The process is a lot for these classes, but they learn that it is possible to do these things. It builds a lot of confidence as they go through the entire process.”

Within this case, the process is covert in nature and while it is clear that the process includes both cognition and performance components, the steps are never made explicit. In spite of this covert nature, participants discuss the need for students to utilize the process as a means of completing a product, which typically is evidence of the culmination of a STEM experience. The products often vary greatly and this is accepted and even expected by the teachers. Processes, however, are spoken about more inconsistently and it remains unclear whether or not there is a single, desired, process for students to follow. For instance, Participant 6 spoke to the process involved in STEM when explaining the role of background knowledge:

> T: They are able to start with what the kids know and the process builds on that background knowledge and the process gives them more background knowledge for the topic you are trying to get them to understand and it also just links up with what they know.

By referencing “the process,” she implies a standard, replicable process although the specifics of it remain unclear. During a categorization task, she explained further in response to my question:

> M: 2? Think about it as if you walked into a classroom and that's what you saw.

> T: It's possible that they are doing STEM.
>
> M: Okay, what conditions would have to be true for them to be engaging in STEM?
>
> T: They would need to be using the design process. That's really the only part of STEM I fully understand. So they would have to be testing it at the end for something to build knowledge on.

Participant 1 used similar language when he discussed the process students must engage in to develop a product. He expressed the expectation that the products created through a process should not be uniform.

> T: That [catergorization] I put as a nonexample because seventh grade students are learning about volcanoes. They are assigned a project in which they build volcanoes and erupt them using vinegar and baking soda. That doesn’t give the students anything else to learn about. Students are going to learn, if they haven’t already learned, that volcanoes are going to erupt. The teacher is giving them this assignment and they are limited to using vinegar and baking soda. Why can’t the student find other material that they can use that can erupt? I think it kind of limits that as to what they can do. Every project is going to be the same. There’s no differentiality [*sic*], no differentiation.

Supports language development. Expressions from several of the participants indicated that STEM supports language development. They articulated beliefs that the engagements and multiple modalities associated with STEM experiences support students’ language development by giving them something they want to talk about, by allowing them to develop content concepts independent of language, and by supporting connections between the Latin roots of English and Spanish science and math terminology.

Participant 4, the most consistent in his expressions of belief that STEM supports language development, explained to me that while his students are engaged in STEM experiences their language is more prolific and precise. He expresses satisfaction in that this oral language development is not only benefiting his students' ability to verbally communicate but also seems to transcend to their writing. Contrary to the prevailing hypothesis (Gilbert, Boulter & Elmer, 2000; Carlsen, 2010; Kelly, 2010), he and the other 11 participants did not articulate an association between language development and STEM that is bidirectional. In other words, the ISD teachers articulated a belief that STEM develops language but not that language develops STEM (content or process). Participant 4 explained:

> If you allow them to [engage in STEM and inquiry specifically] they go more in depth as to what it's all about. And I think that's where you find you'll have more vocabulary and you will see that the kids know more about how those type of, that, let's just go back to the vocabulary. I mean, you know, we did simple machines and things like that. We did the boats. There were things like inertia; there were things like friction—things like that that came out of it. They did the simple machines and they did the different types of machines, you know, they got that more vocabulary. They started using that vocabulary. I think more than anything, them using

> the vocabulary, you know, after we are done with particular units and you still hear them saying that vocabulary word, or, and it happens in math all the time too. Them knowing what it is. You know, them not just saying this is a pulley, you know, they know what's a pulley, how it works, they give me examples of pulleys. They know all those things and they know the differences between the two. . . . They know, so, using that vocabulary is very beneficial for them. It's significant that they use that vocabulary.

Participant 7 further supported Participant 4’s sentiments when she explained the way her students persevere through language challenged in the context of STEM.

> M: So tell me about that. Like, how language and STEM, what's that interaction like?
>
> T: If you do not have a very high vocabulary, you are going to pick it up quickly because it probes a lot for those adjectives and those descriptor words. It's not just safe to say a word, you have to express it in multiple ways. And maybe I'm not expressing it in the verbal language, but maybe I can express it in the visual language. I can write it for you or I can draw it for you. With the STEM, if you do have the language, it is going to increase immensely because when you have the dialogues with the main, your classmates, you don't want to sound like the odd ducky out. So I'm noticing the students are, like, really listening to each other so they can kinda mimic some of those words so they are not really mimicking all the time. They're like, that person used that word, like, six times. And you can

> tell they are processing that word and then I'll hear them use it correctly. So I'm noticing that when they have that partner talk, you are really building up that vocabulary. I'm noticing more descriptives. But when I go back to more traditional, linear style of teaching, it seems like they drop all of that because we look for that direct key words, not that tell me more, tell me more . . . I'm noticing with the STEM, they are becoming more expressive. And if they cannot get it out orally, they find some other way to get it out. I find the favorite way is, the Spanish word means . . . what's that one in English, I can't think of it in English. And then the kid will say something in English; they're like no, no, no that's not the word I'm looking for. So they kinda become their own thesauruses, with their classmates and they are so wanting to get that thought. When you give them a provoking thought, they want to answer you and they do not like it when you cut them off from their responses because they are, like, no I have this thought, it has to be heard. So I also notice they are more aggressive in their language.

The only challenge language seems to pose is in the context of assessing STEM learning. Teachers expressed a strong reliance on students’ explanations of what they did and why or how they chose to do so within a STEM experience as a means of assessing learning. For example, upon being asked, Participant 11 told me:

> M: So what I'm hearing you say is that in either case, the learning target is the same: for them to own the concept of erosion. How do you know in an instance of STEM, if they know what they are supposed to know?
>
> T: I think that they, that they would be able to verbalize it. They are going to be able to say, well I know that we had this mound of dirt and when you poured water over it and it made a big trench or a ditch or whatever or whatever it made and I know that when we tried this over here, it didn't happen because there was some grass and we still had a little bit, but it wasn't as bad as the other one and they can verbalize it. They can start to put it into their own words. And I've become very good at saying why, explain the steps to me. If you are doing a math problem, explain to me what you are doing as you are doing it. Just don't give me an answer. I don't just want an answer. I want what did you do, because maybe I look at it differently. And so, I'm doing a lot of why. Tell me how you did it, what did you do, what are you doing, what step came after this one.

Here, it is evident that a student with limited language would struggle to offer the explanations upon which she relies to determine content concept development.

Challenge and rigor. Teachers in this case presented a strong need for students to be challenged and for STEM experiences to be what they identify as rigorous. They should require careful thought and planning. Typically, data should be collected and then reflected upon as part of a challenging experience and students will likely experience frustration.

During categorization task dialogue, teachers often present the challenge and rigor theme when they classified artifacts as nonexamples because the students in them were “just” playing or “just” completing a project for fun. When discussing the fifth artifact, Participant 5 reasoned that her categorization of this artifact was dependent:

> Oh if they just built it to be some cutesy putesy or unless they actually measured it to see if it actually worked, that would be some science and engineering to it because there is a way that an instrument is designed for it to actually play musical sounds out of it. But if they just created some pretty little flute, I would say that is just an art project than them using science and using math to build an instrument.

Conversely, Participant 1 categorized artifact seven as an example because it was hard and integrated. He explained:

> I think it was good. I like how it, they saw the episode and then they had to measure the class and draw to scale the people within the show. That itself is very hard: to draw something to scale. But that takes a lot of math. It incorporates math and art, because in art you have to draw. But just being able to measure and downsize things. It may be in your classroom for someone who is not your size or for someone who is small. I think that was a good example right there.

Ownership. The idea of ownership was one of the themes most frequently noted in the data. Eleven of the 12 participants spoke to the idea of ownership in STEM and many did so in all three sets of data. The theme was frequently presented through dialogue around students with the terminology “getting it” and not “getting it.” This was presented by Participant 1 who stated:

> you obviously need to spend more time or use some of those other students to help those students work it out and so there’s not like, “okay, we only read for thirty minutes and if you didn’t get it, you didn’t get it.” You know, like, you kind of go to the point where make sure everybody in the class gets it.

Participants demonstrated a propensity to conceptualize knowledge as a commodity to be obtained. The students and teacher work to ensure that they “get it” or gain possession of and thus have ownership over the concepts.

From a more constructivist perspective, data presented within this case also speak to ownership as something obtained through creation or construction. Similar to the data examined by Minner et. al. (2009) and advocated for by the National Research Council (2000, 2012), students come to own information and experiences when they engage in inquiry and discovery. Through inquiry and discovery, students construct knowledge and understanding; because they have built it, it is theirs. Participant 7 utilized lack of student ownership as a means of categorizing artifacts during the categorization task. When explaining her thinking behind categorizing an artifact as a nonexample, she argued:

> I'm going to say it's a nonexample for me. Yes, they read stories beforehand, but I think, I'm kind of on the point, they created their own musical instrument, but I think we give them too much information here versus let's create an instrument and go and research some more. Like, I

> feel like that exploration is lacked on what instrument did you create, why did you create it, oh, here are other examples of people that have created. I don't feel that it's really theirs. It's very limited and to me, very linear in that assignment so I'm saying non[example] on that one.

Minor Themes. In addition to the triangulated, major themes, additional themes that were not present in all three data sources emerged. These themes, referred to as *minor themes*, occurred in the interview data but may or may not have presented in one of the categorization task data sets. Due to the limitations of the categorization task, the absence of these codes cannot be interpreted as lacking significance and therefore they have been included in the data analysis and interpretation. Minor themes are discussed in greater detail in the following material, and include barriers, longevity, inclusion, and perspective.

