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ASSESSING STEM LITERACY IN AN INFORMAL LEARNING ENVIRONMENT

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Digital Object Identifier: https://doi.org/10.13023/ETD.2017.062

Recommended Citation

Cavalcanti, Maureen Ann LaFemina, "ASSESSING STEM LITERACY IN AN INFORMAL LEARNING ENVIRONMENT" (2017). *Theses and Dissertations--Education Sciences*. 22.
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ASSESSING STEM LITERACY IN AN INFORMAL LEARNING ENVIRONMENT

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Education
at the University of Kentucky

By
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Lexington, Kentucky

Director: Dr. Margaret Mohr-Schroeder, Associate Professor of STEM Education

Lexington, Kentucky

2017

ABSTRACT OF DISSERTATION

ASSESSING STEM LITERACY IN AN INFORMAL LEARNING ENVIRONMENT

This mixed methods study investigated methods for assessing STEM literacy amongst middle grades students participating in an informal learning environment, specifically, a summer STEM camp. Adopting a situated perspective on STEM literacy, this dissertation employed psychometric techniques and discourse analysis to answer the overarching research question: How can STEM literacy amongst middle school students be assessed in the context of a summer STEM camp? An integrated review of literacy within and across STEM disciplines first offered a new direction for conceptualizing STEM literacy. With this understanding, subsequent research methods applied novel approaches for investigating STEM literacy in the context of a summer STEM camp.

Quantitatively, various measurement models were tested for reasonableness in representing pre- and post-survey data to show a two-tier bifactor solution can be used to model the chosen quantitative survey. The calibrated data was represented by four correlated primary factors (science literacy, technological literacy, mathematical literacy, and engineering literacy) and four uncorrelated specific factors, orthogonal to the primary factors. The final four specific factors were characterized by affective components related to definitions of literacy in STEM disciplines and STEM literacy more holistically including: (1) self-efficacy/perception of ability, (2) attitude and interest (willingness to engage, career belief, disposition), (3) role and utility of STEM in society, and (4) sense of community.

Qualitatively, written reflection data were analyzed by first dichotomizing qualitative themes and then by using three of Gee's inquiry tools (1999, 2005, 2011): situated meanings, social language, and Discourses; to analyze three of Gee's building tasks of language (1999, 2005, 2011): significance, practices, and identities. Aspects of STEM literacy that involve knowledge and skills related to STEM activities were the focus of analyzing qualitative data. The findings from the discourse analysis suggest the style of language supportive of emerging STEM literacy can be understood through the context for learning; the enactment of STEM identities and STEM practices allow for this emergence as students utilize STEM language.

The combination of psychometrics and discourse analysis to analyze data collected during STEM camp allowed for investigating how different research tools can offer insight into assessing different aspects of STEM literacy. This research offers applications of research methods to data collected in an informal learning environment to investigate how STEM literacy can be assessed. The overall conclusion involves the recognition of the complexity in understanding STEM literacy amongst middle school students and the need to consider knowledge, skills and dispositions when assessing STEM literacy. Possible implications of the work to assess STEM literacy in an informal context are discussed. Recommendations for designing and implementing assessment to measure STEM literacy in an informal learning environment are made. Ultimately effective consistent methods for measuring STEM literacy could shape learning opportunities for K-12 students to achieve STEM literacy as an outcome and promote equitable educational experiences for all students.

KEYWORDS: STEM Literacy, Two-Tier Bifactor Model,
Discourse Analysis, Informal Learning Environments,
Equity

Maureen Ann LaFemina Cavalcanti

April, 11, 2017
Date

ASSESSING STEM LITERACY IN AN INFORMAL LEARNING ENVIRONMENT

By

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April, 11, 2017

I dedicate this dissertation to my daughters, Luana and Julianne, and to my former and future students. They are the reasons I am impassioned to work toward making rigorous and enriching learning opportunities accessible to all.

ACKNOWLEDGEMENTS

I am very much of the mindset that my accomplishments today are the result of the many experiences I have had in education over the past 12 years and of the many people who have impacted my personal and professional journey up to this point. I would like to thank my dissertation committee, Dr. Margaret Mohr-Schroeder, Dr. Michael Toland, Dr. Cindy Jong and Dr. Bruce Walcott. Your probing questions and thoughtful feedback at various stages of my doctoral studies helped me think differently about my research. I would like to express by deepest appreciation to my committee chair Dr. Margaret Mohr-Schroeder whose guidance and continuous encouragement were instrumental in aiding my transition from a decade of working to returning to the classroom as a student. You have valued my contributions and supported me along the way. It has been a great pleasure to take on various projects with you and learn from your expertise and dedication to STEM education. I am immeasurably grateful for having you as an advisor, mentor, supervisor, and friend throughout my doctoral studies and during my time in Lexington. Dr. Michael Toland, thank you for checking in on me and helping me talk through ideas, and for letting me take over your extra computer whenever I needed.

The support from my family has been limitless. To my husband, Rafael, I love you and I am immensely grateful for your love and partnership always, especially the past three years. It has been a constant balancing act of planning, scheduling, rescheduling, and replanning to ensure our two daughters remain happy, healthy, and engaged as we complete our professional training. For taking on even more around the house and with our girls without hesitation during the especially critical times of my program and after working insane hours, I am grateful. To my daughters, Luana and Julianne, thank you for keeping me grounded. Looking at the two of you is a constant reminder of why it has been important for me to pursue this path. I loved the conversations with Luana about mommy studying at the library across from her school. I am thankful for all the days my daughters were on point getting ready for school so I could get to the library as early as possible.

To my parents and Rosália and Francisco Cavalcanti, thank you for taking care of my daughters at different stages of writing my dissertation. Knowing my children were in good hands helped me maintain focus on my research and writing. Mom and Dad, you have always been a source of endless support and models of hard work. Thank you for your guidance as I hit mental roadblocks along the way. Mom, to me, you are the closest thing to a real life superhero. You have helped me stay focused on the goal line, and provided a nonjudgmental sounding board during challenging moments. You have spent countless hours watching my children and talking with me on the phone so I can pursue this route. To my siblings and their spouses − Jennifer and Chad, Michael and Anne Marie, and Steven and Veronica − you are all amazing and supportive. My pride in all of you pushes me harder to succeed. Steven, your timing in helping me talk through my thinking especially during the home stretch of writing my dissertation was perfect. You have always been able to lead me to clarity through our conversations around life and education.

I would be remiss if I did not extend my gratitude to former colleagues and friends. I am indebted to my CS*Uteach* family − Joanne, Courtney, Rick, Toni, Debbie, Renee, Rob, Gina, and all of the preservice STEM teachers with whom I worked. My introduction to STEM teaching and learning with the CS*Uteach* program led me to the University of Kentucky to study STEM Education further. The friendships I developed working with all of you came at a critical time in my personal and professional life. I am grateful to Dr. Pamela Hilton, Dr. Barbara Ferrer, and friends and colleagues at Parkway Academy of Technology and Health because my relationships and experiences there helped me become a teacher leader, a necessary step in my move to teacher education. I became a teacher at UCLA, but not without my awesome cohort and professors who cared and continue to care about helping all students succeed. Lastly, at the University of Kentucky, I have appreciated my conversations with Emma, Thomas, and David as a diversion from work and as a vehicle to think more deeply about ideas.

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CHAPTER I

INTRODUCTION

“Literacy itself refers to a continuum of skills—it is not a condition that one has or does not have (i.e., literacy or illiteracy), but rather each person’s skills place them in a particular place on the literacy continuum.” (Lemke et al., 2004, p. 2)

Science, technology, engineering, and mathematics (STEM) have received much attention as individual disciplines, and as an integration of disciplines, as stakeholders have investigated ways to meet the demands of the 21st century (e.g., Surr, Loney, Goldston, Rasmussen, & Anderson, 2016). Included are the design and implementation of STEM learning experiences that provide students opportunities to develop 21st century skills (Bybee, 2010; Department of Education, 2016). Stakeholders have worked to develop frameworks for STEM education including, The United States (U.S.) Department of Education (2016), California Department of Education (State Superintendent of Public Instruction Tom Torlakson’s STEM Taskforce, 2014), and Bybee (2010). In their *STEM 2026* report, the DOE (2016) outlined a vision for transformative education aimed at expanding opportunities for all students in STEM. They identified six components that can be interpreted as a framework for STEM Education:

1. Engaged and networked communities of practice.
2. Accessible learning activities that invite intentional play and risk.
3. Educational experiences that include interdisciplinary approaches to solving “grand challenges.”

4. Flexible and inclusive learning spaces.
5. Innovative and accessible measures of learning.
6. Societal and cultural images and environments that promote diversity and opportunity in STEM. (pp. ii-iii)

One of the challenges (DOE, 2016) to implementing a framework for STEM education is ensuring moves toward equity in STEM. Gutiérrez (2009) identified four dimensions of equity: access, achievement, identity, and power. Flores (2007) characterized the inequitable educational experiences in mathematics as an “opportunity gap” and Gutiérrez pinpointed from where differences “in scores on standardized achievement tests mirror discrepancies in opportunities and life chances that students from different backgrounds experience in their everyday lives” (2008, p. 360). The call for more readily accessible opportunities is not a new one (e.g., Lederman, 1998), yet the need to address this call persists. Establishing consistent measures of learning can help ensure all students have equitable opportunities in STEM.

Informal learning environments are one learning environment that can contribute to gains in STEM learning. An absence of early informal experiences with science gives way to differential academic performance (Morgan, Farkas, Hillemeier, & Maczuga, 2016). Empirical studies and reports on the importance of STEM learning experiences suggest early STEM learning experiences can impact career choice (Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016; Sahin, Ayar, & Adiguzel, 2014; Wang, 2013) and the integration of STEM subjects may improve student outcomes in STEM (Bybee, 2013; Kennedy & Odell, 2014; NRC, 2011; The Committee on STEM Education National Science and Technology Council, 2013; Wang, Moore, Roehrig, & Park, 2011).

Middle school, in particular, is a critical time for targeting student interest in STEM areas (e.g., Christensen & Knezek, 2017; Mohr-Schroeder et al., 2014; Riegle-Crumb, Moor, & Ramos-Wada, 2010). The beliefs a person holds about him/herself can be difficult to change by adolescence (Pajares, 2006). Research has indicated interest in mathematics at the start of high school predicts STEM career interest among females (Sadler, Sonnert, Hazari, & Tai's, 2012); a finding that parallels earlier findings on the impact of early interest on intent to pursue STEM (Tai, Qi Liu, Maltese, & Fan, 2006).

By looking at the ways middle school students engage in STEM learning experiences in an informal setting, STEM literacy can be assessed in the context of a short-term summer intervention. STEM literacy is one possible intended outcome of STEM learning, but one that can be achieved differentially if all students do not have access to learning experiences that support the development of STEM literacy. The goal of much of the reform efforts in STEM education has been to prepare a STEM-literate workforce, one that will bolster social and economic well-being (e.g., The Committee on STEM Education National Science and Technology Council, 2013; Kennedy & Odell, 2014; National Science Board, 2015) of the United States in STEM areas. But, who is envisioned to comprise the STEM workforce? What opportunities prepare students and in what ways? When I read Lemke et al.'s (2004) quote (above), three thoughts came to mind: (a) What are the skills of a STEM-literate individual?; (b) How do we know where a student is located along that continuum?; and (c) What can we do to ensure all students move forward along that continuum? If STEM literacy can be identified as a targeted outcome, then consistent measures to assess STEM literacy should help ensure equitable STEM pathways can emerge.

Statement of the Problem

Some research has been undertaken to examine the relationship to develop literacy in STEM disciplines and how individuals develop literacy in individual STEM disciplines. For example, Sullivan (2008) examined the relationship between robotics at a summer camp and science literacy. Robinson and Kenny (2003) studied engineering literacy as a result of participation in a high school integrated science course. However, the connection between learning environment and STEM literacy has not been firmly established in the literature.

In a nation where technologies are advancing exponentially, opportunities to support literacy must be targeted to ensure positive outcomes of efforts to produce STEM-literate individuals who can perform the necessary functions of the 21st century (Bybee, 2010; Ejiwale, 2013; NSB, 2015; Sanders, 2008). Even more, those targeted opportunities should be designed and implemented from an equity perspective (e.g., Gutiérrez, 2008). Experiences aimed at participants becoming STEM-literate "are shaped by and contribute to social practices, purposes, and contexts" (Moje, Collazo, Carrillo, & Marx, 2001, p. 472). Moje et al. (2001) continued, describing the significance of become literate in an area:

> Thus, being literate in science or any other social activity has implications that extend beyond the ability to make meaning from or about scientific text. Scientific literacy serves as a tool for and signifier of both school and social success, and thus can be considered an important tool for gaining or denying access to opportunities for success. (p. 472)

One challenge to helping all students develop STEM literacy arises from the diversity of perspectives on STEM and STEM literacy. The need to develop a definition of STEM within the context of education is clear (Brown, Brown, Reardon, & Merrill, 2011; Bybee, 2013). However, the way individuals think about STEM education impacts how they define it (Mohr-Schroeder et al., 2015). Faculty in STEM disciplines conceptualize the idea of STEM within the context of their individual STEM discipline (Breiner, Harkness, Johnson, & Koehler, 2012). As a consequence, creating a shared operational understanding of STEM may be challenging. There is a connection between literacy within and across STEM disciplines (Mohr-Schroeder, Cavalcanti, & Blyman, 2015; Zollman, 2012), which needs to be considered to understand STEM literacy from an integrated perspective.

To promote STEM literacy, it is important to consider the experiences of young minds that impact their engagement in STEM activities and, subsequently, support the development of STEM identities. This work proposes that advancing efforts to assess STEM literacy necessitates identifying connections across perspectives held by stakeholders to understand the meaning of literacy within and across STEM disciplines, and the contexts in which literacy can arise. This can be accomplished by first defining STEM literacy from an integrated perspective, and, second, investigating evidence that student STEM literacy can be measured within the context of an informal learning environment (i.e., a STEM camp). Doing so has the potential to encourage a more coordinated effort toward designing informal learning experiences that supports STEM literacy for middle school students when interest in STEM areas is at a critical juncture for college and career STEM pathways. Additionally, exploring informal learning experiences are a way to employ a broader view of equity related to identity and literacy for groups historically underrepresented in STEM (Gutiérrez, 2008). The See Blue STEM Camp is one example of a learning environment where the DOE’s framework (2016) can be applied to help deliver on key components of the framework while advancing equity in STEM. The See Blue STEM Camp provides a platform to investigate ways to assess STEM literacy for all students.

Purpose of the Study

The overall purpose of this concurrent embedded mixed methods study (Creswell, Plano Clark, & Garrett, 2008) was to investigate the ways STEM literacy can be assessed in an informal learning environment. Central to the investigation was the context, where students participated in authentic, hands-on STEM learning experiences during STEM camp. Given the short-term nature of the intervention, much of the purpose was realized through coordination on understandings of identity and literacy (e.g., Moje, 2011; Reveles & Brown, 2008). The goal of this study was to operationalize a definition of STEM literacy, by investigating how components of STEM literacy are enacted by students in the context of STEM camp as an informal learning environment. I propose that first defining STEM literacy was important for understanding the nature of learning within the explored informal environment. Subsequently, quantitative and qualitative methods were employed within a concurrent embedded design (Creswell et al., 2008) to investigate STEM literacy using self-reported data, and reflections and feedback forms. The complexity of STEM literacy as a construct was considered through the exploration of literacy as the knowledge, skills, and dispositions toward engagement in STEM-related activities. I first thought about learning outcomes in terms of knowledge, skills, and dispositions during my work at my prior institution, where all syllabi addressed learning with respect to each of those three areas. Since, I have seen this triangulation of learning as common in education related contexts (e.g., National Governors Association Center for Best Practices & Council of Chief State School Officers, 2013). For example, NSB (2015) reported that "STEM knowledge and skills enable multiple, dynamic pathways to STEM and non-STEM occupations alike" (p. 1). The work presented here is aimed at aligning perspectives of knowledge, skills, and dispositions in STEM to define STEM literacy, and subsequently operationalize that definition to measure STEM literacy quantitatively and qualitatively. Doing so could broaden understanding of ways informal learning environments can address the global importance of STEM teaching and learning. I was interested in how to assess student STEM literacy within the context of STEM camp because of the national importance for all students to achieve STEM literacy and because informal learning environments provide a platform in which diverse students can engage in STEM. Just as the Common Core State Standards have been identified as "a unique moment" in schools "to leverage excellence and equity for all and to build on efforts to foster critical thinking and problem-solving, creativity and innovation, and communication" (The Equity and Excellence Commission, 2013, p.15), informal learning environments, such as the See Blue STEM Camp, can similarly help realize goals of equity in STEM. Assessing STEM literacy is one part of meeting those goals.

Research Questions

This mixed method study utilized a concurrent embedded quasi-experimental design (Creswell et al., 2008) to understand STEM literacy as it related to participation in a STEM-focused summer camp. Quantitative data included pre- and post-survey data generated through self-report; thus quantitative data were intended to measure levels of STEM literacy via student perception. Embedded are the qualitative methods where reflection data were collected as students participated in STEM camp (Creswell et al., 2008). The overarching research question was: *How can STEM literacy amongst middle school students be assessed in the context of a summer STEM camp?* In order to address and answer the overarching research question, the following ancillary questions also guided this work.

Article 1: From an Integrated Review to a New Direction for STEM Literacy

1. How can historical perspectives of literacy in STEM-related disciplines be used to define STEM literacy?
2. What are the components of STEM literacy?

Article 2: Assessing STEM Literacy by Fitting a Two-Tier Bifactor Model to the STEM-CIS

1. How can a two-tier bifactor model of STEM-CIS contribute to the understanding of STEM literacy amongst middle school students?
2. How do measures of STEM literacy change from the beginning to end of summer STEM camp?

Article 3: Emerging STEM Literacy: A Discourse Analysis of Student Reflections at STEM Camp

1. How can discourse analysis be used to understand emerging STEM literacy amongst middle grades students attending a summer STEM camp?
2. What STEM practices and STEM identities are enacted in student reflections of learning?

STEM Camp at a Glance

In 2013, as part of National Science Foundation's (NSF) Experimental Program to Stimulate Competitive Research (EPSCoR) initiative, a large public university in the mid-south received a five-year grant to implement a model for a summer STEM camp which focused on engaging rising middle grades students (grades 5 – 8) in authentic, hands-on STEM experiences, particularly to increase awareness and interest in STEM and STEM careers. Additionally, researchers aimed to broaden participation in STEM by purposefully recruiting females and *underrepresented minorities* (Black, Latino/a, Native American) who are traditionally underrepresented in STEM fields to attend camp. As part of the five-day summer day camp, students participate in hands-on, authentic STEM sessions led by STEM faculty and supported by pre- and in-service STEM teacher leaders and graduate students. Each day, students participate in two STEM content sessions, one content area focus that changes daily, and the other LEGO robotics. Students experience LEGO robotics as a daily part of camp by programming their robots to complete challenges. Student-student, student-teacher, and student-STEM professional interactions are important to accomplish the goals of camp. The camp runs 9 a.m. to 4 p.m. daily. Camp enrollment by gender and race for 2014, 2015, and 2016 is displayed in Table 1.1. Students are divided into two groups – 5th and 6th, and 7th and 8th.

Table 1.1

Camp Participation Breakdown by Underrepresentation Status (Gender, Race/Ethnicity), 2014-2016

	2014		2015		2016	
	Actual	Percent	Actual	Percent	Actual	Percent
Gender						
Female	54	38.03%	66	45.52%	87	40.28%
Male	88	61.97%	79	54.48%	129	59.72%
Race						
White and Asian	106	74.65%	108	74.48%	155	71.76%
Underrepresented minorities[a]	33	23.24%	37	25.52%	61	28.24%

Note. Data are reported from camp registration and confirmed enrollment

[a] Underrepresented minorities include Black, Latino/a, Native American students

Significance of the Study

My dissertation is my response to the DOE's call to action in the *STEM 2026* report, namely to "propel research and development that can build a stronger evidence base for what works in various contexts, best serves diverse learners, and motivates action toward achieving transformative change" (2016, p. 1). Bybee (2010) asserted it will take at least 10 years to achieve higher levels of STEM literacy. We are creeping closer and closer to 2020, yet the vision of STEM literacy for all has yet to be achieved broadly. STEM careers are increasing exponentially as is the need for a workforce qualified to meet the demands of such careers (e.g., DOE, 2016). The desire to build capacity for global competitiveness and to prepare students who are able to solve national and global problems (DOE, 2016; The Committee on STEM Education National Science & Technology Council, 2013) has influenced the momentum with which STEM issues are being pursued at all levels of education pursuit. These goals can be achieved through an integrated approach to STEM teaching and learning (e.g., Bybee, 2010). I aimed to show that targeted STEM learning experiences in an informal learning environment can provide opportunities to develop STEM literacy. Informal learning experiences could bridge the existing opportunity gap (Flores, 2007) and give more students who have been historically underrepresented in STEM access the ability to achieve a high standard.

Some empirical studies have looked at the association between summer camp and interest in or attitudes toward STEM areas (Elam et al., 2012; Kong, Dabney, & Tai, 2014) and how learning experiences impact literacy in STEM areas (Robinson & Kenny, 2003; Sahin et al., 2014; Sullivan, 2008). However, the research on the informal environment and learning experiences in STEM literacy is absent. Literacy in STEM areas has been studied more so in the context of formal learning environments (e.g., Ortman, 2015). The earliest literature I found on the ways in which informal learning can potentially support STEM literacy addresses the impact of museum, zoo, and botanical gardens visits, and media resources on three types of scientific literacy – practical, civic, and cultural (Lucas, 1983). Informal learning environments facilitate the learning of science and promote literacy (e.g., Gerber et al., 2001). Research to determine how STEM literacy can be achieved in different settings is important to advance STEM education (Bybee, 2010). Unless we can achieve equity, people who are at risk of being left out of frameworks for STEM education, will continue to be underrepresented.

Conceptual Framework

Literacy, in general, has been identified as an outcome of education (e.g., AAAS, 1993; Asunda, 2012; Bybee, 2013), and STEM literacy has been identified as a priority in pursuing STEM fields (NRC, 2011). Research has suggested that learning experiences influence interest and career choice (Cantrell & Ewing-Taylor, 2009; Hall, Dickerson, Batts, Kauffmann, & Bosse, 2011; Hazari, Sonnert, Sadler, & Shanahan, 2010; Lent, Brown, & Hackett, 2000; Tang, Pan, & Newmeyer, 2008). What about STEM literacy? I was particularly interested in what the students know and how they come to know, specifically in the context of STEM camp. If learning and literacy can be facilitated in STEM-focused informal learning environments, then what aspects of the informal learning environment lend themselves to individuals developing the knowledge, skills, and dispositions of a STEM-literate person? I hypothesized that participants can begin to develop STEM literacy through participation in informal learning opportunities.

For this dissertation, my investigation of how informal learning environments can provide a context for assessing STEM literacy is grounded in situated cognition, or situated learning theory (Brown, Collins, & Duguid, 1989). Situated learning theory asserts that the environment, context, setting, event, etc. impact how an individual constructs knowledge. Situated learning theory arises from constructivism. A key principle of constructivist theories informed by Dewey, Piaget, and Vygotsky is that social interactions play an important role in individuals constructing knowledge. Through *legitimate peripheral participation*, an individual acquires knowledge and develops their identity (Lave, 1991, p. 64). Lave (1991) further described the process of learning as a social practice. I subscribe to the view that individual construction and social practice are key aspects of mathematics knowledge (Cobb, Yackel, & Wood, 1992), and I assume, by extension, this same interaction applies to STEM knowledge more generally. Brown et al. (1989) operationalized the relationship between cognitive and social factors when they presented situated learning theory. Recent contributions to situated cognition come from Roth and Jornet (2013) and Semin and Smith (2013).

The decision to ground this work in situated learning arises, in part, by the interplay between cognitive and sociocultural constructivist perspectives (Billett, 1996; Cobb, 1994; Kirshner & Whitson,1997; Sfard, 1998). What learners understand about a domain and context of the domain are complementary ideas in the cognitive and sociocultural perspectives on learning (Bell, Lewenstein, Shouse, & Feder, 2009; Kirshner & Whitson, 1997). Billett (1996) identified six aspects of cognitive and sociocultural theories that are complementary,

1. Expertise is domain-specific;
2. Knowledge is constructed through problem solving;
3. Compilation is negotiated in social circumstances;
4. Transfer is a socially and culturally constructed;
5. Individuals' efforts are relational to social practice; and
6. Socially determined dispositional factors are relational to cognitive structures and activities. (p. 266)

Applied to learning mathematics, Cobb (1994) argued that constructivist and sociocultural are complementary, and are bridged through situated activity. Gee (1997), as an example, has taken such an approach of sociocultural to literacy within a larger framework of situated cognition to study how children make sense of words (p. 238).

Linking Literacy and Informal Learning Environments

Central to investigating how STEM literacy amongst students can be assessed in STEM camp is examining informal learning environments, literacy, identity, and affective factors from a situated learning perspective. Direct experience, cognitive conflict, and social interactions are factors that can lead to learning within informal contexts (Gerber, Cavallo, & Marek, 2001, p. 537). Individuals can construct knowledge and foster interest in STEM through social interactions with their peers, and with the STEM professionals who facilitate learning. Peers, camp staff, and STEM professionals all contribute to the way a student engages in camp. Learning occurs when an individual participates in many experiences, supported by *cultural models* (Gee, 1997, p. 255). The cultural models that are context and content specific facilitate the meaning making within the domain and setting. The role of the experts as teachers is to provide the opportunities in which students may engage (Glaserfeld, 1996, p. 7). Having role models has been shown to help underrepresented groups be successful in STEM (Weber, 2011).