Barriers. The theme of barriers initially presented through three separate subthemes, which were ultimately coded together as a result of their metaphorical presentation. All three subthemes (language, teacher knowledge, and time) were directly referred to as barriers, challenges, or were discussed as something to get past or get over, which is a physical metaphor (Lakoff, 1987; Lakoff & Johnson, 1980) indicating an obstacle to the metaphorical quest of STEM.

Language. Within the barriers theme, language was cited by 58% of participants as a barrier to STEM. Contrary to existing literature (Boulter & Elmer, 2000; Carlsen, 2010; Kelly, 2010;), which argues language is critical for science learning, the presentation of this theme was limited in its scope as a barrier for assessing STEM, not for the learning involved in STEM.

An example provided by Participant 4 illustrated the metaphorical presentation of language as a barrier to STEM assessment:

> I think how you try to divide up what you can do is definitely get the vocabulary out of the way but know what the vocabulary is going to be when you get into it. Do a whole thing of vocabulary with them. Then go into that background connection with them.

Later, he expanded his idea of assessment in STEM, reasoning that:

> For the most part, I think them explaining to me, verbally, also helps because you do have some kids that struggle with writing. Just talking with them and keeping research notebooks. I think the research notebooks help a lot because they put all their thoughts in there. If they can explain their thoughts to me, then I think that's success for me.

Here, as was the case with seven other participants, the teachers' ability to fully assess STEM learning and measure success is bound to students' language abilities. Whether written or verbally, there is an expectation for students to explain their thinking and comprehension. Additionally, this limitation is contextually bound and assumes English is the only language in which the teacher is assessing student success and learning.

Teacher knowledge. Although less aberrant than the barrier language presented to assessing STEM learning, teacher knowledge imposed a barrier to STEM for seven of the 12 participants. Inclusive of both PCK and SMK

(Shulman, 1987), teachers expressed awareness that they were deficit in one or both types of knowledge and that this lack of knowledge posed a distinct challenge to their ability to not only implement but also fully conceptualize STEM.

Time. Time also presented as a barrier to STEM independent of teacher PCK and SMK. In these instances, time was contextualized by the schedule teachers are required to follow. This was not only the rigidity of the schedule, byt also the requirements of specified minutes for each content area regardless of the lesson objective posed a challenge to teachers. Participant 3 stated: “Time is the enemy here. Are [the students] all going to have time to . . . interact?” Participant 12 shared a similar thought. She explained:

> You really have to have an open-ended schedule so that your learning drives the schedule. I think with STEM you can't be right in the middle of something and be, like, we are going to stop and move into something else. You really need be able to allow the learning to flourish and let it run when it is going to run because that's part of the connection. If you cut off a thought right in the middle, it's going to make an impact on how those kids absorb the information and make those connections. I mean, obviously there's an end of school day, but I mean, we have math chunked here, we have science chunked here. With STEM, they just kind of have to bleed into each other and then just move at the pace that the class is moving so that everybody gets the opportunity to make the big picture.

Longevity. Participant 10, like four other participants, spoke to idea that STEM has longevity. Most frequently referred to in terms of retention, this theme also appears to have a relationship with grappling. When students have engaged in the process of STEM, when they have grappled with data and confronted misconceptions, and taken ownership of the content concepts, then they remember it. Participant 10 explained:

> M: Does the STEM approach effect retention?
>
> T: I think so.
>
> M: How?
>
> T: I think that when my kids can look at things and they'll be, like, no, I know that doesn't work. Like, we had a discussion the other day, what was it? Oh, when we were doing our discrepant event today, a kid was like, I think that's the box. The box is magnetic and I think it is connecting to the can and the other kids are like, no, remember the metal, plastic is not a magnetic and we know these things, we tested it and we know it's not magnetic. So, I think it does play a huge part in being able to retain things, and doing things that are very connected between the two.

Collaboration. This theme became evident as participants spoke to students learning in groups during a STEM experience. While slight, there is a difference between learning in groups as presented by the theme of collaboration and working in groups. Working in groups may include students doing so as a means of enhancing content learning, but group work is often focused on completing tasks. When students collaborate, on the other hand, they are engaging with one another in order to increase their understandings and the learning that occurs in these situations. Participant 9 explained:

> I'm trying to get them to say, you know, I agree with you because this is what I did or how did we get the same answer, but this is what I did, let me look at what you did. More of a talking conversation . . . I try to tell him, you are very smart, you have, you know, when you are thinking you need to get used to telling the other kids at your table what you are thinking because they can learn off what you're thinking.

Eight out of 12 of Participant 9's group peers agreed, which demonstrates that collaboration is a key component of their STEM prototypes.

Inclusion. Of the teachers who participated in this study, 25% articulated a belief that one of the advantages of STEM is that it is inclusive. This is the notion that all students are capable and should come to understand the content concepts. Metaphorically, participants articulated that no one gets left behind. This is contrasted to traditional or non-STEM instruction in that teachers believe that once the majority of students have come to understand a concept, they can move on in their instruction. Best explained by Participants 1 and 8, the notion of inclusion seems to be connected to the themes of integration and barriers as well. Participant 1 explained the connection to time as a barrier:

> T: So, like, if you are overlapping two different things and some groups are getting it, and some groups are not understanding it, or they can't get the connection to work of what you are trying to do, you obviously need to spend more time or use some of those other students to help those

> students work it out and so there’s not like, “okay, we only read for thirty minutes and if you didn’t get it, you didn’t get it.” You know, like, you kind of go to the point where you make sure everybody in the class gets it. Essentially, before you move forward and beyond, say, to the next topic or maybe that topic you’re on goes into another section, so it’s like segmented, somewhat.
>
> M: So what happens in non-STEM instruction then, where, I think you said 30 minutes. We have 30 minutes, we read, we do whatever in the lesson, and some kids get it and some kids don’t. What happens when they don’t get it?
>
> T: They get left behind. They don’t know what’s going on. Then, I mean, at that point, you’ve kind of already lost that student. It’s hard to go back and catch them up to where everybody else is. You kind of just put them, assume they are where everybody else is essentially, as opposed to taking the time to get them where they should be.

Participant 8 explained the idea of inclusion in the context of student ability. This is the more common of the two presentations, and four other participants affirmed the belief she presented that all students can be included in the STEM process regardless of experience or academic level. She stated:

> a lot of times, even my lower academic students came up with, solved the problem, solved whatever problem it was that they were having. Maybe the higher academic maybe created it, but then it didn't work. And this

> happened in several cases. And then the lower academic was like “Wait a minute, I think it's this”

Perspective. Most frequently described as, “another way of looking at it,” the notion of perspective is illuminated as participants responded to questions around the role of students and the rational behind offering STEM experiences to them. This idea was spoken about with a distinctly positive tone as participants explained that the perspective offered by STEM was an opportunity and a benefit. Participant 6 told me:

> sometimes a light bulb will turn on because they know that, oh that's another way to look at it. Or if they do it differently, that doesn't necessarily mean its wrong, it's just another way of looking at it and it gives the students an opportunity, a different way of looking at the same idea.

Participant 11 echoed her positive sentiments toward the perspective provided by STEM and its connection to the world in the following dialogue:

> M: Do they need those things?
>
> T: I think they do.
>
> M: For what?
>
> T: I just think for life in general. I think that it gives them a different perspective. I think they look at things different if they know how plants grow or if they know what the process is to do this. And I think it also gives them an appreciation, an appreciation of farmers, of bakers, if you know how much work goes into making bread. I think it gives them a broader perspective; it gives them a broader outlook on life in general.

STEM is Real. The first metaphor that emerged was that STEM is real. Marked by dialogue around plausibility and purpose and frequently presented as a contrast to the traditional means of presenting new learning to students, the metaphor that STEM is real emerged with varying frequency in the discourse of 10 of the 12 participants. Participant 3 explained:

> Well, they are obviously doing this for, I mean, I think the biggest thing about STEM is that you are going to be asked to do this in life and most everything that you do will involve these four things, no matter what it is. And so, when. That's another thing that's different, I'm going back now, between old science instruction and STEM is that old science instruction these things are already out there, you can Google them. And with STEM instruction, you are really giving them the opportunity to solve problems that they will face in the future. You are not telling them a list of ways to get there; you are giving them a process to get through any sort of problem.

*STEM is Preparation***.** Potentially connected to the metaphor that STEM is real, STEM is preparation speaks to the benefits of students engaging in STEM experiences. This metaphor often emerged through dialogue of being a scientist or engineer, or when describing the challenges that students will face in the real world. The metaphor asserts that, through STEM experiences, students are better prepared and thus more likely to enter STEM fields and to problem solve through various challenges in their future.

For instance, Participant 10 spoke to the confidence that her students are able to build by engaging in STEM that then, “translates or transfers to other fields.” The students were:

> learning that they can do things and taking them home and showing their parents look what I did I was successful on these things. It helps them be more confident in that class but also it reflects into the other class experiences . . . and outside.

She also explained, it took “lots of perseverance . . . and now they've gotten to a point where they've just learned, you know, part of being a scientist and an engineer is failure and that you learn from those things and you can improve from those things.”