Studies about STEM-related informal learning environments have explored student interest in STEM areas (e.g., Elam, Donham, & Solomon, 2012), changes in student knowledge (Bell et al., 2009, Yilmaz, Ren, Custer, & Coleman, 2010) and reasoning (Larkins et al., 2013; Sullivan, 2007), identity development (Weinberg, Basile, & Albright, 2011), achievement (Bell et al., 2009; Niehaus, 2012; Nugent et al., 2010), college and career readiness (Bell et al., 2009), and intentions to take more STEM classes (Bhattacharyya et al., 2011). Participation in STEM summer camps (Bell et al., 2009; Elam et al., 2012; Fields, 2009; Kong, Dabney, & Tai, 2014,; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; Larkins et al., 2013; Mohr-Schroeder et al., 2014; Weinberg et al., 2011; Yilmaz et al., 2010) or other informal STEM programs (Afterschool Alliance, 2015; Baran, Bilici, & Mesutoglu, 2016; Luehmann, 2009; Newell, Zientek, Tharp, Vogt, & Moreno, 2015; Sahin, Ayar, & Adiguzel, 2014) have been shown to increase student interest in STEM areas. That interest could lead to further explorations of STEM fields.

Authentic learning. The learning that occurs in informal learning environments arises from the authentic activity in which participants engage. Authentic activity is defined as “the ordinary practices of the culture” (Brown et al., 1989, p. 34). Authentic learning opportunities can foster literacy among diverse groups of students (Israel, Maynard, & Williamson, 2013). Herrington and Oliver (2000) outlined characteristics of situated learning environments in which authenticity is central. Those characteristics highlight the importance of content, context, support, and assessment in creating environments that support learning. Authentic activity within informal learning environments could inform pedagogical changes to the formal learning environment (Gomez & Lee, 2015). Brown et al. (1989) presented a tool analogy to explain how engaging in authentic activity leads to learning just as a comprehensive understanding of tools arises from using the tool. “People who use tools actively rather than just acquire them, by contrast, build an increasingly rich implicit understanding of the world in which they use the tools and of the tools themselves” (p. 33). Students need opportunities to use the tools and practices of a domain in a useful and meaningful way (Luehmann, 2009, p. 1833; Sullivan, 2008). Authentic experiences allow an individual to construct knowledge (Kirshner & Whitson, 1997). STEM camp is an authentic setting for students to engage in the practices of STEM professionals. While the meaning and sense making students experience is ultimately up to the student, the hands-on experiences provide a context where camp staff can help facilitate and foster learning and literacy among students.

Identity. Individuals are able to make sense of their learning when they engage in authentic activity. In doing so, aspects of a STEM identity form. Cobb (2004) identified a relationship between mathematical tasks, identity development, and mathematical literacy: “Students will come to identify with mathematical activity as it is realized in the classroom, and in the process develop mathematical literacies that have clout in wider society” (p. 39). He seems to have acknowledged the importance of mathematical literacies as a way to participate in society. Where *identity* refers to “being recognized as a certain ‘kind of person’ in a given context” (Gee, 1997, p. 99), identity within STEM literacy involves a person identifying as someone who can engage in the practices of STEM as part of STEM camp.

Literacy. Cobb (2004) identified a shift in perspectives on mathematics as one patterned by “evolving, historically contingent literacies” (p. 39). Where language and literacy are concerned, the context, social language, and domains of social practice determine situated meanings that individuals form (Gee, 2014). The “acquisition of language from the social environment results in qualitatively improved thinking and reasoning, or intellectual development” (Wadsworth, 1971, p. 11). Hence, as learning is situated, so is literacy. Gee’s perspective on language and literacy (2014) incorporates sociocultural and situative views. He generalized learning a social language as a sociocultural process. The language used by STEM professionals is a social language. To understand social language tied to STEM, the context needs to reflect the domain in which it’s used. STEM professionals use domain specific language to communicate and facilitate STEM learning. Students have opportunities to use the language verbally during STEM content sessions and in writing by completing reflection and feedback forms. In doing so, students act as *legitimate peripheral participants* (Lave, 1991) to develop expertise in the context of STEM literacy. The relationship between STEM literacy and STEM practices can be interpreted with respect to Barton and Hamilton’s (2000) framework for literacy as social practice (Table 1.2). Their work applies the ideas of *literacy events* and *literacy practices* in a way consistent with modern perspectives on literacy within and across STEM disciplines (e.g., Zollman, 2012).

Table 1.2

STEM Literacy as Social Practice

Barton and Hamilton (2000) framework	Adapted framework
1. Literacy is best understood as a set of social practices; these can be inferred from events which are mediated by written texts.	1. STEM literacy is a set of social practices, and by understanding the learning environment and activities, the literacy practices associated with STEM arise from STEM learning opportunities can be understood.
2. There are different literacies associated with different domains of life.	2. STEM literacy can be thought of as an integration of STEM disciplines as well as literacy within individual STEM disciplines.
3. Literacy practices are patterned by social institutions and power relationships, and some literacies are more dominant, visible and influential than others.	3. STEM literacy practices are patterned by societal demands for a STEM literate workforce and educational policy and practices.
4. Literacy practices are purposeful and embedded in broader social goals and cultural practices	4. STEM literacy practices are purposeful and embedded in broader social goals and cultural practices.
5. Literacy is historically situated.	5. STEM literacy has evolved from historical perspectives on literacy, and remains dynamic as societal needs change.
6. Literacy practices change and new ones are frequently acquired through processes of informal learning and sense making (2000, p. 8).	6. STEM literacy practices change and new ones are frequently acquired through processes of informal learning and sense making

Advancing STEM Literacy in Informal Learning Environments

Situated learning applied to informal learning and STEM literacy offers a way to think about what it means to be STEM-literate and how individuals develop STEM literacy through participation in informal learning environments. Conceptually, I view the development of STEM literacy as a process of individual knowledge construction situated in authentic learning contexts (Kirshner & Whitson, 1997) and mediated by social interactions with peers and STEM professionals. While not applied in its entirety, the framework I adopted for STEM literacy aligns to aspects of the conceptual framework for integrated STEM teaching and learning developed by Kelley and Knowles (2016), mainly because both are grounded in situated learning theory.

Situated learning theory provided the theoretical foundation for investigating STEM literacy in informal learning environments; resulting in a framework for advancing STEM literacy (Figure 1.1). The framework was conceived using relevant theory and literature, but more specifically by applying aspects of Kelley and Knowles (2016), DOE (2016), Gutiérrez (2009), and Cannady, Greenwald, and Harris's (2014) work to my study of STEM literacy as it arises in the See Blue STEM Camp. Informal learning environments can promote accessible pathways to STEM literacy. By implementing an equity-based framework for situated STEM learning, students can foster levels of STEM literacy that fall along a continuum. With continued intervention and remediation across varied learning environments students can move along pathways to become STEM-literate. The STEM pathways analogy comes from Cannady et al. (2014). The four routes connecting the situated STEM learning to the person represent those pathways.

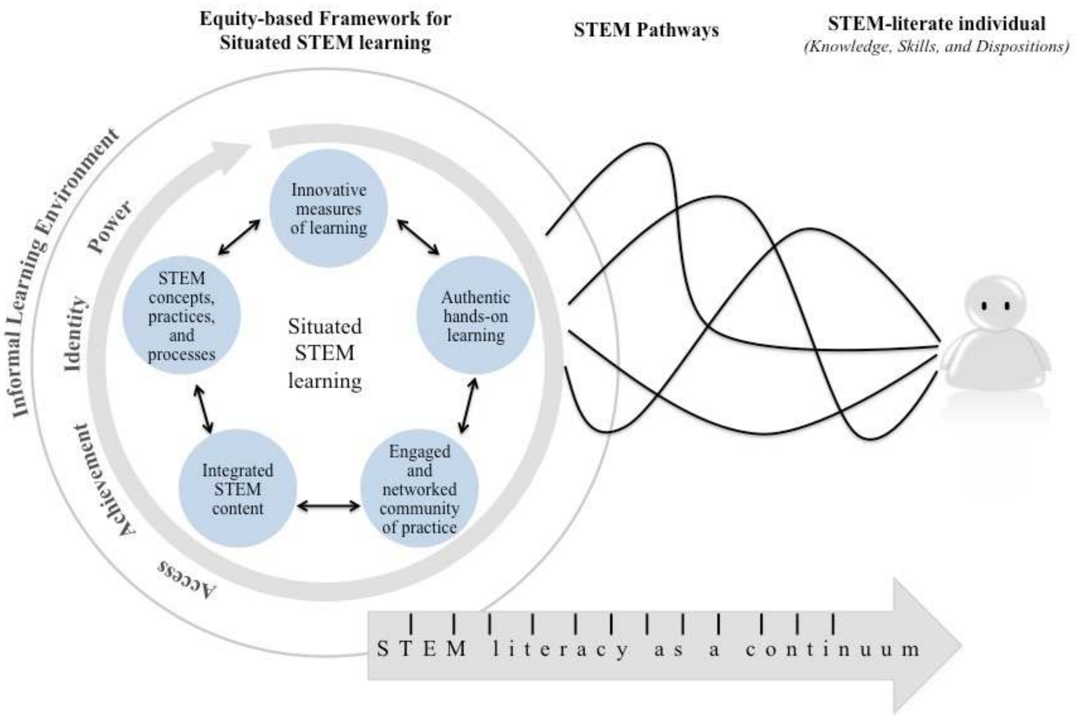


Figure 1.1. Framework for advancing STEM literacy in informal learning environments.

In this framework, the terminology, situated STEM learning, comes from Kelley and Knowles's (2016) work. They conceptualized integrated STEM education from a situative perspective relating community of practice, social discourse, and authentic learning (p. 7). Kelley and Knowles (2016) asserted, "often when learning is grounded within a situated context, learning is authentic and relevant, therefore representative of an experience found in actual STEM practice" (p. 3). There are five components of situated STEM learning represented in the framework — innovated measures of learning, authentic hands-on learning, engaged and networked community of practice, integrated STEM content, and STEM concepts, practices, and processes. In coordination with Kelley and Knowles' (2016) conceptions, the vision outlined in *STEM 2026* (DOE, 2016) directly informed how the components of situated STEM learning were represented. Two of the components — innovative measures of learning, and engaged and networked community of practice — were taken verbatim because each can be interpreted in the context of the informal learning environment. For the See Blue STEM Camp, innovative measures of learning include assessment tools such as surveys, reflections, and interviews can be used to assess student STEM literacy. While other outcomes of See Blue STEM Camp have been studied, including interest, engagement, or intent to pursue a STEM career (Mohr-Schroeder et al., 2014), STEM literacy is the specific outcome under examination in this study. The community of practice involves a broad range of individuals and groups that support the situated STEM learning (i.e., teachers, community partners), but in this study refers specifically to the role of the STEM professionals in serving as role models and modeling STEM discourses as they facilitate authentic hands-on learning opportunities. When STEM concepts, practices, and processes guide those experiences, STEM professionals can intentionally integrate STEM content during STEM content sessions. The arrows between the five components of situated STEM learning depict the continuity of intentionality in engaging students in situated STEM learning.

Four dimensions of equity — *access, achievement, identity*, and *power* — (Gutiérrez, 2009) wrap around situated STEM learning in the framework. The dimensions addressed in this dissertation are *access* and *identity*. This visual is intended to emphasize the need to be mindful of how opportunities are designed and implemented to reach a diverse group of students. In the case of STEM, groups historically underrepresented in STEM are at risk of disengaging from STEM (e.g., Beasley & Fischer, 2012; Morgan et al., 2016; Museus, Palmer, Davis, & Maramba, 2011). The See Blue STEM Camp was designed to target participation of those groups, and recruitment efforts have resulted in camp demographics that represent gender and racial diversity as depicted in Table 1.1. Because of this, the See Blue STEM Camp created an opportunity to apply this framework to the whole group of students.

Relevant Terminology

Informal Learning Environments

Informal learning involves learning outside a formal classroom (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). *Informal learning environments* involve learning experiences outside the formal classroom environment (Gerber et al., 2001; Mohr-Schroeder et al., 2014; Olsen, Cox-Peterson, & McComas, 2001). Informal learning experiences take place outside of the traditional school setting and includes some sort of an intervention that, when related to STEM, focuses on student engagement, targets underrepresented populations, and involves first-hand experiences in STEM for participants (Mohr-Schroeder et al., 2014).

STEM learning experiences

In this research, *STEM learning experiences* referred to those learning experiences focused on either a single STEM area or utilizes an integrative approach to STEM teaching and learning. There are targeted outcomes associated with STEM learning experiences. Those intended outcomes apply to camp in general and to individual STEM content sessions.

STEM Literacy

The definition of *STEM literacy* as it is developed in Chapter 2 is the "conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (Bybee, 2010, p. 31); the ability to engage in

STEM specific discourse; a positive disposition toward STEM areas (e.g., Wilkins, 2000, 2010, 2015), including a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015); an understanding of the utility of applying STEM concepts to solve real world problems; and, an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change.

Emerging STEM Literacy

Within a given context at a specific point in time, students who exhibit *emerging STEM literacy* place themselves in a position to engage in STEM related activities (i.e., attending STEM camp) and are able, to some varying extent, to communicate their learning or experience within a situated STEM activity. Through those socially situated experiences, students are "gradually adding on" to their literacy development, and their knowledge, skills, and dispositions toward STEM act as a "springboard" (Strickland & Morrow, 1989, v) for moving forward along the continuum of STEM literacy (Lemke et al., 2004).

STEM Identity

Generally, *STEM identity* refers to the ways an individual identifies with STEM as a domain, and the way those in the domain recognize an individual as a member of the domain (Gee, 1997, 1999, 2000; Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008; Moje, 2011).

STEM Pathways

STEM pathways refer to the multiple trajectories, or paths, an individual can take in STEM (Cannady et al., 2014; Stevens et al., 2008). In this research, the focus in on pathways related to STEM literacy.

STEM Education

The definition of *STEM education* drawn on in this dissertation comes from the Southwest Regional STEM Network (2009):

> an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy. (p. 3)

This definition was selected for this dissertation because it has been broadly cited in the literature on STEM education (e.g., Ejiwale, 2013, Mohr-Schroeder et al., 2015), directly identifies STEM literacy, and highlights the interdisciplinary nature of STEM education.

Assumptions

1. Respondents provided accurate information.
2. There are constructs related to STEM literacy that could be drawn upon to investigate student STEM literacy. For example, STEM identity can serve as a proxy for STEM literacy. Given the connections between identity and literacy suggested by research (e.g., Broughton & Fairbanks, 2003; Reveles & Brown, 2008), I assumed it is reasonable to assess STEM literacy by studying identity development.
3. The measurement model that is the focus of Chapter 3, namely the two-tier bifactor model, was first described in the literature seven years ago (Cai, 2010a). There are many aspects of how to apply the two-tier model yet to be determined. For that part of the analysis, I used extended evaluation methods of more

parsimonious models such as the correlated traits model and bifactor model to the two-tier case.

Delimitations

There were a number of limitations of this study that impact how findings could be interpreted. Different data sources were only available for certain years. For instance, while the survey instrument was first administered June 2015, the student reflections were first administered following each STEM session in 2012.

Sample size for quantitative data posed some concerns that were remedied by choice of psychometric techniques to assess the instrument itself and draw conclusions about student STEM literacy. Additionally, the survey data are self-reported, which suggests participant response could be influenced by various biases.

Organization of Dissertation

The overall organization of this dissertation framed the work as a concurrent embedded quasi-experimental mixed method design (Figure 1.2).

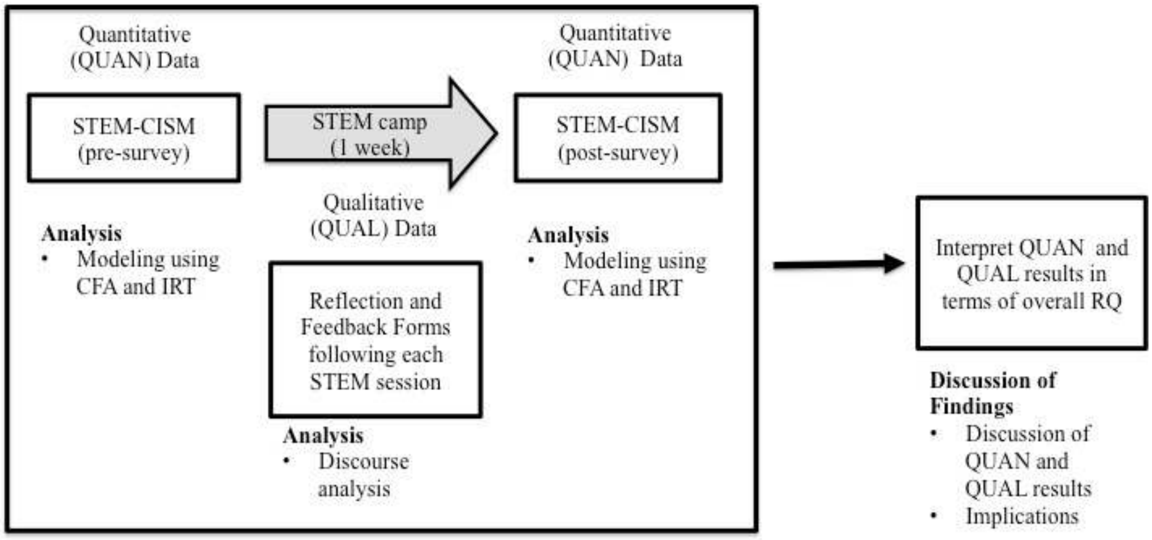


Figure 1.2. Visual diagram of concurrent embedded mixed methods design.

This dissertation utilized a three article format. The chapters of this dissertation that follow are organized as three articles, each one a separate chapter; and a conclusion chapter. The structure was intended to define STEM literacy (Chapter 2), and subsequently use data generated from the See Blue STEM Camp to offer first a quantitative (Chapter 3), and second a qualitative way (Chapter 4) to assess student STEM literacy as it develops along a continuum in an informal learning environment. Chapter 2 involved an integrative historical review of literacy in STEM areas. Included were the historical development of literacy within and across STEM areas, relevant empirical studies, the school context presented from a standards perspective, and a discussion of related constructs that can be used to define STEM literacy. The goal of the first article was to offer a definition of STEM literacy informed by the research, literature, and policy. The overall findings related to the overarching research question were discussed using the new direction offered for defining STEM literacy.

Chapter 3 focused on a psychometric evaluation of the Likert-scale items on the STEM camp pre- and post-survey using a two-tier bifactor model (Cai, 2010a). Confirmatory factor analysis (CFA) and item response theory (IRT) were performed to complete the analysis. This article additionally explored differences in STEM literacy at the start and end of camp using classical test theory (CTT) and IRT.

Chapter 4 focused on the ways students express what they know, want to know, and are interested in related to specific targeted STEM learning experiences. Data were analyzed using discourse analysis (Gee, 1999, 2005, 2011).

Chapter 3 and Chapter 4 treat quantitative and qualitative data separately. In Chapter 5, my purpose was to triangulate the findings of the two preceding chapters. I offer a mixed methods discussion of how perceived STEM literacy and STEM literacy align within the context of the STEM camp as an informal learning environment and the STEM learning experiences that occur throughout the week of camp. Doing so allowed me to answer my research question in a more comprehensive way. Further, it provided greater credibility in drawing conclusions on assessing STEM literacy in the See Blue STEM Camp, and making recommendations regarding the potential impact of STEM learning experiences on STEM literacy, and the need for evaluative tools to assess STEM literacy to monitor achievement toward a nation goal of developing a STEM-literate workforce.

I. Introduction
II. Article 1: From an Integrated Review to a New Direction for STEM Literacy
III. Article 2: Assessing STEM Literacy by Fitting a Two-Tier Bifactor Model to the STEM-CIS
IV. Article 3: Emerging STEM Literacy: A Discourse Analysis of Student Reflections at STEM Camp
V. Discussion, Conclusion, Recommendations

CHAPTER II

ARTICLE 1: FROM AN INTEGRATED REVIEW TO A NEW DIRECTION FOR STEM LITERACY

There is general agreement that science, technology, engineering and mathematics (STEM) literacy should be an educational priority (e.g., Bybee, 2010; DOE, 2016) and efforts should be placed on helping all students achieve STEM literacy (e.g., DOE, 2016). Stakeholders have responded to the call of STEM literacy for all. A number of initiatives focused on developing a STEM-literate population including, the Common Core State Standards (CCSS), STEM-focused schools, and STEM learning networks have been identified in the literature (e.g., Mohr-Schroeder et al., 2015). The integration of STEM subjects in K-12 education is important to help students make connections between STEM concepts (Honey et al., 2014; NRC, 2011). Means, Wang, Young, Peters, and Lynch (2016) found a positive impact of enrollment in STEM-focused high school on student interest and achievement in STEM. Students at the STEM-focused high school experienced integrated curriculum, informal learning opportunities, and interactions with professionals. Assessment is a way to identify possible connections between content and practices within and across STEM disciplines (Neidorf et al., 2016). In evaluating performance expectations of STEM subjects for grades 4 through 12, there is some alignment to the National Assessment of Educational Progress (NAEP) science framework, Technology and Engineering Literacy (TEL) framework, or both (Neidorf et al., 2016, p. 88).

Schleicher (2010) posed the following question about achieving literacy, “How do educational systems encourage a transition to ‘new literacy skills’?” (p. 433). This transition is needed because the relationship between different STEM disciplines has resulted in new literacy demands (i.e., daily workplace; Asunda, 2012). New literacy demands relate to the amount and nature of information calling for a new set of skills to interpret information (Schleicher, 2010). The work in the fields of STEM education have addressed issues of defining literacy and describing what it means for an individual to be literate in a specific discipline. It is important to understand how the relationship between STEM disciplines informs a definition of STEM literacy; a definition of STEM literacy would subsequently inform efforts to address concerns over shortages in the STEM workforce identified in national reports such as the National Science Board's (NSB) report titled, *Revisiting the STEM Workforce* (2015) and The Committee on STEM Education National Science and Technology Council's strategic plan, *Federal Science, Technology, Engineering, and Mathematics (STEM) Education: 5-Year Strategic Plan* (2013). In part, this is attributed to differential preparation of diverse groups in STEM fields, and a need to broaden participation of groups who have been historically underrepresented including minorities (Black, Latino/a, Native American) and females.

Literacy in a broader sense applies to "the ability to negotiate and create texts in appropriate ways or in ways other members of a discipline would recognize as 'correct' or 'viable'" (Draper & Siebert, 2010, p. 30). It can be viewed as an outcome or goal for education (AAAS, 1993; Asunda, 2012; Bybee, McCrae, & Laurie, 2009; Gardner, 1983; Tout, 2000). It can viewed as a continuum where "each person's skills place them in a particular place on the literacy continuum" (Lemke et al., 2004, p. 2). The integration of STEM disciplines in curricula could support the development of STEM literacy and pathways to STEM-related careers (Asunda, 2012). It is important for individuals to be literate so they may participate fully in society (e.g., Gardner, 1983; NSB, 2015). I propose a historical literature review of how disciplinary literacies have been conceived in science, technology, engineering, and mathematics can inform a definition of STEM literacy. The potential benefits of such an approach would involve positive and sustainable change in STEM teaching and learning, as well as a well-prepared technical workforce.

The Problem and Purpose

The purpose of this historical literature review is to examine historical perspectives on *disciplinary literacy* (e.g., Shanahan & Shanahan, 2012) in STEM areas, identify themes across those perspectives of literacy, and draw connections to current efforts to define and enact STEM literacy in educational settings. The outcomes of aligning diverse perspectives on literacy can help address many of the current needs in the United States educational system and inform a new direction for STEM literacy. The socio-political climate in the United States has influenced shifts in education throughout history. For instance, in mathematics, Gutiérrez (2013) identified the increasing importance of identity and power in learning mathematics. The launch of Sputnik in 1957 spurred reforms in mathematics, science, and engineering rooted in a desire to grow the capacity for Americans to contribute to STEM fields.

Alongside the importance placed on STEM disciplines, there has been a reoccurring call for equal access to educational opportunities (Flores, 2007; Lederman, 1998). Equity must remain an intentional part of conversations in STEM to ensure delivery of key components of STEM education to all students. Yet, it is concerning that in 2017, equitable educational opportunities continue to be a vision not achieved by all students within existing frameworks for STEM education. As STEM literacy is increasingly identified within those frameworks and across the literacy (e.g., DOE, 2016), concerns over ensuring positive outcomes for students in STEM have expanded to include all students achieving STEM literacy. Literacy has, in a sense, become an issue of equity in education as greater opportunities to engage in STEM are related to improved academic outcomes for students (DOE, 2016). Given the advantages of certain groups to participate in such opportunities, it should be no surprise limited opportunities produce a barrier for groups, particularly underrepresented minorities (Black, Latino/a, and Native American), to persist in STEM (e.g., Morgan et al., 2016; Museus et al., 2011; Wang, 2013). For all students to achieve STEM literacy, all students must have access to STEM learning experiences. A clear conceptual understanding of STEM literacy is necessary to design and implement integrated STEM learning experiences. I aim to develop one possible direction for STEM literacy by answering the following questions:

1. How can historical perspectives of literacy in STEM-related disciplines be used to define STEM literacy?
2. What are the components of STEM literacy?

My process to build a definition of STEM literacy using history and research is intended to offer an integrated view of STEM literacy that incorporates knowledge, skills, and psychological attributes associated with STEM literacy. The call for integration in defining literacy has been answered in different ways ranging from centering understanding of literacy across STEM disciplines on literacy in one STEM content area (AAAS, 1993) to defining literacy broadly (e.g., DeBoer, 2000). These recommendations pre-date definitions of STEM literacy specifically, but have remained relevant as conversations have shifted to helping students develop 21st century knowledge, skills, and dispositions, inclusive of the practices and processes to engage in STEM. Undoubtedly, there is great overlap between literacy within and across STEM areas and 21st century skills (Mohr-Schroeder et al., 2015). Consequently, I aim to support future research on STEM literacy as an outcome by highlighting connections between concepts related to STEM literacy. That way, stakeholders can begin to effectively assess STEM literacy, and surround efforts to achieve STEM literacy for all with assessment tools.