*STEM is an Equalizer***.** Five of 12 participants used the metaphor of STEM is an equalizer at some point during their discourse. This use was particularly strong in its presentation for Participants 4, 10, and 12—all three of whom articulated a belief that students like theirs who were economically disadvantaged, often academically behind benefited greatly from STEM. Participant 12 elaborated:

> With our kids, you can also look at it from a different perspective to where our students would get more from it, because if you are looking at it like the bulk of their academic exposure is going to be within these four walls, it's going to be more important for them to get something like that here, because they are not going to get real world exposure to the things that will lead them, that they would need to think critically in life in general.

Generally, this metaphor is marked by future tense dialogue, comparison to students who are demographically dissimilar to ISD students, and discourse around compensation for lacking academic and experiential background knowledge. In this metaphor, STEM is viewed as an opportunity and much of the value ascribed to STEM lies in the belief that it will afford ISD students opportunities to compete in a more equal fashion with their more affluent, advantaged, peers. Participant 12 explained this idea in response to my request:

> M: So then, talk to me about STEM in terms of kids like ours instead versus, say, kids like affluent, you know, ethnically homogenous Paradise Valley, let's say.
>
> T: Well, the biggest thing is as long as the resources are there to provide them with the same experiences inside the classroom as opposed to outside of the classroom. The other thing that you see is that if they are not getting those experiences outside of the classroom, these students could be behind because these students who are in a more affluent area, they are exposed to a lot more at younger ages, and the younger you are exposed to experiences, the more, developmentally, you are going to see connections and you are going to use those connections later on and that's going to build at a faster pace. The other thing that we see, and I don't know if this is what you are talking about or not, is support at home. You've got parents that are educated most of the time instead of in our demographic, a lot of parents that are not educated. Um, and most of the time, educated parents already start to expose their children to things that

education and that foundation, and the more that they are exposed to it, it is just going to benefit them. Whereas students here, the exposure that they are getting is within these four walls. So, is that what you are asking?

M: It is, and talk to me about then, too, are STEM experiences any more or less important for one group compared to the other?

T: That's kind of a trick question because in theory I would say they're just as important, because the more interactive and exploratory something is for a student, the more they are going to retain, the more they are going to understand, and the more they are just going to get from it in the long run. But, with our kids, you can also look at it from a different perspective to where our students would get more from it, because if you are looking at it like the bulk of their academic exposure is going to be within these four walls, it's going to be more important for them to get something like that here, because they are not going to get real world exposure to the things that will lead them, that they would need to think critically in life in general. Everything outside of these walls, you know, when you've got uneducated parents, unfortunately criminal parents, just poverty parents, it's just go outside and play. They are not exposed to technology, not exposed to how the world works, they are not exposed to anything that isn't just taking care of your basic survival needs. You know, eating, getting dressed, taking care of yourself, and surviving. Whereas kids from more affluent areas, they are going on vacation, they are getting exposed to more people, more cultures. They have the ability to play with technology on their own,

> even if it comes to figuring it out on their own, but they have the technology where a lot of our kids don't have the technology outside the classroom.

Stage 2*.* The second stage of Phase 2 was axial coding. The axial coding process identified and explained the relationships between various themes, many of which are causal in nature. Here, each axially coded relationship will be stated, depicted when applicable and explained. Many of these relationships are representative of tensions within the data that need to be explored further.

Grappling in relation to positive attitudes, behaviors, beliefs, and ownership.

Grappling → Positive Attitudes, Behaviors and Beliefs
Grappling → ownership

Throughout the data, the concept of grappling is believed to be valuable and is consistently associated with the development of positive attitudes, behaviors, and beliefs as well as increased ownership of content concepts and problem solving processes. The relationship presents causally in the case of positive attitudes, behaviors, beliefs, and ownership. Aside from a mutual connection to grappling, a relationship among positive attitudes, behaviors, beliefs, and ownership did not emerge within this case.

Participant 10 explained that grappling stretches beyond confronting the ideas students have around content concepts, but also around the ideas they have of themselves as learners. Referred to as attitude and behavioral attributes

(Dweck, 2006), learners develop beneficial skills through the grappling process. According to Participant 10:

> The experience is lots of hands-on stuff and lots of perseverance. I had a discussion with my class the other day when we did our very first STEM activity. It was building the paper tables with the cardboard and I had kids that before they'd tried were, like, I hate science, I can't do it, I don't know, I give up it's not possible, Miss S, this is a trick, you can't even do this. They were just done and they didn't have any interest. They went home frustrated, and I just being, like, “I can't believe it.” But now, they love it, this is such good stuff and now they've gotten to a point where they've just learned, you know, part of being a scientist and an engineer is failure and that you learn from those things and you can improve from those things. So when a student first walks into the class they are going to be, like, holy crap, this is a lot of work to it because it's not just a simple multiple choice or it's not just a simple underlining a word in the text to find the answer. The process is a lot for these classes, but they learn that it is possible to do these things. It builds a lot of confidence as they go through the entire process.

The notion of grappling within this case appears to be more inclusive than what currently exists in empirical literature. As such, the relationship between grappling and the development of positive attitudes, behaviors, and beliefs is likely connected to the all-encompassing nature of grappling as presented here. For this participant group, confrontations of previously constructed ideas, hypothesis, or even self-concepts add to the distinct benefits of grappling. Similarly, grappling also appears to cause increases in student ownership of content concepts and problem solving processes. This relationship is consistent with assertions in existing literature that posit grappling as a necessary and beneficial exercise in that it assists students in making conjectures and generalizations around the concepts they are working with. The idea that ownership would then succeed these conjectures and generalizations follows the line of logic previously presented in that students had to construct these and thus own the concepts behind them as possessions of creation.

Time and teacher knowledge are negatively correlated.

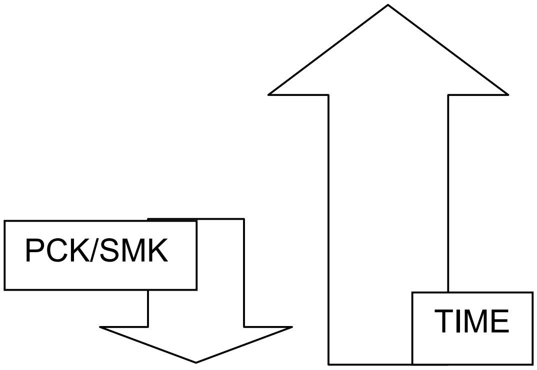


Figure 17. Relationship between teacher knowledge and time.

Represented graphically in Figure 17 above and perhaps most clearly stated by Particpant 7 the linkage between teacher knowledge and time was clear when this teacher wondered:

> And with STEM, you are also expecting, because we were talking about the roles for the teacher and the student, as a teacher, the only part of STEM that I feel is pressuring me is, number one: do I have an overview myself?

The relationship between teacher knowledge and time as barriers to STEM became very apparent within this case study. The specific subtheme of teacher knowledge as a barrier arose through the parallel discourse around time as a barrier to STEM. “There just isn’t enough time,” Participant 7 told me. She explained further:

> T: And I'm also finding that with the STEM, you need more in depth and I’m very lightly covering the surface, and so I don't feel like I have enough time to prepare for the kids. And so when I'm teaching, I'm falling back into, here is the comprehension component, if you really get the comprehension but then they aren't experimenting on it, so they don't have that in depth of, oh I just discovered that weather and climate means this. I'm not seeing the two bridges together because I'm not prepared for the kids as well as I should be.
>
> M: Prepared in what way?
>
> T: I don't feel that sometimes, I don't know that topics as in depth. I feel I can hit it on the surface, and then I'm trying to embed to a test question versus it being more of an exploration of what the actual concept is . . . . Also with you STEM, you are also expecting, because we were talking about the roles for the teacher and the student, as a teacher, the only part of STEM that I feel is pressuring me is number one, do I have an overview myself. Do I know what my own thinking is? Have I studied enough in my own thinking that I can give you a visual representation of it and now can I pass it on to you? Because when you are doing the STEM, I am really

> removed from it. I am facilitating the conversation and I am trying to probe you, but I have to have my own basis of what I feel it is, so that I know what it is and what it isn't. I know that these terms connect and now I can talk about it. But once you have that material, and that's what the hardest thing is, I don't have that material gathered up to say, “oh, I'm going to look at weather so what are some terms I need to know?”

Here, it becomes evident that teacher knowledge and time are negatively correlated. When teacher knowledge is low, more time is required in preparing for STEM experiences. This is particularly evident through teacher dialogue around SMK, because they must bolster content knowledge through lengthy research and reading in order to meet students’ needs and to answer their questions during a STEM experience.

Integration helps break down the barrier of time. Often, the theme of integration presented as a solution to the barrier presented by time. Participant 6 told me:

> [STEM] takes a lot of time. It does take a lot of time. It would be easier if we figured out a way to incorporate everything, like the math, the science, and the reading all into it so we are meeting all of the other standards within STEM. So that way it would be, it wouldn't matter that it takes so much time.

Here, she explained that by bringing the subject areas together, by integrating them, the time spent on STEM instruction would likely remain the same, but the utility of the time would increase as she became more able to address additional standards.

It is important to note that this relationship is limited to integration assisting in overcoming the challenge of time in a limited scope. Integration does not seem to have an effect on time as a barrier when time is challenging because teacher PCK or SMK are low. The effect of integration on time when working with students who are behind or lacking prerequisite knowledge or skills like so many teachers described, cannot be discerned from this data.[[

Student interest can compete with the predetermined learning goals.