Methods

Across the literature, the basis for disciplinary literacy is knowledge. Literacy has been characterized, for example, by three aspects-the presence of knowledge, the ability to solve problems and apply the design process, and the ability to think critically and make informed decisions (Garmire & Pearson, 2006; NRC, 1999). Similarities and differences of what knowledge and understanding consists of within each discipline becomes evident by examining disciplinary literacies in STEM areas with respect to perspectives on literacy from the 20th and 21st century and empirical studies of literacy within and across STEM disciplines. In doing so, this paper offers an integrative literature review of disciplinary literacy in STEM areas with the goal of providing a new direction for operationalizing STEM literacy.

The literature discussed in this paper was drawn from a broad range of publications related to literacy, including research studies, conceptual articles, reports, historical documents, and other relevant sources. This integrated historical literature review was carried out in three phases to first, examine perspectives of literacy in STEM disciplines historically, synthesize themes within and across STEM disciplines, and compare identified themes to current definitions of STEM literacy; second, investigate empirical studies where STEM literacy (or literacy in individual STEM disciplines) was studied to understand how the concept of STEM literacy has been measured or assessed; and third, highlight literacy components implicitly and explicitly presented within and across accepted standards and practices in STEM disciplines. During the first two phases, educational databases including ERIC and ProQuest were searched followed by a general Internet search for relevant websites largely related to professional organizations until saturation occurred. The search terms and inclusion criteria for Phase I and Phase II are displayed in Table 2.2.

Additional combinations of relevant terms were searched as patterns arose in the literature. Particularly during Phase II, inclusion was an iterative process, in that as patterns among definitions emerged, efforts where literacy could be implicit were considered for inclusion, to achieve the overall goal of offering a new direction for STEM literacy.

Regarding the historical progression of definitions of literacy in mathematics, science, technology, and engineering, period of time explored was dependent on individual histories of when and how the term “literacy” was used. For instance, in the case of science, the term science literacy dates back to 1958 (Hurd, 1958), while for mathematics, the term literacy was used as early as 1945 (Berman, 1945). Therefore, while perspectives were explored into 21st century, the starting time was discipline dependent. For each discipline, it was a goal to illustrate continuity and shifts in thinking about literacy by including literature from each decade following its first use identified in the literature.

Table 2.1

Search terms and Inclusion Criteria for Literature during Phases I and II

Phase	Search terms	Inclusion Criteria
Phase 1	science literacy, scientific literacy, scientifically literate, mathematical literacy, quantitative literacy, numeracy, math literate, engineering literacy, technology literacy, technological literacy, technologically literate, digital literacy, computer literac	I narrowed the results to include articles, scholarly books, reports, and historical documents that met the following criteria: - The literature offered an explicit definition of science, mathematics, engineering, or technological literacy, or literacy in a related field. - The definition was found in an article, book or other publication, or historical document. - The definition has been cited elsewhere in the literature. - The definition parallels relevant historical events in education, but is not restricted to education in formal settings.
Phase 2	same as above search terms to identify empirical studies + fraction literacy, visual literacy, statistical literacy, diagrammatic literacy, information literacy, literacy development (for individual STEM disciplines), STEM literacy development, literacy AND content knowledge (for individual STEM disciplines), literacy AND knowledge (for individual STEM disciplines)	I narrowed the results to include peer-reviewed articles that met at least one of the following criteria: The research focused on students developing literacy in or across STEM areas. - The research identified literacy as a goal or outcome of the study; or examined ways that subjects demonstrated literacy in a relevant area. - The research described some form of literacy related to a STEM disciplines, including learning experiences related to literacy practices. - The study addressed literacy within the context of a STEM discipline were considered for inclusion.

Current Definitions of STEM Literacy

STEM literacy has been referred to frequently in publications within the last 10 years (e.g., Asunda, 2012; Bybee, 2010, 2013: Gonzalez & Kuenzi, 2012; Hayford, Blomstrom, & DeBoer, 2014; NRC, 2011; Vasquez, Sneider, & Comer, 2013; Zollman, 2012). Much of the research on STEM literacy has focused on the definition or application of STEM literacy to classroom teaching and learning (e.g., Zollman, 2012). The definitions most widely cited come from Balka (2011), Bybee (2010), the National Governor's Association (NGA; 2007), and the National Research Council (NRC; 2011). Those definitions of STEM literacy are displayed in Table 2.2. A recent definition cited by the Department of Education's (DOE) in their recent report, *STEM 2026: A Vision for Innovation in STEM Education (*2016) comes from the Business Roundtable and Change the Equation (2014):

> "Basic STEM literacy" refers to foundational science, technology, engineering and math skills that all U.S.-educated working-age adults should possess. 'Advanced STEM knowledge' refers to science, technology, engineering and math knowledge and skills typically taught in post-secondary institutions as preparation for specialized occupations that require deeper STEM knowledge. (p. 7)

Current perspectives on STEM literacy can be additionally understood by considering the characteristics of an individual who is STEM-literate (Abts, 2011; Meeder, 2014). Abts (2011) identified four attributes of someone who is STEM-literate: (1) problem-solver, (2) interdisciplinary thinker, (3) self-reliant, and (4) technology capable. Meeder (2014) also noted the problem solving aspect, but additionally identified conceptual knowledge of STEM subjects, connecting STEM content to STEM careers, and psychological aspects of achieving in STEM.

Similarities between definitions exist. For example, the concept of integration is implicit or explicit amongst the definitions of STEM literacy. However, it appears the definition of STEM literacy authors adopt in their research reflects their perspective of STEM, STEM education, and STEM literacy. As an example, interdisciplinary or transdisciplinary approaches can be taken to facilitate STEM teaching and learning (Mohr-Schroeder et al., 2015). My goal is to build off Balka's recommendation and look at different components of STEM literacy. The historical perspectives on literacy and efforts to integrate learning in STEM inform the way components of STEM literacy are identified.

Table 2.2

Current Definitions of STEM Literacy

Reference	Definition
National Governor's Association (2007, p. 7)	STEM literacy refers to an individual's ability to apply his or her understanding of how the world works within and across four interrelated domains. STEM literacy is an interdisciplinary area of study that bridges the four areas of science, technology, engineering, and mathematics. STEM literacy does not simply mean achieving literacy in these four strands or silos.
Bybee (2010, p. 31)	STEM literacy includes the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues. STEM literacy involves the integration of STEM disciplines and four interrelated and complementary components. STEM literacy refers to the following: - Acquiring scientific, technological, engineering, and mathematical knowledge and using that knowledge to identify issues, acquire new knowledge, and apply the knowledge to STEM-related issues. - Understanding the characteristic features of STEM disciplines as forms of human endeavors that include the processes of inquiry, design, and analysis. - Recognizing how STEM disciplines shape our material, intellectual. and cultural world. -Engaging in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as concerned, affective, and constructive citizens.
Balka (2011, p. 7)	STEM literacy is the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems and to innovate to solve them. To understand and address the challenge of achieving STEM literacy for all students begins with understanding and defining its component parts and the relationships between them.
National Research Council (2011, p. 5)	the knowledge and understanding of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity for all students

20th and 21st Century Perspectives on Literacy in STEM Disciplines

This historical perspective involves a look at how literacy has been defined and described in the literature. Much of the work on defining literacy comes from professional organizations and prominent figures within those organizations. When the term literacy has not explicitly been used, the description of how a person engages in a subject, and applies knowledge of a subject are detailed, giving light to how literacy can be considered. Included is what it means for a person to be literate in a STEM discipline. While specific definitions of literacy have arisen in science, mathematics, and technology; literacy in engineering is approached in a slightly different way, namely by looking at the outcomes for engineering education.

Literacy in Science

Why is science studied? In order to understand perspectives on science literacy, it is important to first visit the history of science education. Some aspects of science education to address include, the changing perspectives on curriculum in the 20th century, and common education themes that have arisen in the context of science education. Science literacy takes into account important educational themes throughout history (DeBoer, 2000). For instance, the idea of the utility of science comes up at multiple points in history (AAAS, 1989, 1993; DeBoer, 2000; Hurd, 1998; Miller, 1983). For example, Miller (1983) argued scientific literacy should include the impact of science and technology on society. The role of science education is related to science literacy, the latter being the larger goal of science education (DeBoer, 2000; Hurd, 1958; NRC, 1996; Riechard, 1985).

Paul DeHart Hurt is credited with first using the term *science literacy,* in a paper published in 1958 (De Boer, 2000; Laugksch, 2000). Hurd (1958) characterized scientific literacy as a professional responsibility for young Americans and goes further to claim it is missing from programs in schools. Miller (1983) used the general meaning of being literate to define scientific literacy as the "ability of the individual to read about, comprehend, and express opinion on scientific matters" (p. 30). Forty years after his initial publication on scientific literacy, Hurd continued to work toward defining what it means for an individual to be scientifically literate. The attributes Hurd described include, but are not limited to, using scientific knowledge to make decision for life and society, analyzing and processing information, understanding how science concepts are constantly changing and evolving, and understanding how science and technology influence the global economy (1998). These attributes have appeared elsewhere in publications. American Association for the Advancement of Science (AAAS), National Research Council (NRC), National Science Teachers Association (NSTA), and Next Generation Science Standards (NGSS) Lead States are among the authors of reports and standards who advocate for fostering scientific literacy within the population of K-12 students.

In *Science for All Americans* (AAAS, 1989), authors offer a definition for what it means for someone to be science literate, being aware of that,

> science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. (p. xvii)

This definition came 18 years after the National Science Teacher Association (NSTA) released a position statement titled "School Science Education for the 70s" which emphasized the important role of science literacy in science education (DeBoer, 1991). The phrase “understands the interrelationships between science, technology and other facets of society” is found in the NSTA statement (NSTA, 1971, pp. 47-48) and sounds like a precursor to the AAAS definition. Other definitions that have come after have arisen in the context of standards, particularly the *National Science Education Standards* (NSES) where interrelationships are not specified but the study of the natural world and work to solve problems through inquiry are highlighted (NRC, 1996). The learning of science has more consistently been focused on the process and the use of inquiry, ideas reinforced by key documents such as the NSES (NRC, 1996) and *Science for All Americans* (AAAS, 1989).

Literacy in Mathematics

During the early to mid 20th century, what is now discussed as literacy, was discussed under a variety of different names. Mathematical literacy has been thought of as numeracy, quantitative literacy, quantitative reasoning, functional mathematics, or functionality and competence in mathematics (Berman, 1945; Betz, 1948; De Lange, 2003; Gardner, 1983; National Academy of Sciences-National Research Council, 1989; Steen, 1997, 1999; Steen, Turner, & Burkhardt, 2007; Wilkins, 2000). Roper, Threlfall, and Monaghan (2005) referred to numeracy as the “mirror image of literacy and high level skill” (p. 91). This is just one example of how connections between the different descriptions, which have become known as mathematical literacy, have been made.

Curricular changes and cooperation are two areas addressed as needed to achieve mathematical literacy. Berman (1945) called for an increase in the level of mathematical literacy. Among the recommendations, he emphasized the importance of communication, greater accessibility to mathematics, and the use of real and practical problems that would show students mathematics is meaningful and valuable. Betz (1948) described similar aspects of mathematical literacy with respect to applications. He referred to the construct as *functional competence*. Functional competence was defined in terms of interrelated components — "the systematic study…of the underlying concepts principles, and modes of thinking" (p. 200) and the emphasis on connecting theory and application achieved through "understanding, mastery, and transfer" (p. 202). While Berman used the term mathematical literacy, there did not seem to be common usage of this term to describe seemingly similar descriptions of the knowledge, understanding, purpose, and application of mathematics. Through a review of literature, it appears the term *mathematical literacy* began to be more consistently used in the literature (to describe the knowledge, skills, practices, and processes of mathematics) following the second Program for International Student Assessment (PISA) in 2003. The OECD definition (2003) of mathematical literacy shown in Table 2.3 has been referenced multiple times in the literature (Asunda, 2012; Zollman, 2012).

Problem solving to address demands of everyday life (e.g. Hekimoglu & Sloan, 2005) is common to many definitions of mathematical literacy (or its equivalent) over the 50-year review of such definitions as presented in Table 2.3. More recent definitions make the notion of making decisions a bit clearer, even though there is evidence in the literature of the purpose of mathematics to include the ability to make decisions.

Table 2.3

A Glance at Definitions of Mathematical Literacy, 1959-2007

Definition	Reference
Mathematical literacy is the capacity to make effective use of mathematical knowledge and understanding in meeting challenges in everyday life.	Steen, Turner, & Burkhardt, 2007, p. 285
Mathematics literacy is an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgments and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen.	OECD, 2003, p. 24
Numeracy is the bridge that links mathematical knowledge, whether acquired via formal or informal learning, with functional and information-processing demands encountered in the real world. An evaluation of a person's numeracy is far from being a trivial matter, as it has to take into account task and situational demands, type of mathematical information available, the way in which that information is represented, prior practices, individual dispositions, cultural norms, and more.	Tout, 2000, p. 5
Quantitative Literacy-the knowledge and skills required to apply arithmetic operations, either alone or sequentially, using numbers embedded in printed material	Kirsch, 1993, p. 28
We would wish the word 'numerate' to imply the possession of two attributes. The first of these is an 'at-homeness' with numbers and an ability to make use of mathematical skills which enables an individual to cope with the practical mathematical demands of his everyday life. The second is an ability to have some appreciation and understanding of information which is presented in mathematical terms, for instance in graphs, charts or tables or by reference to percentage increase or decrease.	Cockcroft, 1982, p. 11
It is perhaps possible to distinguish two different aspects of numeracy that should concern the Sixth Former. On the one hand is an understanding of the scientific approach to the study of phenomena - observation, hypothesis, experiment, verification. On the other hand, there is the need in the modern world to think quantitatively, to realise how far our problems are problems of degree even when they appear as problems of kind.	Crowther, 1959, p. 270

While the Common Core State Standards for Mathematics' *Standards for Mathematical Practice* (SMP) do not use the specific term mathematical literacy (NGA Center & CCSSO, 2010), the language that appears in the SMPs is consistent with the definitions and implied meaning of mathematical literacy over the fifty years (Table 2.3). The SMPs (NGA Center & CCSSO, 2010) are

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

Mathematical literacy is related to goals and outcomes of mathematics education (Tout, 2000). However, the goals of mathematics education have fluctuated over time, placing varying emphases on the more practical and theoretical aspects of mathematics and the question of who should learn mathematics and to what extent. Related to literacy, in 1963, the Newsom report out of England, distinguished between numeracy and literacy, advocating for minimal computation abilities (Newsom, 1963; Roper et al., 2005). While this comparison came out of work outside of the United States, similar sentiments about the minimum requirements have arisen through various reform movements in the history of mathematics education.

Literacy in Engineering

The important educational role of literacy in engineering was being discussed during the pre-Sputnik era in the United States. Literacy in a subject should be the aim of engineering courses (Everitt, 1944). Everitt's definition of literacy looked at what it means for someone to be literate, identifying two aspects of being literate: (a) having the ability to read and understand materials within a subject (e.g. literature), and (b) the desire to continue reading in the field (p. 511). Before the launch of Sputnik, engineering education related to higher education and efforts to prepare engineers for the professions. The focus was largely placed on the practical side than applications that integrate other STEM disciplines (Prados, Peterson, & Lattuca, 2005).

It appears literacy has not been defined specifically within the specific context of engineering, but rather through discussion of literacy in general or as an application of literacy in different content areas. Some research has claimed it is difficult to see the difference between engineering and technology literacy (Asunda, 2012; Heywood, 1993). However, proficiency in engineering has been investigated and involves developing an understanding of what engineering is and the work of an engineer. The sentiment of Everitt (1944) that engineers must produce something useful to society is one such aspect of the purpose of engineering which has continued to resonate with engineering educators and professionals. As a logical extension then, it is no surprise Herbert Hollomon addressed similar aspects of engineering in a 1965 speech to the ASEE World Congress on Engineering Education. He described engineering as "knowledge applied to the solution of society's problems" (1965, p. 654) and identified traits of engineers including knowledge and training as well as the ability to analyze problems and stimulate change through innovation. Another aspect of engineering addressed in multiple contexts involves a relationship between engineering and social responsibility (Doherty, 1939), including a link to literacy (Asunda, 2012). Among debates about the purpose of engineering in the early to mid 20th century were advocates for increasing the social responsibility of engineers (Doherty, 1939).

Much of the current understanding of what could be viewed as literacy in engineering relates to the science and engineering practices (NGSS Lead States, 2013; NRC, 2010), American Society of Engineering Education (ASEE), National Academy of Engineers (NAE), National Assessment of Educational Progress (NAEP) Technology and Engineering Literacy (TEL; National Assessment Governing Board, 2014), accrediting agencies, and connections to the *Standards for Technological Literacy* (Gorham, Newberry, & Bickart, 2003; Wulf, 2000). The NAEP TEL Framework (2014) defined technology and engineering literacy as “the capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals” (p. 3). According to the framework, the practices associated with technology and engineering literacy relate to using reasoning skills to engage in problem solving, and communicating understanding.

The Accreditation Board for Technology and Engineering (ABET) has established standards for colleges and university to prepare students for engineering professions since its founding in 1932. The *Engineering Criteria 2000* was a complete shift in the standards for engineers to an emphasis on learning outcomes and the use of assessment for continuous improvement (Prados et al., 2005). The student outcomes outlined in the criteria for accrediting engineering technology programs identify the skills, knowledge, and behaviors students should acquire or learn as part of an engineering program (ABET, 2014). The term literacy is not explicitly stated in the ABET document, but the description of student outcomes address similar sentiments as earlier work to formalize engineering education. Some of the common terminology includes communication, responsibility, and problem solving.

Literacy in Technology

Bybee (2000) emphasized the need for technological literacy, classifying it as a national imperative. Unlike mathematics and science, technology literacy does not always have a clear-cut location for implementation because of the varying presence of technology education courses in schools. Waetjen's (1987) discussion of technology literacy, for example, addressed technology in terms of general education with connections to other STEM disciplines. The development of technology education in the United States has not had as strong of an impact as other countries where such courses have become part of national curricula (Heywood, 1993).

Before the International Technology Education Association (ITEA) published the Standards for Technological Literacy (STL), Gagel worked to define technological literacy. Technological literacy involves knowledge and proficiency with technology (Gagel, 1997). Early work to define technological literacy centered on the terms *technology* and *literacy* (Gagel, 1997; Waetjen, 1987). Gagel advocated for thinking about technology in terms of literacy to develop an understanding of technological literacy that is not context dependent, but rather can apply across various contexts and subject areas. Waetjen defined technological literacy in terms of the abilities of a technologically literate individual, as one who can "understand basic scientific concepts; know societal needs and moral constraints; be able to cognize the application of scientific principles to tools and materials; and, to a certain extent be able to utilize these tools and materials" (1987, p. 31).

ITEA defined technological literacy as “the ability to use, manage, assess, and understand technology” (2000, 2002, 2007, p. 242). The goal of technology literacy, as with the other goals of literacy examined involves interactions with society and being able to make informed decisions. The connection between technology and service to individuals and society (Heywood, 1993) was made before standards explicitly laid out how interactions with society contribute to technological literacy. Greater technological literacy has the potential to benefit society, especially preparing students for high-skilled technical positions (Wulf, 2000). The International Society for Technology in Education (ISTE) developed their first set of standards for technology education in 1998, and has made revisions in 2007 and 2016. Literacy is not directly stated in the standards (e.g., ISTE, 2016). ITEA was the first organization to work to establish K-12 standards for technological literacy in the United States. Technology literacy began being assessed by NAEP in 2014. Since technology literacy has begun being assessed, there seems to be more of an emphasis on connecting technology as part of the integrative approach to STEM education (Sanders, 2008).

The Association for Computing Machinery, Code.org, Computer Science Teachers Association, Cyber Innovation Center, and National Math and Science Initiative in partnership with states and districts developed the 2016 *K-12 Computer Science Framework*. Within the framework, the authors define computer literacy as “the general use of computers and programs, such as productivity software” including “performing an Internet search and creating a digital presentation” (p. 13) and identify the goal of literacy within the framework as “foundational literacy in computer science” (p. 16).

Emergent Themes in Perspectives of Literacy in STEM Disciplines

The STEM disciplines have similar needs and therefore, literacy should be able to be defined to unify themes that arise across definitions of literacy for the subjects. These commonalities can be seen in the Crowther report (1959) where the needs of literacy of the scientist and numeracy are characterized as being complementary (p. 271). The relationship has been reiterated in more recent years. *Science for All Americans* (AAAS, 1989) identified criteria related to the common core of learning in science, mathematics, and technology. Those criteria include utility, social responsibility, intrinsic value of knowledge, philosophical value, and childhood enrichment. These criteria have arisen in descriptions of literacy in the STEM areas before and after the 1989 publication. In addition to these criteria, scientific and technological change, role of the standards, and decision-making have also been addressed in discussions of literacy.

Utility involves the service to individuals and society, and is part of the answer to the question, *Why study science, technology, engineering, and mathematics?* Part of the utility involves how the work in those subject areas drives work to create and solve problems for individuals and society (Asunda, 2012; Heywood, 1993). Another piece of the utility involves the adaptability of the STEM discipline. Literacy itself changes (Gagel, 1997) and the ability to adapt impacts how useful it is to people. The ability to change is further spurred by how fast changes are occurring in the modern day, highly technical world, but is not limited to modern day.

Scientific and technological changes have influenced the direction of education in the United States (DeBoer, 2000; Gardner, 1983; Hurd, 1958; McCurdy, 1958) as the workforce has become increasingly more technical since the 20th century. The changes occur in different contexts and as a result of different factors. For instance, thinking about science, as information changes the "essence of science," means its processes and products change (Riechard, 1985, p. 109). Change in the STEM disciplines influences change in society as well, such as the impact of changing technologies (Heywood, 1993) on society.

To meet the needs of society, young people in the United States must become literate in the STEM fields. Politically, there have been incentives to prepare scientists, engineers and teachers (Riechard, 1985) for the growing technical workforce. Those incentives have only grown as conversations have focused on funding, innovation, equity in STEM, and pathways to STEM careers. In the K-12 setting, efforts to promote literacy in STEM areas have been tied to curriculum reform, and now since the beginning of the 21st century, to content standards.

The relationship between literacy, although sometimes described in more general terms, and making decisions is a recurrent theme across the STEM disciplines (AAAS, 1989; Asunda, 2012; Betz, 1948; NGA Center & CCSSO, 2010; Everitt, 1944; Gorham et al., 2003; Miller, 1983; NGSS Lead States, 2013; NRC, 1996; Steen 1999). The result has been practices in mathematics and science calling for students to use judgment and make arguments as they use the knowledge and processes of the content areas to communicate informed decisions.

Efforts to Study STEM Literacy

The way disciplinary literacy within and across STEM disciplines have been studied can inform a way of thinking about STEM literacy. Themes from the historical development of definitions of literacy in STEM areas are consistent with the rationale behind much of the work in studying literacy. However, the way researchers have attempted to describe, measure, and analyze literacy and components of literacy present additional areas to consider in defining STEM literacy.

Literacy related to STEM disciplines have taken on different names and meanings in the literature. Qualitative (e.g., Johanning, 2008) and quantitative (e.g., Wilkins, 2015) studies have been conducted to investigate different facets of mathematical literacy, including literacy related to specific mathematical content such as fraction literacy (Johanning, 2008), statistical literacy (Hannigan, Gill, & Leavy, 2013), and visual literacy (Dimmel & Herbst, 2015). Wilkins (2010) distinguished between quantitative literacy and mathematical literacy where the former is an expanded definition to include affective factors and the latter refers to a specific discipline of study. Elsewhere, it appears terms are used interchangeably. For example, diagrammatic literacy, referring to analyzing graphics, has been studied in mathematics (Dimmel & Herbst, 2015) and science (Kragten, Admiraal, & Rijlaarsdam, 2013). Information literacy is addressed in the context of technology and engineering (e.g., Scharf, 2014), and digital literacy has been examined as it relates to technology (Meyers, Erickson, & Small, 2013). Literature related to literacy was the most difficult to find for engineering. A search for “literacy” in the archives of the *Journal of Engineering Education* yielded six results. The focus of each included aligning engineering accreditation and *Standards for Technological Literacy* (Gorham et al., 2003), information literacy in engineering design tasks (Wertz, Purzer, Fosmire, & Cardella, 2013), literacy instruction in engineering curriculum (Napp, 2004), college and career readiness related to engineering education (Nathan, Tran, Atwood, Prevost, & Phelps, 2010), and programming and computer literacy (Urban-Lurain & Weinshank, 2001).

Research studies have shown the benefit of integrating STEM content to support literacy in a STEM discipline (Becker & Park, 2011; Pecen, Humston, & Yildiz, 2012; Robinson & Kenny, 2003) and pedagogical practices to support literacy instruction (e.g., Krajcik & Sutherland, 2010). Inquiry based learning supports literacy development (McCright, 2012). Given the limited presence of engineering courses in K-12 settings, much of the current information about engineering literacy in the K-12 studies comes from ways engineering units and principles of engineering design can be applied to the science classroom (e.g., Wilson-Lopez & Gregory, 2015). O'Neil and Polman (2004) recommend students have an active role in learning science to support scientific literacy.

Since it is the teachers who implement curriculum, it makes sense to study the pedagogical practices of teachers, and instructional strategies that support literacy. Reading and writing in the content area are important to support literacy. There is agreement in the literature across disciplinary literacies about the importance of purposeful selection of texts for classroom use (e.g., Wilson-Lopez & Gregory, 2015). Koomen, Weaver, Blair, and Oberhauser (2016) investigated the impact of a summer professional development focused on reading, interpreting, and adapting primary science literature for classroom use. K-12 teachers used the products they created during the summer professional development as a way to engage students in scientific discourse and support disciplinary literacy. Impact on classroom instruction was accomplished qualitatively, and showed teachers felt their learning and confidence benefited from the experience, and they were able to "support the discourse of science and embed elements of disciplinary literacy" (p. 858), and use the adapted literature as a "bridge to the scientific enterprise in classroom instruction" (p. 858). Other research has examined specific literacy strategies such as use of diagrams and graphics (Kragten et al., 2013; Zucker, Staudt, & Tinker, 2015), interactive notebooks (Mallozzi & Heilbronner, 2013; Marcarelli, 2010), and read-alouds and hands-on learning (Varelas, Pieper, Arsenault, Pappas, & Keblawe-Shamah, 2014). When read-alouds and hands-on learning were utilized in teaching elementary Latino students, student scientific reasoning benefited (Varelas et al., 2014). In mathematics, Schema instruction and Self-Regulated Strategy Development (SRSD) were shown to help students who struggle with mathematics develop mathematical literacy (Kiuhara & Witzel, 2014). It may be reasonable to assume the literacy strategies empirically studied in individual STEM disciplines may be effective across STEM disciplines.