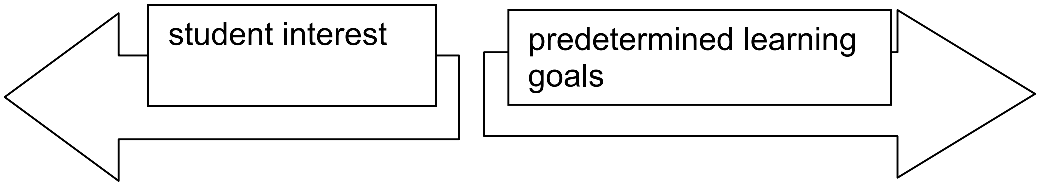


Figure 18. Competition between student interest and learning goals.

Seven participants expressed dissonance around the driver for STEM experiences. In many cases, teachers spoke to conceptual learning goals or occasionally the state standards when asked directly. When speaking to this notion peripherally, however, they frequently cited unintentional learning that occurs as a result of student interest and questioning. Figure 18 depicts the competition between described learning goals. Even within a single interview, participants presented contradictions to this idea by making statements like “you never know where you will end up.” Participant 1 showed her reasoning in the following discussion:

M: What determines where you go?

> T: Student interest and questions that they pose, that they ask you. I had kids ask me a question the other day about the body. We weren't even focusing on that. We were talking about something else. Until their questioning led to something else that was important, so I went down that path of questioning to a certain point to answer their question because they were interested in it. It was valuable because they wanted to know. They obviously had an interest in it. So, I was like, okay. So student interest, a lot, I think, and questioning, whether it's from the teacher or the student.

Participant 1 is not alone in thinking that student interest is a strong driver in the content presentation and learning. Three other participants, including Participant 11, for whom student interest was the most frequently alluded to theme, expressed a belief that student interest should at least strongly influence the direction of the lesson, if not control it. The lack of clarity around what should be the driver of student learning is further compounded by the idea that students should be working toward what he or she wants. This may or may not be contradictory. If the teacher desire is different than the content concept that he or she selected as the learning goal, then there could be conflict. If the two are synonymous, the notion of conceptually targeted experiences is reinforced.

Processes and products are in competition with one another. The processes and products presented within the STEM experiences and discussed by the National Research Council (2012) and Minner et. al. (2009) appeared to be in tension for ISD participants. With the exception of Participants 4, 3, 5, 6, and 10, the other participants presented a competition between these two ideas. In the competition, the more important in the learning experience continuously changes throughout participants' explanations. This is particularly true when teachers were asked to decide if it is the process or the product associated with a STEM experience that provides evidence of student success. Within a thread of dialogue around this specific question, which involved how to determine success in a STEM experience, Participant 1 explained:

> M: Is there an assessment piece in STEM?
>
> T: Yes, there is. I feel there is. One, that you are able to see what the kids know and don't know, based on where they are going. Two, if they are creating something on their own, whether it is a written explanation of what they are creating or they actually created something themselves or as a group, you can see the product of what they made, almost like an art class. So, they may not have been able to create something, but they are able to verbalize it and write it down in like a script in how they went about or would go about doing it in sequence. That would be the same kind of assessment as a test.
>
> M: Okay, so, am I understanding right when you say "there's this scenario and they need to produce something. And that some kids may or may not produce the thing that I may not have wanted them to initially, but that it's in the explanation, not the actual product, that's the assessment"?
>
> T: Yes, it's two pieces I think. So, yeah, you are correct in that.
>
> M: So, is there a right answer in STEM?

T: Is there a right answer? That's tricky.

M: Tell me why that's tricky.

T: It depends on the subject areas you are using. Because with some things there is this definitive, "yes, this is the correct answer." And some subjects there can be multiple different answers that are all valid answers. It's hard to say, "No, there is no final answer, or definitive answer."

M: So let me ask you this. In a math lesson, where two plus two always equals 4, always, no matter what, why would I teach it STEM versus not STEM?

T: You had to do two plus two? Why would you teach it STEM? Because if you teach it not STEM, two plus two, that's essentially more just rouge memory. Doing it the STEM way, you can make it more engaging, because a kid looks at two plus two and they don't, they just visually see the numbers 2 and 2. If you put two pennies, and two other pennies, they may not understand that 2 + 2 = 4, and that's something you can do over here in STEM. You can engage other things to teach that 2 + 2 = 4.

Ownership affects longevity.

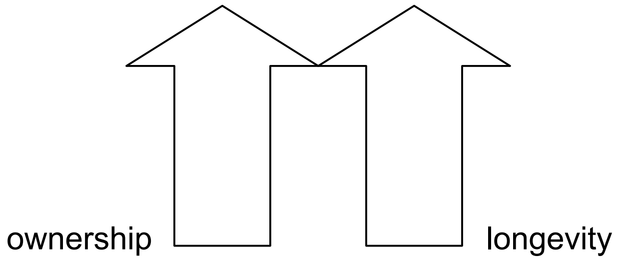


Figure 19. Teacher-reported relationship between student ownership of learning and longevity of learning.

The themes of student ownership and longevity, or retention of knowledge, present a positive correlation within this case. Teachers speak to the increased retention of learning as a point of advocacy for student ownership of learning. As depicted in Figure 19, they believe that the more a student takes ownership of what he or she learns, the more likely he or she is to retain the information and use it in a later circumstance. As illustrated by Participant 3, students' ownership over their learning likely results in a positive effect. She explained:

> Really having the kids think about it in their own way instead of saying think about it this way, and having them learn these concepts based on projects that they do. And it stays with them, just like with other inquiry-based science or math curriculum . . . you let them work through it and kind of create their own way, their own strategy, that will stick with them longer; it will be more long term. They've created it themselves. There's ownership.

Chapter 5

Conclusions, Discussion, and Recommendations

Sparked by recent policy talk around science, technology, engineering, and mathematics (STEM) instruction, this study sought to answer the question, “What are generalist trained, fourth grade teachers’ prototypes of STEM instruction?” It also explored the following subquestions: What are the similarities and differences between and among fourth grade teachers’ prototypes of STEM instruction? What is the relationship between teachers’ experience and their prototypes of STEM?

Through grounded theory (GT) analysis of interviews and categorization transcripts, I was able to discern that the most robust prototypes among the fourth grade generalist teachers were that of the journey, adventure, and puzzle. Additionally, a significant number of teachers did not present a dominant metaphor, which was a finding that I suspect to be related to teachers’ experience or lack thereof with STEM content development and engaging students in STEM.

Throughout the GT process, my personal and professional experiences as well as historical and theoretical review of the research literature greatly increased my theoretical sensitivity. Professionally, I have experience as a middle school reading, writing, English language learner (ELL), and science teacher. I also have experience as a science and math coach and as an STEM Director in conjunction with my personal experience as a sociology and premedical student. Together, these personal and professional experiences have positively impacted my theoretical sensitivity by assisting me in becoming acutely aware of the STEM themes within the data as well as the interactions between the participants and their context.

Conclusions

Revisiting the research questions. This work set out to answer the question, “What are generalist trained, fourth grade teachers’ prototypes of STEM instruction?” as well as the associated sub questions, “What are the similarities and differences between and among fourth grade teachers’ prototypes of STEM instruction?” and “What is the relationship between teachers’ experience and their prototypes of STEM?”

Using a GT approach consisting of open, axial, and selective coding, teachers’ emerging prototypes of STEM were conceptualized. Open coding of the interview, categorization task examples, and categorization task nonexamples revealed 18 themes. During the process of triangulation, it was determined that 14 of these themes were major themes (present in all three sets of data) and four minor themes. The major and minor themes characterized the collective prototype of STEM for ISD fourth grade teachers. During the process of axial coding, each theme was then examined in terms of the others, and this process illuminated the interactions and relationships between the themes. Six significant relationships were identified, all with varying influence within selectively coded, amorphous, journey, puzzle, bridge, and adventure prototypes.

Limitations

While the highly contextualized nature of the conclusions drawn in this case study have contributed to their validity and reliability within the confines of the particular case, they may be limited when expanded to a broader audience or participant group. The limitations in this study include its sample size and the nonrepresentative nature of the participants in the group as compared to the teacher population of the state and nation. Expansion of the study to include a larger, representative sample of participant teachers would strengthen the findings and positively impact the generalizability of the findings. In addition, variation in the length of participant interviews may have created inconsistency in the frequency of themes and metaphors and may not have allowed for adequate exploration of all open and axial codes. Additionally, follow up interviews or more in depth interviewing structures could strengthen the data especially around the metaphors and relationships between the themes.

Recommendations for Future Research

Based on the findings of this work as well as its limitations, I suggest four specific areas for further research:

1. Expansion of study to other demographically similar districts
2. Analysis of the required congruence to a prototype when classifying occurrences as examples and nonexamples of STEM
3. Comparative analysis of teacher prototypes between low socioeconomic status (SES), high needs districts, and high SES, low needs districts
4. Analysis of private sector, university and policy maker prototypes

Expansion of the study to include demographically similar districts would afford additional and more generalizable insight into the prototype trends identified in this study. During any expansion of the study, additional research questions should be dedicated to understanding the relationship between the demographic characteristics of the school and the teachers' prototypes. Specifically, additional insight to the role of language and language acquisition would benefit the larger body of research.

Work that seeks to understand the relationship between congruence to the teacher prototype and the example or nonexample classification of artifacts would provide greater insight to the specific role and weight of each theme. Such work would further substantiate the conclusions drawn in this study by examining the major themes from a different perspective.