Large-scale assessments such as PISA (e.g., Bybee, McCrae, & Laurie, 2009) and TIMSS (e.g., Wilkins, Zembylas, & Travers, 2002) have aimed to measure literacy related to student content knowledge. Research has more recently considered how affective factors relate to literacy. Even PISA more recently has included measurements of attitudinal components and the extent to which students value scientific ways (Bybee et al., 2009). Bybee et al., in describing the rationale for investigating such affective components wrote,

> Attitudes toward science play an important role in scientific literacy. They underlie an individual's interest in, attention to, and response to science and technology…An important goal of science education is for students to develop interest in and support for scientific inquiry as well as to acquire and to

> subsequently apply scientific and technological knowledge for personal, social, and global benefit. That is, a person's scientific literacy includes certain attitudes, beliefs, and motivational orientations that influence personal actions. (p. 869)

Survey instruments have been utilized to measure facets of disciplinary literacy in STEM areas (Romine, Sadler, & Kinslow, 2016; Wilkins, 2010, 2015). Self-efficacy (e.g., Ainley, Fraillon, Schulz, & Gebhardt, 2016) and social components (e.g., Price & Lee, 2013) are among the factors investigated as related to literacy in STEM areas. Some have taken an indirect route by measuring attitudes toward a discipline using pretest – posttest designs, where intervention intended to increase knowledge in an area. In a cross-national study of computer and information literacy researchers found significant associations in some, if not all, countries between computer and information literacy and SES, between achievement and self-efficacy, and between interest and enjoyment and literacy scores (Ainley et al., 2016). Ozgen and Bindak (2011), investigated self-efficacy beliefs related to mathematical literacy among high school students in Turkey using a social cognitive perspective. Among their findings, males had higher self-efficacy than females; 9th grade students had higher self-efficacy than 12th graders; family SES was predictive of mathematical literacy self-efficacy; and students who place more importance on mathematics class had higher self-efficacy. Wilkins (2010, 2015) hypothesized three factors related to quantitative literacy – cognition, disposition, and beliefs. Wilkin's study (2015) of quantitative literacy among 4th grade students utilized multiple methods to create a second-order three-factor model for quantitative literacy. Wilkins validated the survey tool measuring mathematical dispositions using linear factor analytic techniques. Wilkins found prior knowledge statistically significantly predicted quantitative literacy scores; students with free and reduced lunch had lower quantitative literacy; females had lower quantitative literacy than males; and black students had lower quantitative literacy scores than white students.

The themes of utility arising in defining literacy in STEM disciplines could be considered in terms of how students apply their learning. Johanning (2008) conducted a two-phase qualitative study of middle school students' knowledge and application of fraction. Johanning wrote, "the literate use of fractions develops out of understanding situations where fractions are used" (p. 307). The goal was to investigate how the middle school students determined appropriateness of applying their knowledge of fractions to different settings. Explicit instruction in fractions (phase 1) occurred in 6th grade and the application and use of fraction knowledge (phase 2) occurred in 7th grade classrooms. Related to fraction literacy, "the development of the disposition to look for and use connections is related to the development of mathematical power. For a fraction-literate person, this is a natural part of their fraction-literacy discourse" (p. 306). On multiple occasions, the notion of dispositions is presented in the literature in the context of becoming or being literate in mathematics-related contexts. In the case of Wilkin's work (2010, 2015) dispositions aligned to affective factors while in Johanning's work (2008) the use of the term dispositions holds similarities to the SMPs.

Participation in STEM learning experiences impacts student interest in STEM areas, and, subsequently, their STEM literacy. In the out of school setting, two studies on robotics camps for middle school students reported seemingly contradictory results on scientific inquiry. While one study indicated students "utilized the thinking skills and science process skills associated with scientifically literate people to solve a robotics problem" (Sullivan, 2008, p. 387), another found while camp increased student content knowledge, it did not show gains in student scientific inquiry (Williams, Ma, Prejean, Ford, & Lai, 2007). The context for learning in an informal learning environment would be something for researchers to consider further, including the duration of camp, camp structure, expected outcomes, and follow-up to the informal experience. Results from a week long engineering camp suggest the camp impacted student attitudes toward engineering and perceptions of engineers (Hammack, Ivey, Utley, & High, 2015). The definition of literacy may impact how it is studied within the context of a short-term summer camp.

Advancing STEM Literacy in a Standards Based Environment

Standards for individual STEM disciplines as learning outcomes have held an important place within U.S. education for almost 30 years. Lederman (1998) described the national need to assess learning using standards writing, "The nation has the challenge to ensure that all America's children have the opportunity to learn and understand science, mathematics and technology at the higher levels defined by national standards (p. 2). Collaboration between policymakers, schools, teachers, and professional organizations have been essential to designing and disseminating standards.

The standards-based environment received initial momentum from national efforts in mathematics and science education. Since the National Council of Teacher of Mathematics (NCTM) published *Curriculum and Education Standards* in 1989*,* the first of three NCTM standards documents, stakeholders have placed targeted attention on establishing standards for learning in education. The interpretations of the standards brought to light possible meanings of standards-based practices (NRC, 1997, p. 11). In an effort to “preserve the main messages of the original Standards, while bringing together the ‘classroom’ parts of the three Standards documents into a single documents (NRC, 1997, p. 13), NCTM put forth the *Principles and Standards for School Mathematics* (2000) which marked “a new phase in the standards movement” (p. 14). The NRC with the Center for Science, Mathematics, and Engineering Education spearheaded movement toward standards-based science education (NRC, 1997) using the *National Science Education Standards* (NSES; NRC, 1996).

On their website, ISTE identifies the shift in the focus of the ISTE standards since 1998, describing the 1998, 2007, and 2016 standards as learning to use technology, using technology for learning, and transformative learning with technology, respectively. There has, however, always been an absence of national standards for engineering. In 2010, the Committee for Standards for K-12 Engineering Education advised against creating such standards because of the “evolving status of K-12 engineering education” (NRC, 2010, p. 37). Instead, they recommended ways to integrate outcomes for engineering education into mathematics, technology, and science using “infusion” and “mapping” approaches. Even so, some states have independently developed engineering standards (Dugger, 2010). Massachusetts Department of Education (MA-DOE) developed the *Massachusetts Science and Technology/Engineering Curriculum Framework* (MA-DOE, 2001, 2006), with the most recent revisions published in 2016 (MA-DOE, 2016).

The linking across standards, literacy, and integrated content can inform ways to advance STEM literacy in diverse learning environments. There are implications for defining STEM literacy to improve various aspects of the educational system. For example, it is important to define literacy to support curriculum design. The *Standards* *for Technological Literacy* could contribute to changes in curricula, textbooks, and student assessment that would impact students in a positive way (Wulf, 2000) across various subject areas, including mathematics and science.

Science for All Americans (AAAS, 1989) addresses integration directly in describing a science-literate person as

> One who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. (p. xvii)

Sander's (2008) work dealt quite a bit with defining and understanding integrative STEM education. Included is the role of understanding literacy in the context of such an approach to education. He claimed technology and engineering would play a critical role as the shift from science and mathematics to STEM and STEM education occurred. The message of integration in content standards has continued to spread. In fact, the content standards have influenced efforts to integrate STEM (Dugger, 2010). Bybee (2010) identified STEM literacy as a goal of integrated STEM education, and highlighted the importance of standards and assessments at each phase to achieve higher levels of STEM literacy (p. 33). The NRC (2010) and Dugger (2010) offered different ways integration could occur. LinkEngineering (n.d.) highlights the potential of addressing engineering in the context of other STEM disciplines,

> Students engaged in solving engineering or engineering-like problems can learn

> math and science concepts and skills easier and retain them better. This is because these types of experiences provide real-world context for what may otherwise be abstract concepts…Science inquiry and engineering design use similar cognitive tools such as brainstorming, reasoning by analogy, mental models, and visual representations. Scientists use these tools to ask questions about the world around us and try to deduce rules that explain the patterns we see. Engineers use them to modify the world to satisfy people's needs and wants. (para. 3)

The NGSS provide an example of the "infusion" approach (NRC, 2010) to integrate engineering design as part of the Science and Engineering practices (NGSS Release, 2013) of the NGSS. NGSS reflects an expanded role of engineering in thinking about effective practices in science, but also, in the STEM concepts themselves to be assessed in the modern-day standards-based environment. The NGSS additionally include explicit performance expectations (i.e., MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved) and disciplinary core ideas (i.e., ETS1.B: Developing Possible Solutions) related to engineering design (NGSS Lead States, 2013).

Asunda (2012) claimed clear connection between each of the disciplines is missing from definitions of STEM literacy. Given the attention placed on national standards, practices and processes, literacy, and assessment, Asunda's claim may no longer hold true. Further, it may be argued the connections are present but the appropriate lens must be used to think about those connections. Tools and instruments to assess STEM literacy at local and national levels have been developed. The NAEP Technology and Engineering Literacy Assessment, was first administered in 2014 to a sample of eighth graders (NAEP, 2014). National Assessment Governing Board (2014) broadly defined technology and engineering as the “capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals” (p. 3). Defining literacy across these two domains through an integrated perspective is not new. The CCSS include a literacy component under the anchor standards for English Language Arts. These anchor standards are framed in terms of college and career readiness. The CCSS literacy anchor standards have been aligned to the NGSS Science and Engineering Practices (NGSS Release, 2013). The NGSS additionally make explicit connections to CCSS for ELA and Mathematics. If the language of the various documents related to K-16 education were dissected, I would expect great overlap in the language and intended outcome of processes and practices outlined by standards. As an example, the SMPs (NGA Center & CCSSO, 2010) and the Science and Engineering Practices (NGSS Lead States, 2013) are intended to support a common goal of acquiring knowledge and the ability to use knowledge to solve problems; these goals being consistent with current definitions of STEM literacy.

Commonalities across the SMP and Science and Engineering Practices build understanding of shared practices related to literacy. Cheuk (2013) represented convergence in practices across CCSS-ELA, CCSS-M, and NGSS in a Venn Diagram. In identifying relationships, she noted the relationships she identified are not definitive and other relationships could be argued (2012). Her work coupled with my reevaluation of the language of the practices was the basis for the relationships between SMP and the

Science and Engineering Practices I developed (Table 2.4). As an example, part of the description of SMP4 (“Models with mathematics”) includes:

> In middle grades, a student might apply proportional reasoning to plan a school event or analyze a problem in the community. By high school, a student might use geometry to solve a design problem or use a function to describe how one quantity of interest depends on another...They are able to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas. They can analyze those relationships mathematically to draw conclusions. They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose. (NGA Center & CCSSO, 2010, para. 5)

Among the language used to describing modeling is “analyze a problem,” “solve a design problem,” “map their relationship,” and “draw conclusion.” NGSS described relationship between S&E practices using similar laguge: "For example, the practice of “asking questions” may lead to the practice of “modeling” or “planning and carrying out an investigation,” which in turn may lead to “analyzing and interpreting data" (NGSS Release, 2013, p. 3). Taken together, the description of SMP4 led me to link SMP4 to five Science and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;

8. Obtaining, evaluating, and communicating information. (NGSS Lead States, 2013)

Table 2.4

Standards for Mathematical Practice (NGA Center & CCSSO, 2010) and Related NGSS Science and Engineering Practice (NGSS Lead States, 2013)

	Science and Engineering Practices							
	1. Asking questions (for science) and defining problems (for engineering)	2. Developing and using models	3. Planning and carrying out investigations	4. Analyzing and interpreting data	5. Using mathematics and computational thinking	6. Constructing explanations (for science) and designing solutions (for engineering)	7. Engaging in argument from evidence	8. Obtaining, evaluating, and communicating information
SMP1. Make sense of problems and persevere in solving them.	X	X	X			X		
SMP2. Reason abstractly and quantitatively				X	X			
SMP3: Construct viable arguments and critique the reasoning of others							X[a]	X
SMP4: Models with mathematics	X	X[a]		X	X[a]			X
SMP5: Use appropriate tools strategically		X	X			X		
SMP6: Attend to precision.	X							X
SMP7: Look for and make use of structure					X			
SMP8: Look for and make use of regularity in repeated reasoning.				X	X			

Note. SMP1–SMP8 represent CCSS Standards for Mathematical Practices.