Comparative analysis of teacher prototypes between low SES high need districts and high SES low need districts would assist in bolstering the academic and professional communities' understanding of the role context plays in prototypes as well as their development. This expansion could delimit some of the findings of this work by fleshing out the relationships between the urban, low SES context and teacher prototypes.

Finally, replication of this study to examine the prototypes of individuals driving the policy conversation (university faculty, recognized experts in STEM subject areas and fields, individuals from the private sector) would afford the research and practicing communities critical insight into the conceptions these individuals hold of the policies they are driving. While it is likely that a similar range of prototypes exists within this group as does within the teacher group, additional knowledge as to the mental models driving the policy conversations would be of great benefit to the practitioner community. Following, this work could be expanded to determine the degree of semblance between the working prototypes (teachers' prototypes) and what are arguably the desired prototypes (*expert* prototypes). Because the policy talk around STEM is deeply rooted in the private and higher education sectors, in the event that there are coalesced and articulated prototypes among the policy making group, it is critical that educators come to know these *expert* prototypes. Similar to the student journey in STEM education, the ideal prototypes are the learning targets toward which teachers are journeying.

Summary of the Prototype

This case study served as a glimpse into the prototypes independent school district (ISD) fourth grade teachers have of STEM. Not surprisingly, I was able to discern that the most well developed and consistent prototype amongst participant teachers was that of the nonexample (what STEM is not) in which teaching and learning are conceptualized using a passive *knowledge is nutrition and learning is consumption* metaphor. Through this image, teachers have come to understand that STEM is *not* the passive consumption and regurgitation of knowledge fed to the student by the teacher. Students must be active. In fact, not only is the passive consumption of teacher-distributed knowledge not categorized as STEM, is not valued in the same way STEM is. In many ways articulated by practitioners, the absence of STEM instructiondoes not lead to college and career ready attitudes, mindsets, behaviors and beliefs. Teachers recognized that the absence of STEM would leave students with inadequate knowledge and tools for productive lives in today's society.

In addition, the study revealed that the themes of integration, grappling, the use of tools, and especially technology, affect, creativity, inquiry, process, and product are central to the STEM prototypes of participant teachers. Metaphorical analysis revealed the centrality of student action through all of these themes. Students should be physically and cognitively involved in STEM. They should be making decisions, asking questions, engaging in metacognition, and creating physical objects or solutions to problems. These problems should reflect the reality of the world outside of school because doing this will better prepare students for their futures.

Primarily, success is measured in growth toward a content concept, but a secondary source of success and a highly valued component of the prototype is the development of attitudes and behaviors (i.e., perseverance, patience, curiosity, etc.) that teachers believe will serve their students well in the future. In fact, these factors are more frequently spoken to as the preparation STEM provides than the content. As the old adage posits, if you give a man a fish he will eat for a day, but if you teach a man to fish he will eat for a lifetime. For these teachers, STEM teaches their students to fish. The value of STEM lies in the experience and the skills that are cultivated through the struggle to teach the material and wonderment encouraged with it. Teachers believe that STEM skills will not only transfer with students to other content areas and contextual situations, thus increasing their utility and value, but that through the STEM experience students are likely to refine their own self-concepts.

Additionally, STEM experiences support students in their development of language. This is likely a result of providing students a concrete experience to engage in with a collaborative group. Their excitement and interest in the subjects encourage them to communicate through whatever means they are able in their second language. As is the case with sharpening most skills, practice is believed to be a key component to perfecting one's English abilities.

Gaps in Teacher Knowledge Challenge Prototype Construction

Teachers who articulated gaps in their own pedagogical content knowledge (PCK) or subject matter knowledge (SMK) presented fewer strong themes and metaphors in their discourse. In general, data indicated that these teachers had a less developed prototype of STEM than their peers who did not report gaps or shortcomings in PCK or SMK. While the sample size and context of this case study prevented generalizability, it does appear as though teacher-identified gaps are related to prototype construction in that they likely pose a challenge to prototype development.

This is not surprising. STEM, belonging to the pedagogical family of constructivism, requires the teacher to assume the role of facilitator while students lead and construct the learning experience. To do this, teachers must rely on their knowledge and skills to both question students appropriately and to manage the learning environment to ensure students are situated for success and moving toward the desired conceptual knowledge. The teachers must also possess a strong enough command of content concepts to not only facilitate students coming to understand them through carefully designed learning experiences and questioning, but to also recognize the same concept in multiple forms and stages and students work through the learning and develop them in their own rights.

Prototypes May Develop in Teams

Disaggregation of the data revealed strong similarities in the presentation of themes, the relationships between the themes presented, and the use of metaphors for teachers on the same team. As themes and metaphors communicate components of the teachers’ prototypes, it is possible that prototype development and teaming are related. The data presented here is too limited in scope to determine causality, but the trend is clear, and within the confines of this case, the trend does not appear to be dependent on a long history of working in the same team.

The Eucalyptus School teachers, Participants 4 and 10, and the Monarch School teachers all displayed prototype trends similar to those of their teammates. The teachers at Eucalyptus school had been on a team for two years and participated in the pilot training with Arizona State University in the 2011-2012 school year. Conversely, the teachers at Moss School were in their first year as a team. Participants 3 and 5 were currently in their second year of working together, but Participant 6 joined the team the year the study was conducted. They have not participated together in any specific professional development outside of what has been offered at their schools, and their school has only begun its work with STEM in the six months leading up to the study.

Further investigation into this finding did reveal two distinct differences in the school context and structures of Moss and Eucalyptus schools that may have contributed to the team prototype effect. At Moss school, Investigations, a constructivist math curriculum has been implemented with fidelity for the last three years. Teachers there continue to receive ongoing professional development and support for curriculum implementation and although they did not receive Investigations math training at the same time, the same consulting group has facilitated all trainings. At Eucalyptus School, teachers begin to specialize and students rotate classes in the fourth grade. Within this model, Teachers 4 and 10 are math and science teachers only and both have a two-hour block of time to use however they see fit between the two subjects each day.

The Most Desirable Prototype Within this Group is That of the Journey

Based on my interpretation of the data, the teachers who present a prototype with the metaphor that STEM is a journey are the teachers who hold the most desirable prototype of STEM in an elementary context. As a district STEM director, this prototype is marked by several beneficial themes and beliefs that make the prototype more advantageous for the high need students they serve. To begin, a clear learning destination coupled with a belief that STEM should be inclusive, inquiry-based, and integrated both between other subject areas and within STEM itself are indicative of a congruent understanding with that the district is attempting to cultivate. In addition, the positive view of students' background knowledge and a belief that STEM supports language development are philosophically aligned to the district vision. Finally, as it is the district's belief that fostering academic knowledge as well as social and academic skills, attitudes, and behaviors lead to successful learning. As such, this prototype is considered to be the most beneficial and highly sought after.

Discussion

Implications. Implications of this work stretch to both the research community and kindergarten through 12th grade (K-12) education. In this section, the implications for the research community will be discussed. Then, implications for the K-12 practicing community will be discussed. Because this work is limited in its generalizability, the majority of the discussion centers on its use as a preliminary research work that should be followed up with larger studies and its application in K-12 STEM education, specifically professional development and hiring. Implications for further research will be discussed in the final section of this chapter.

Research. Within the research community, implications of this work will likely present in two domains. The first domain is in prototype literature and the second is in understanding the relationship between inquiry-based instructional approaches such as STEM and language development. In the area of the first domain (prototype literature), this study found that prototypes and teams demonstrate a relationship. The study also found that recognized deficits in teacher knowledge and lack of dominant metaphor usage or thematic presentation in discourse may be related and indicative of low teacher knowledge, which is a hindrance to prototype development. Together, these two findings represent gaps in the current work on teacher prototypes. Further study will have to occur to address these gaps in the academic conversation. While the presentation of these trends is limited in generalizability, they are indicative of a potentially more pervasive trend, and are therefore important to study further.

In addition, findings somewhat challenge literature around second language learners and inquiry-based scenarios. More needs to be done to understand the relationship between language learning and inquiry-based scenarios more fully, especially because the findings of this study were contrary to the present academic literature, which indicated that teachers were prone to believe that STEM and the inquiry-based approach associated with it supported students' language development.

There are also loose indications that teachers believe content development for students speaking English as a second language is also supported while their language it developing. The numbers of instances suggesting this relationship are too small to determine if the belief is specific to one teacher or representative of the group. As such, it remains unclear if teachers believe that students' language development is in competition with their content concept development.

Both of these aspects should be addressed through further research in two ways. First, the study of stakeholder beliefs and attitudes relative to the relationships between STEM and language development and language development and content concept development in the context of STEM are important. Work on teacher beliefs and mindsets dating back to the 1970s and continuing into the new millennia (substantiate the power that these mental constructs have over observable actions and results. However, too little is known about the effects teacher mindsets have in these specific areas. Second, further study to understand the relationship between student language development and content concept development would be greatly beneficial. Further study would be particularly beneficial if this study addressed student growth or quantified conceptual development through student achievement measures.

Practice. Professional practice may be impacted in a number of ways as a result of this work. Areas of potential impact include interviewing and STEM professional development.

Interviewing. The first area of practice that may be impacted by this study is interviewing. The interview process is very likely to be impacted as districts move toward STEM and science, technology, engineering, art, and mathematics (STEAM) in the years to come. Because metaphors are so common in everyday language and can be specifically examined in interview responses, the metaphorical presentation of STEM in candidate discourse can be examined to determine the level of congruence between the candidate's metaphor and the metaphor of the district, or the desired metaphor the district is working toward. For instance, the idea that STEM is a journey is most congruent with the vision set in the district in which I work. As a result, interview candidates who present this metaphor would potentially be more philosophically aligned to the direction of the district and a potentially better fit for a teaching position within the organization. Conversely, candidates who present a dominant metaphor of as an adventure may not be a good fit because this metaphor diverges from the district's desired metaphor in critical areas such as learning targets.

In addition to exploring metaphors as a facet of the interviewing process, data from this study suggested that teachers who are interviewed to teach in a STEM environment should be highly flexible and comfortable with change while confronting the unknown. In all three of the dominant metaphors (STEM is a journey, adventure, and a puzzle), the students take ownership over their learning experience and the teacher takes on a facilitative role. Within this context, it is both implied and stated that the teacher must be comfortable working with the unexpected. The students are likely to reach their learning target through varied and unique pathways, and the teacher is expected to facilitate each student's learning along the route he or she explores. Thus, the teacher must possess the ability to quickly change course to follow students' needs and interests during the lesson.

In addition, as ownership of the learning experience shifts to students, it is necessary for teachers to have high levels of PCK and SMK. For a teacher to facilitate the learning of his or her students in accordance with each of their individual interests and learning styles, the teacher must possess strong enough content knowledge to recognize the students' conceptual development as it unfolds and then immediately pose questions or redirect students' efforts to ensure complete content development.

The need for PCK and SMK is further illuminated in the discourse of those participants who speak to students who have produced what the teacher had envisioned as the product from a learning experience. This is reflective of a common pitfall in inquiry-based instruction in which the content target is overly ambiguous and the student is covertly asked to engage in a session of guesswork around the teacher’s desires for product development. The exercise then becomes one of affect, and while frustrating, the frustration is not productive the way the frustration associated with grappling and confronting misconceptions is. Higher levels of teacher PCK and SMK would help to mitigate this issue by ensuring appropriate questioning or probing on the part of the teacher. Appropriate levels of PCK and SMK would provide teachers with the conceptual knowledge and pedagogical skills to first recognize the errors in the students’ thinking and then to respond in a way that encourages students to continue to discover without either handing them the answers or inadvertently withholding the content concepts.

Professional development. The findings of this study will also likely impact the professional development (PD) structures created by districts and ultimately the PD opportunities offered to teachers. Specifically, the findings indicate a potential need to ensure that PD occurs in teams and that it addresses clarity around the goals of STEM instruction as well as how to appropriately measure success during STEM instruction. The commonality of teacher prototypes within teams indicates a cohesion and rumination of the mental models of teamed teachers. As such, teaming teachers for PD or professional growth opportunities in which teachers' prototypes of STEM will be affected is beneficial. Given that content and pedagogy generally ground most PD opportunities and is understood to be related to teachers' prototypes, it stands to reason that most PD could impact a teacher's prototype of STEM.

In addition, PD that brings clarity to the goals of STEM as well as the measures used to ascertain whether or not these goals have been achieved would benefit student learning and prototype development among teachers. This idea is potentially linked to the subtle variation in the metaphorical presentation of STEM as a journey versus STEM as an adventure. The journey is a more desirable understanding of STEM in that the learning goal or the destination is clear. In turn, the teacher is able to distinguish levels of attainment or progress toward the goal as it is clearly conceptualized from the onset of the STEM experience. The adventure, on the other hand, is problematic in both the goal and the measures toward the goal. PD that assists teachers in refining their understanding of the goal of STEM would greatly impact the prototype of the teacher and would likely result in a shift in their metaphorical representation of STEM as well.

Policy. From a policy perspective, the findings of this study are cause for concern. Specifically, the juxtaposition of the greatly varied and grossly underdeveloped STEM prototypes and the single, nearly universal, counter narrative is most alarming. The counter narrative is presented in such a way that it is clear teachers understand STEM to be a stark contrast to what they know and have for many years done. As a policy making collective, spanning local, state and federal levels, we recognize that teachers, especially those in urban, high needs areas lack the knowledge and experience that is likely necessary to successfully implement STEM yet we are designing policies that require them to engage in educational alchemy; creating something from the little to nothing we know they possess. This issue will only begin at the prototype level.

The inconsistency and lack of clarity around components of teachers' prototypes such as what should drive lessons and how to measure success are highly problematic from a policy implementation perspective. The implementation of these components of STEM will likely be as inconsistent at the prototypes of the teachers implementing them. More concerning still is that the student results yielded from this implementation will be equally unreliable.

These inconsistencies will likely affect our neediest students in the most significant way. Urban, high needs students; especially Latino students stand to lose the most when faced with inconsistent prototypes and policy implementations. These students are markedly behind their peers in measures of mathematics, science and graduation rates.

Considering this, additional consideration should be given to the prototypes necessary for successful policy implementation. What must teachers know and believe to ensure that their students are afforded the critical opportunities advocated for in policies such as Race to the Top.

As the driving force behind policy talk and new standards, the industry and expert prototype (or perhaps lack thereof) is growing into an entire educational movement yet it is not being communicated to the individuals charged with putting it to action. As a collective from policy makers at the federal, state and local levels to the teachers and paraprofessionals in classrooms we must develop a clear, consistent understanding of what STEM is. Knowing what it is not, is not enough. Just as content concepts guide the development of inquiry-based lessons, the desired prototype should guide the professional development of teachers and the shifts in their craft. Individual abstractions of the concept will not suffice to implement the systemic, sustainable, high impact change our students so truly deserve and that STEM education promises. In fact, without this understanding, I wonder, are we not engaging in the same undesirable behaviors teachers often do during inquiry instruction? Are we asking teachers to engage in a guessing game of what does the policy want instead of focusing their efforts on developing a deep, rich understanding of STEM and its associated content and pedagogy?

Furthermore, does this issue begin long before teachers reach the classroom and stakeholders from outside of education begin the policy conversations in teacher preparation programs? Data indicates a need for additional training for teachers in STEM from both a content and pedagogy perspective. We must carefully examine the work we are asking teachers to engage in and ensure that they are adequately prepared in a timely fashion to meet the needs of their students and the growing demands of educational policy.

Prototypes govern how we understand and engage with the world. They are the filters through which experiences are moderated and sorted. They are the foundations upon which action and thought are built. Inextricable from human behavior and understanding, our definitions, productions, and categorizations can only be as accurate as the prototypes against which they are compared. In the case of STEM in this study, and presumably STEM at large, the tremendous variation among teacher prototypes, will likely lead to equally large variation in the experience of students STEM and ISD education within Arizona and the US. If it does not, I wonder if things will significantly change at all. When the metaphors used to describe STEM in this urban, high needs context are the same as those frequently used by teachers as a larger collective to describe teaching and learning, I wonder, what really is different about this work on curriculum reform? Perhaps this is the most significant question that should be addressed as we move forward. What does it mean to teach and what does it mean to learn? Only after we have continued to examine that the congruence of policy and practitioner responsescan we assess the degree of semblance or dissonance between what we have traditionally done and what we are calling for under the new guise of STEM.

REFERENCES

Abell, S. K., & Lederman, N. G. (Eds.) (2010). *Handbook of Research on Science Education.* New York, NY: Routledge.

Abell, S. K. (2010). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 493- 536). New York, NY: Routledge.

Andersen, J. B. (2011). Science education and test-based accountability: Reviewing their relationship and exploring implications for future policy. *Science Education, 96*(1), 104–129.

Appleton, K. (2010). Elementary science teaching. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 493-536). New York, NY: Routledge.

Arzi, H. J., & White, R. T. (2008). Change in teachers' knowledge of subject matter: A 17-year longitudinal study. *Science Education, 92*(2), 221-251.

Atwood, R., Christopher, J., Combs, R., & Rowland, E. (2010). In-service elementary teachers' understanding of magnetism concepts before and after nontraditional instruction. *Science Educator, 19*(1), 64-76.

Barsalou, L. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577-660.

Berry, R. S. (1999). Collecting data by in-depth interviewing. Paper presented at British Educational Research Association Annual Conference. Sussex, UK: September 3-5.

Beyer, C., & Davis, E. (2008). Fostering second graders scientific explorations: A beginning elementary teacher's knowledge, beliefs and practice. *Journal of the Learning Sciences, 17*(3), 381- 414.

Blanchard, M., Southerland, S., & Granger, E. (2008). No silver bullet for inquiry: Making sense of teacher change following inquiry-based research experience for teachers. *Science Education, 93*(2) 322-360.

Boswell, D. A., & Green, H. F. (1988). The abstraction and recognition of prototypes by children and adults. *Child Development, 53*(4), 1028-1037.

Bracken, J., Bandeh-Ahmadi, A., de la Cruz, R., Flattau, P. E., Sullivan, K. (2006). *The National Defense Education Acto of 1958: Selected Outcomes.* Washington DC. Science and Technology Policy Institute.

Business Roundtable Forum. (2005). *Tapping America's Potential: The Education for Innovation Initiative.* Washington DC. Business Roundtable.

Carlsen, W. S. (2010). Language and science learning. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 57-74). New York, NY: Routledge

Coleman, L., & Kay, P. (1981). Prototype semantics: The English word lie. *Language, 57*(1), 26-55.

Conley. D.T. (2007). *Redefining college readiness.* Eugene, OR: Educational Policy Improvement Center.

Corbin, J., & Strauss, A. (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory (2nd ed.). Thousand Oaks, CA: Sage.

Crawford, B. (2006). Learning to teach science through the rough and tumble of practice. *Journal of Research in Science Teaching, 44*(4), 613–642.

Creswell, J. (2002). Research design: Qualitative, quantitative, and mixed method approaches (2nd ed.). Thousand Oaks, CA: Sage.

Dalton, B., Morocco, C., Tivnan, T., & Mead, P. (1997). Supported inquiry science: Teaching for conceptual change in urban and suburban science classrooms. *Journal of Learning Disabilities, 30*, 670–684.

Denzin, N. K., & Lincoln, Y. S. (1994). *Handbook of qualitative research*. Thousand Oaks, CA: Sage Publications.

Denzin, N. K., & Lincoln, Y. S. (2007). *The Sage handbook of qualitative research*. Thousand Oaks, CA: Sage.

Denzin, N. K., & Lincoln, Y. S. (2008). *Strategies of qualitative inquiry* (3rd ed.). Thousand Oaks, CA: Sage.

Díez Valsco, O. I. (2001). Metaphor, metonymy, and image-schemas: An analysis of conceptual interactional patterns. *Journal of English Studies, 3,* 47-63.

Drake, K., & Long, D. (2009). Rebecca's in the dark: A comparative study of problem-based learning and direct instruction/experiential learning in two 4th-grade classrooms. *Journal of Elementary Science Education, 21*(1), 1-16.

Dreschler, M., & Van Driel, J. (2008). Experienced teachers' pedagogical content knowledge of teaching acid-base chemistry. *Research in Science Education, 38*(5). 611-631.

DuFour, R., DuFour, R., Eaker, R., & Many, T. (2010). Learning by doing: A handbook for professional learning communities at work. Bloomington, IN: Solution Tree.

Dweck, C.S. (2006). Mindset. New York: Random HouseElliot, A., & Dweck, C.S. (Eds.)

Elementary Certificates. (2012). Arizona Department of Education. http://www.azed.gov/ educator-certification/files/2011/09/elementary-certificate.pdf

English-Language Learners. (2011.) *Education Week.* Retrieved from http://www.edweek.org/ew/issues/english-language-learners/

Executive Report of 2010 President's Council of Advisors. (2010). *Prepare and Inspire: K-12 Education in Science, Math, Technology, Engineering, and Math (STEM) for America's Future.* Retrieved from www.whitehouse.gov/ sites/default/files/microsites/ostp/pcast-stemed-execsum.pdf

Fact sheet: New No Child Left Behind eligibility: Highly Qualified Teachers (2004). Retrieved from U.S. Department of Education website: http://www2.ed.gov/nclb/methods/teachers/hqtflexibility.html).

Fenstermacher, G. D. (1994). Chapter 1: The knower and the known: The nature of knowledge in research on teaching. *Review of Research in Education*, *10*, 3-56. Retrieved from http://rre.sagepub.com/content/20/1/3.

Fischman, G., & Haas, E. (2012). Beyond idealized citizenship education: Embodied cognition, metaphors, and democracy. *Review of Research in Education, 36*, 196-196.

Frequently Asked Questions. (2012). Retrieved from Next Generation Science Standards Website at http://www.nextgenscience.org/faq#1.1

Furtak, E., & Alonzo, A. (2010). The role of content in inquiry-based elementary science lessons: An analysis of teacher beliefs and enactment. *Research in Science Education, 40*, 425-449.

Gee, J. P. (1999). *An Introduction to Discourse Analysis.* New York, NY: Routledge.

Gee, J. P. (1999). Critical issues: Reading and the new literacy studies: Reframing the National Academy of Sciences report on reading. *Journal of Literacy Research, 31*, 355-374. doi: 10.1080/10862969909548052

Gilbert, J., Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. Gilbert & C. J. Boutler (Eds.), *Developing models in science education* (pp. 3-19). Dordrecht, Netherlands: Kluwer.

Glaser, B. G. (1998). *Doing grounded theory: Issues and discussions*. Mill Valley, CA: Sociology Press.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory*. Chicago, IL: Aldine Publishing Company.

Glass, G. (2008). *Fertilizers, pills, and magnetic strips: The fate of public education in America*. Charlotte, NC: Information Age.

Glynn, S. & Winter, L. (2004). Contextual teaching and learning of science in elementary schools. *Journal of Elementary Science Education, 16*(2) 51-63.

González, N., Moll, L. C., & Amanti, C. (2005). *Funds of knowledge: Theorizing practice in households, communities, and classrooms*. Mahwah, NJ: L. Erlbaum Associates.

Gordon, P. R., Rogers, A. M., Comfort, M., Gavula, N., & McGee, B. P. (2001). A taste of problem-based learning increases achievement of urban minority middle school students. *Educational Horizons*, *79*(4), 171-175.

Haas, E., & Fischman, G. (2010) Nostalgia, entrepreneurship, and redemption: Understanding prototypes in higher education. *American Educational Research Journal. 47*(3) 532-562.

Hauslein, P. L. (1989). *The effect of teaching upon the biology content cognitive structure of teachers*. Baton Rouge, LA; Louisiana State University.

Hauslein, P. L., Good, R. G., & Cummins, C. L. (1992). Biology content cognitive structure: From science student to science teacher. *Journal of Research in Science Teaching, 29*(9), 939-964.

Henig, J. (2008). *Spin cycle: How research is used in policy debates: The case of charter schools*. New York, NY: Russell Sage Foundation.

Jena, S. B. P. (1964). An analysis of errors of pupil teachers teaching general science in criticism lessons. *Science Education*, 48, 488-490.

Jones, M. G., & Carter, G. (2010). Science teacher attitudes and beliefs. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 1067-1104). New York, NY: Routledge.

Kanter, D., & Konstantopoulos, S. (2009). The impact of project-based science curriculum on minority student achievement, attitudes, and careers: The effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Science Education, 94*(5), 855-887. doi: 10.1002/sce.20391

Kelly, G. J. (2010). (2010). Discourse in science classrroms. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 443-470). New York, NY: Routledge

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38,*(6), 631-45.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. Chicago, IL: University of Chicago Press.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Larsson, A., Halldén, O. (2009). A structural view on the emergence of a conception: Conceptual change as radical reconstruction of contexts. *Science Education, 94*(4), 640-664.

Lee, O. & Luykx, A. (2010). Science education and student diversity: Race/ethnicity, language, culture, and socioeconomic status. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 171-198) New York, NY: Routledge.

Longo, C. (2010). Fostering creativity or teaching to the test? Implications of state testing on the delivery of science instruction. *The Clearing House, 83*(2), 54–57. doi: 10.1080/0098650903505399

Marzano, R. J. (2004). *Building background knowledge for academic achievement: Research on what works in schools*. Alexandria, VA: Association for Supervision and Curriculum Development.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage Publications.

Minner, D., Levy, A., & Century, J. (2009). Inquiry-based science instruction: What is it and does it matter? Results from a Research Synthesis 1984-2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Morrison, J. (2006). *TIES STEM* education monograph series, attributes of STEM education.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

National Research Council (U.S.). (1996). *National Science Education Standards: Observe, interact, change, learn*. Washington, DC: National Academy Press.

National Research Council. (2012). "Front Matter." *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press. http://www7.nationalacademies.org/bose/Frameworks_Report_Brief.pdf

Nation's Report Card. (2011). http://nationsreportcard.gov

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching, 46*(2), 147-165.

Ragin, C. C., & Becker, H. S. (1992). *What is a case? Exploring the foundations of social inquiry*. Cambridge, UK: Cambridge University Press.

Roehrig, G., H. (2004). Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *International Journal of Science Education, 26*, 3-24.

Rosch, E. (1973). *Natural categories. Cognitive Psychology, 4,* 328-350.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General, 104,* 192-233.

Roth, K.J., Druker, S.L., Garnier, H.E., Lemmens, M., Chen, C., Kawanaka, T., … Gallimore, R. (2006). *Teaching science in five countries: Results from the TIMSS 1999 video study* (NCES 2006-011). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office.

Rowlands, S. (2000). Turning Vygotsky on his head: Vygotsky's scientifically based methods and the socioculturalist's social other. *Science and Education, 9,* 537-575.

Rowlands, S., Graham, T., & Berry, J. (1999). Can we speak of alternative frameworks and conceptual change in mechanics? *Science and Education, 8*, 241-271.

Schmidt, C. (1978). *Development of picture measurement to measure the experiential background knowledge of pre-reading children.* A seminar paper for the University of Wisconsin. Retrieved from http://minds.wisconsin.edu/handle/1793/38931.

Shaver, A., Cuevas, P., Lee, O., & Avalos, M. (2007). Teachers' perceptions of policy influences on science instruction with culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching*, *44*(5), 725-746.

Shulman, J. (1987). From veteran parent to novice teacher: A case study of a student teacher. *Far West Laboratory for Educational Research and Development*. Retrieved from www.sciencedirect.com.ezproxy1.lib.asu.edu/science/article/pii/0742051X8790031X.

Smith, J., P. (1996). Efficacy and teaching mathematics by telling: A challenge for reform. *Journal for Research in Mathematics Education*, *27*, 387–402.

Stohlberg, T. L. (2008). W(h)ither the sense of wonder of pre-service primary teachers' when teaching science? A preliminary case study of their personal experiences. *Teaching and Teacher Education, 24*, 1958-1964.

Strauss, A. L., & Corbin, J. M. (1997). *Grounded theory in practice*. Thousand Oaks, CA: Sage Publications.

Sutton, S. (1998). Predicting and explaining intentions and behaviors: How well are we doing? *Journal of Applied Social Psychology, 28*, 1317-1338.

Treagust, D. F. (2010). General instructional methods and strategies. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 373-392). New York, NY: Routledge.

Tsupros, N., Kohler, R., & Hallinen, J., 2009. *STEM education: A project to identify the missing components.* Intermediate Unit 1: Center for STEM Education and Leonard Gelfand Center for Service Learning and Outreach, Carnegie Mellon University, Pennsylvania.

Tyack, D. B., & Cuban, L. (1995). *Tinkering toward utopia: A century of public school reform*. Cambridge, MA: Harvard University Press.

US Department of Labor. (2007). The STEM Workforce Challenge

Urban, W. J. (2010). *More than science and Sputnik: The National Defense Education Act of 1958*. Tuscaloosa: University of Alabama Press.

Weiss, I., Banilower, E., McMahon, K., & Smith, P. (2001). Report of the 2000 National Survey of Science and Mathematics Education. Retrieved from http://2000survey.horizonresearch.com/ reports/status.php

Wicks, D. (2010). Deviant case analysis. In A. Mills, G. Durepos, & E. Wiebe (Eds.), *Encyclopedia of case study research.* (pp. 290-292). Thousand Oaks, CA: SAGE Publications, Inc. doi: 10.4135/9781412957397.n109

APPENDIX A

INITIAL SURVEY

Teachers Prototypes of STEM Survey

1. Name
2. Gender
    a. Male
    b. Female
3. Age
    a. 20-25
    b. 25-30
    c. 30-35
    d. 35-40
    e. 40-45
    f. 45-50
    g. 50-55
    h. 55-60
    i. 60-65
    j. 65+
4. Years of teaching experience
    a. 0-3
    b. 4-6
    c. 7-10
    d. 11-14

    e. 15-18
    f. 19-22
    g. 23-26
    h. 27-30

5. Number of years in the district
    a. 0-2
    b. 3-5
    c. 6-8
    d. 9-11
    e. 12-14
    f. 15-17
    g. 18-20
    h. 20+
6. Please describe your teaching certificate, including any endorsements, highly qualified areas and other information.
    a. K-6
    b. K-8
    c. 7-12
    d. Other:
7. Teaching is my…
    a. First career
    b. Not my first career
8. Please describe your pathway to becoming a teacher.

    a. Undergraduate degree in education
    b. Alternative certification program (Teach for America, Teaching Fellows, Etc)
    c. Post-bacc in education
    d. Master’s with certification in education
    e. Emergency certification
    f. Other:

9. How would you modify the following scenario so that it exemplifies STEM instruction?

Mrs. Howard, a fourth grade teacher, is teaching her students about hurricanes. Students read a passage from a leveled reader about hurricanes. They then watch a video clip and write a letter to someone affected by Hurricane Sandy.

10. The following video (http://www.sfaz.org/stemimmersion) contains lesson segments that have been identified by Science Foundation Arizona as examples of excellent STEM instruction. What changes to these lesson segments would cause them to no longer exemplify STEM?

http://www.surveymonkey.com/s/YPCY8MB

APPENDIX B

PARTICIPANT LETTER

STEM: A Prototypical Analysis of an Abstract Noun Concept

November 18, 2012

Dear Teacher:

I am a graduate student under the direction of Professor Gustavo Fischman in the Mary Lou Fulton Teachers' College at Arizona State University.

I am conducting a research study to understand how elementary teachers conceptualize elementary STEM instruction. I am inviting your participation, which will involve completion of this short, preliminary survey, an approximately hour long interview and a categorization task in which you are asked to identify items as examples or non examples of STEM.

Your participation in this study is voluntary. You can skip questions if you wish. If you choose not to participate or to withdraw from the study at any time, there will be no penalty.

Although there is no immediate benefit to you for participating in this study, your responses will be used to further understand elementary STEM instruction and how best to support it. Additionally, this study will further inform the basis of knowledge of elementary STEM and could support additional studies. The information collected in this study will remain confidential and there are no foreseeable risks or discomforts to your participation.

Your responses will be confidential and the following safeguards will be utilized to ensure your protection:

5. Any identifiable person or place, including the district and schools in which this study is taking place as well as the participating teachers will be given a pseudonym for use throughout the study.
6. Audio recordings used in this study will be destroyed by March 1, 2013.
7. While audio recordings are being used they will be stored in a secure, locked location.
8. All information obtained as part of this study will remain fully confidential. None of the information collected as data or derived through analysis will be revealed to participant teachers' supervisors.

The results of this study may be used in reports, presentations, or publications but your name will not be used and the majority of data will be presented in its aggregate form.

If you have any questions concerning the research study, please contact the research team at: Mkenne1@asu.edu or Gustavo.fischman@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Completion of the online survey found at the following URL will be considered your consent to participate: http://www.surveymonkey.com/s/YPCY8MB. When completing the survey, please answer all the questions as accurately as possible. Your name is only given for the purposes of following up to schedule interviews and will be separated from your responses.

If you have any questions please do not hesitate to reach out.

Sincerely,

Meghan Kenney

APPENDIX C

INITIAL INTERVIEW QUESTIONS

Initial Interview Questions: Teachers' Prototypes of STEM

1. What is STEM?
2. Why engage in STEM?

3. What are the roles of teachers and students in STEM?/How do teachers and students engage in STEM?
4. How is this different than non-STEM instruction?
5. Please describe a students' experience when engaging in STEM.

6. What is the role of technology in STEM? Can you give me an example?
7. Can teachers/students engage in STEM without computers, iPads, etc? How? Why not?

8. Does STEM relate to other disciplines/subject areas? How?
9. What is the relationship between science, technology, engineering and math (STEM)?

10. How do we determine if an occurrence of STEM instruction has been successful?

11. Tell me about how language interacts or plays a part in STEM.

12. Tell me about the role of time in STEM.

13. You've mentioned kids connecting or using previous or background knowledge. Tell me more about background knowledge.

14. We've talked a lot about STEM related to ISD tell me, how do you think this would compare to STEM for kids in say Paradise Valley?

APPENDIX D

CATEGORIZATION TASK INSTRUCTION SCRIPT

[Researcher] At this point, we are going to begin the next segment of our work. This is the categorization task. The categorization task is made up of two sections; the task itself and the debrief or post interview afterward. I will explain each segment prior to beginning it. Do you have any questions?

[Wait for participant to respond.]

[Researcher] For the categorization task, we will use this PowerPoint slideshow [show slideshow]. It contains images, text and video clips of instruction. You will advance through the slideshow at your own pace, reviewing each artifact and deciding if it is an example or non-example of STEM. After you decide, record the artifact number in the example or non-example on this sheet [show recording sheet]. Do you have any questions?

[Wait for participant to respond.]

Now that we have completed the categorization task, lets talk about it. If its OK, I will take some notes and record this segment of our work. Lets first discuss the examples and non-examples. Tell me how you determined which were examples and which were the non-examples.

APPENDIX E

CATEGORIZATION TASK

STEM Categorization Task Meghan Kenney

Artifact #1

To begin a unit on natural disasters the teacher tells students that they will have to use their knowledge to design a disaster proof house. They may choose the disaster their structure should withstand and they must design and test it to determine the effectiveness of their design.

Artifact #2

Artifact #3

A seventh grade class is learning about volcanoes. They are assigned a project in which they build volcanoes and erupt them using vinegar and baking soda.

Artifact #4

Artifact #5

Students are learning about the Renaissance and Classical periods. They read stories about Copernicus, Mozart and DaVincci. They also created their own musical instruments, wrote a report about them and presented them to the class.

Artifact #6

Artifact #7

Students are learning about proportionality. They watch an episode of “Little People Big World” and then measure everything in the classroom. They must then complete a scale drawing of the classroom with all objects at the correct proportion for the people in the show.

Artifact #8

Students are learning about the early explorers. They read about Columbus, Magellan and Ponce De León. They calculate the distance that all three traveled together and then they draw a picture of what their ship would look like if they were explorers.

Artifact #9

https://www.youtube.com/watch?v=CnbQqA1TbcI

Artifact #10

Artifact #11

https://www.youtube.com/watch?v=CiEBNDaTFOc

Artifact #12

https://www.youtube.com/watch?v=Xda7b7wq2-w

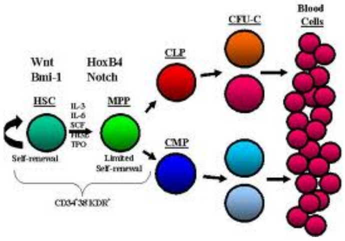
Artifact #13

During PE, students learn some new terms; dribble, travel, jump shot and lay up. After using sentence stems to practice the words, they take turns playing basketball on an X- Box Kinect. The other students shout out the appropriate vocabulary term when they observe the action and record the number of occurrences for each in a data chart.

Artifact #14

Artifact #15

Artifact #16



Artifact #17

Students use their text books to learn about plate tectonics and the formation of the Earth. Their teacher then shows a demonstration of how convection causes plate collisions.

Artifact #18

In a computer class, students use an internet based typing program to play a racing game and develop keyboarding skills.

Artifact #19

https://www.youtube.com/watch?v=ZQqNL4srbEg

Artifact #20

https://www.youtube.com/watch?v=cgbLAreElNI

APPENDIX F

CATEGORIZATION TASK RECORDING SHEET

EXAMPLES	NON-EXAMPLES