[a] Source: Cheuk, T. (2013). Relationships and convergences among the mathematics, science, and ELA practices. Refined version of diagram created by the Understanding Language Initiative for ELP Standards. Palo Alto, CA: Stanford University

Similar work has been done on a larger scale to compare the *Standards for Technological Literacy* (STL; ITEA, 2007) and ABET Outcomes (2014). The STL offer a pathway for integrating technology across STEM disciplines. Gorham et al. (2003) drew comparisons between STL and ABET Outcomes by identifying implied and direct relationships between concepts outlined in each. For example, they claim this connection between ABET Criteria 3 Student Outcome *e* and 14 of the 20 STL standards (Table 2.5).

Table 2.5

Relating ABET Outcomes to STL Standards

ABET Criteria 3 Student Outcome *e*: An Ability to identify formula and solve engineering problems.
STL Standard 6: Students will develop an understanding of the role of society in the development and use of technology.
STL Standard 11: Students will develop the abilities to apply the design process.
STL Standard 13: Students will develop the abilities to assess the impact of products and systems.

Note. STL means Standards for Technological Literacy.

The standards and practices offer an entry point for incorporating literacy and competency across subject areas into the outcomes for other subject areas. Additionally, they can be viewed as outcomes for developing the core learning in STEM areas that support pathways to STEM literacy. While the standards are largely geared toward the P-12 setting, other stakeholders have expanded the role of literacy such as accrediting agencies for post-secondary work (e.g., ABET). Together, the common goals for learning can be identified to create a unified definition of STEM literacy.

The alignment of ABET Criteria 3 Student Outcome *e* to STL as previously described, and the commonalities among the practices in NGSS and CCSSM (Table 2.4) are two examples of efforts to make clear connections across the disciplines. It is essential to expand work in this area to identify associations between the standards, outcomes, and practices related to literacy across all STEM domains. From an assessment perspective, Neidorf et al.'s (2016) study compared NGSS to NAEP science, NAEP technology and engineering literacy (TEL), and NAEP mathematics frameworks. As intended by the development of the NGSS, the NGSS and NAEP frameworks have similar foci on (Table 2.6).

Table 2.6

Comparison of the NGSS and NAEP Technology and Engineering Literacy (TEL) Framework (Neidorf et al., 2016, p. B-6)

NGSS Science and Engineering Practices	NAEP TEL Framework Practices
1. Asking questions and defining problems 2. Developing and using models 3. Planning and carrying out investigations	1. Understanding technological principles • Demonstrate knowledge and understanding of technology • Reason about facts, concepts, and principles and their interrelationships • Explain features and functions of technologies and systems • Make predictions, comparisons, and evaluations • Identify examples; explain, describe, analyze, compare, relate, and represent technological principles • Understand relationships among components of systems
4. Analyzing and interpreting data 5. Using mathematics and computational thinking	2. Developing solutions and achieving goals • Systematically apply technological knowledge, tools, and skills to address problems and achieve goals • Demonstrate procedural and strategic capabilities and the ability to apply tools and design strategies to address authentic tasks • Analyze goals • Plan, design, and implement problem-solving strategies • Monitor, iteratively revise, and evaluate possible solutions
6. Constructing explanations and designing solutions 7. Engaging in argument from evidence	3. Communicating and collaborating • Use contemporary technologies to communicate for a variety of purposes • Develop representations • Share ideas, designs, data, explanations, models, arguments, and presentations • Engage with virtual (computer-generated) peers and experts to achieve goals
8. Obtaining, evaluating, and communicating information	4. Using Technological Design • Propose or critique solutions to problems given criteria and scientific constraints • Identify scientific tradeoffs in design decisions and choose among alternative solutions • Apply science principles or data to anticipate effects of technological design decisions

They offer recommendations for identifying connections across assessments to inform future assessment developments. Such work could serve as a tool for understanding the ways STEM literacy could be assessed using standard measures of learning.

Literacy, Identity, and Equity – Building a STEM-literate Workforce

Literacy and identity are related constructs (Broughton & Fairbanks, 2003; Moje, 2011; Moje & Luke, 2009; Shanahan, McVee, Slivestri, & Haq, 2016; Tytler, 2014). Identity development is an important aspect of learning and pursuing STEM pathways (Bishop, 2012; Hazari, Sonnert, Sadler, & Shanahan, 2010; Stevens et al., 2008). The relationship between aspects of literacy (e.g., knowledge) and identity have been theorized (e.g., Moje, 2011) and studied empirically (e.g., Stevens et al., 2008).

Stevens et al. (2008) described identity as the way an individual sees herself and is seen by others in a domain. Bishop's (2012) definition of identity extends to affective components (e.g., attitudes, beliefs). For additional definitions of identity, further reading of Bishop (2012) and Gee (2000) is recommended. Moje (2011) defined *disciplinary identities* as "the discourses and practices" a professional/expert in a discipline "might engage in when producing, representing, and critiquing knowledge in her or his everyday work" (p. 54). An important aspect of discourse, *language-in-use* (Gee, 1999), involves talking, writing, and talking like an expert in a domain (Shanahan et al., 2016). Taken together, it may be hypothesized that STEM identities overlap with STEM literacy in that STEM identities entail the knowledge, skills, and dispositions indicative of STEM professionals.

Stevens et al. (2008) conducted a longitudinal ethnographic study of undergraduate engineering students at four post-secondary institutions. Their findings suggest identification plays a very important part in pursuing an engineering pathway, while acquiring knowledge in engineering. Acquiring such knowledge, namely disciplinary knowledge, occurs through engagement in authentic activity and in authentic settings (Moje, 2011). Additionally, formal (e.g., professors) and informal (e.g., family friend) mentors influence identification by providing an image of what it looks like to be an engineer (Stevens et al., 2008). Social interactions provide opportunities for students to enact identities related to disciplines (Bishop, 2012; Price & Lee, 2013), and this can occur through "meaningful discourse" (Bishop, 2012, p. 66).

Individuals need opportunities to engage in the practices of a domain through authentic activity; access to opportunities for disciplinary discourse is especially important for underrepresented minorities and females (Shanahan et al., 2016). As legitimate peripheral participants in STEM activities and through interactions with STEM professionals, individuals acquire the knowledge and identity that may concurrently inform literacy development. Moje (2011) described the relationship between knowledge, literacy, and identity as iterative; by engaging in the practices of a domain, individuals develop knowledge and identity with respect to that domain. In earlier theorizing, Moje and Luke (2009) identified literacy practices as preceding and producing identities. Shanahan et al. (2016) applied an understanding of the relationship between literacy and identity to participation in an after school engineering club for 3rd graders, *Designing Vital Engineering and Literacy Oriented Practices in STEM for Elementary Teachers and Children (DeVELOP STEM, ETC*). They identified identity, productive communication (e.g., writing, reading, non-verbal cues), and vocabulary development as critical aspects of the engineering design process. *DeVELOP STEM, ETC*'s literacy focus to problem solving using the engineering design principles help increase awareness of STEM fields, particularly among groups historically underrepresented in STEM.

Discussions of the relationship between literacy and identity give rise to broader implications for STEM literacy as an equity issue that may inform a definition of STEM literacy. It may further provide an understanding of the context in which STEM literacy develops. Authentic instruction that integrates reading and writing centered instructional practices helps diverse learners access the language of STEM (Israel et al., 2013; Kamberelis, Gillis, & Leonard, 2014; Kiuhara & Witzel, 2014), and, consequently, develop STEM literacy.

Defining STEM Literacy

Understanding STEM literacy involves a comprehensive analysis of many facets of literacy within and across STEM disciplines and contexts. Zollman (2012) recommended thinking about STEM literacy where historical perspectives of literacy in individual STEM disciplines are incorporated alongside the dynamic nature of STEM literacy. The definition of STEM literacy must remain dynamic to reflect the constantly changing technological demands of society. Meyers et al. (2013) have done a good job of describing this balance that needs to be struck in defining STEM literacy, “All literacies are built on a foundation of the traditional literacy skills of reading, writing, speaking, and listening. However, in today’s digital, globalized world, a much broader definition of literacy is required” (p. 361).

It needs to be made clear how to think about literacy within different STEM disciplines to contribute to growing literature on how STEM literacy from an integrated perspective can be defined, and how stakeholders can come to understand how literacy has been defined within and across science, technology, engineering, and mathematics. The question of whether literacy within individual STEM literacy should be defined broadly or within the specific context of the field can be raised in terms of an integrated view of STEM literacy. Bybee (2010) defined STEM literacy as the "conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (p. 31). This definition is more closely aligned to the broadly defined line of thinking, and does generalize some of the common themes that have been discussed. NRC (2011) have also offered a definition for STEM literacy, influenced by NRC's 1996 definition of scientific literacy – "The knowledge and understanding of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity for all students" (p. 5). Using the substantive literature on literacy within the STEM disciplines, it may behoove stakeholders to place more targeted attention to the themes of utility, social responsibility, response to change, communication, decision-making, and knowledge to define STEM literacy in a way that can be understood and applied across a variety of contexts.

This paper ultimately aimed to propose a definition of STEM literacy informed by coordinated perspectives, modern and historical, on disciplinary literacies within and across STEM disciplines, and by relevant research. STEM literacy may be defined as the "conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (Bybee, 2010, p. 31); the ability to engage in STEM specific discourse; a positive disposition toward STEM (e.g., Wilkins, 2000, 2010, 2015), including a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015); an understanding of the utility of applying STEM concepts to solve real world problems; and, an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change. STEM literacy further subsumes the characteristics of STEM professionals. For the school years (K-16), this definition of STEM literacy proposes STEM literacy development exists along a continuum. By engaging in STEM literacy practices in authentic environments, individuals become more STEM-literate; their level of literacy increasingly reflects that of an expert in STEM.

Concluding Thoughts

It is important to think about how literacy can be supported to ensure positive outcomes of efforts to produce a STEM-literate society. The role of curriculum has been touched on, but support also involves the individuals facilitating the work to support STEM literacy. Literacy is not the responsibility of solely the learner, but rather the responsibility of everyone (Steen et al., 2007). The public must develop understanding of science (Miller, 1983; Riechard, 1985; Shen, 1975), technology, engineering, and mathematics to support literacy among students. Collaboration among teachers (NRC, 1996), including the use of a shared language, are important. That importance rings as true today as it did during the mid 20th century. Betz very wisely asserted “If we had only an ounce of a more genuine type of cooperation from the educators and administrators we should have had truly functional mathematical curricula long ago" (1948, p. 197). When such cooperation exists among stakeholders, young minds are given opportunities to develop the STEM literacy imperative for success in the 21st century.

CHAPTER III

ARTICLE 2: ASSESSING STEM LITERACY BY FITTING A TWO-TIER BIFACTOR MODEL TO THE STEM-CIS

Introduction

The Science, Technology, Engineering, and Mathematics Career Interest Survey (STEM-CIS) was developed by Kier, Blanchard, Osborne, and Albert (2014) as a way to measure student interest in STEM areas and careers. The survey items reflect six aspects of social cognitive career theory (SCCT; Lent, Brown, & Hackett, 1994), a) self-efficacy, b) personal goal, c) outcome expectation, d) interest in a specific domain, e) personal inputs, and f) contextual support and barriers. Initial validation by Kier et al. (2014), using confirmatory factor analysis (CFA) indicated the full instrument was reasonably unidimensional. They additionally considered four separate unidimensional scales, each measuring one of the four STEM subjects. They found each subscale represented a single latent trait. Vaino, Vaino, Rannikmäe, and Holbrook (2015) used an adapted version of the technology subscale items as part of a three-section instrument to investigate gender differences related to technology-related career intentions. The other two sections included questions about background information section and a set of open response questions. They took a classical test theory approach (CTT) and treated Kier et al.'s (2014) SCCT aspects as predictors. In doing so, they found gender differences across the predictors under investigation. Koyunlu, Unlu, Dokme, and Unlu (2016) showed a four-factor structure for the STEM-CIS was appropriate using CFA. Their work was supplemented with total score comparisons using *t*-tests in CTT. Kier et al. (2014) and Koyunlu et al. (2016) reported Cronbach's α for the four separate subfactors. Koyunlu et al. (2016) additionally reported McDonald's ω (1999). For both studies, all alphas exceeded the recommend .70 (Nunally, 1978), with science subscale showing the lowest reliability in both study.

Since STEM literacy is not an observable behavior, factor analysis and item response theory can be used to explore how the STEM-CIS, administered as part of a pre- and post-survey for a summer STEM camp, can be used to assess STEM literacy. While it is common for researchers to develop scales aimed at measuring a single construct, unidimensionality is difficult to achieve, particularly in psychological assessments (Reise, Bonifay, & Haviland, 2013). The two-tier bifactor model (Cai, 2010a) can be a novel way to think about the latent structure of Kier et al.'s (2014) STEM-CIS. I felt that a coordination of CFA using *Mplus v.7.11* (Muthén & Muthén, 2013) and IRT using flexMIRT created a richer picture of how the two-tier model could be applied than if the analysis relied on either one on its own. While estimation of categorical data in *Mplus* uses limited-information estimation methods when a CFA is conducted, flexMIRT makes use of full-information estimation methods for IRT modeling. Given the complexity of the chosen model, moving from CFA to assess dimensionality to IRT for further model-fit assessment is justified in part because "while the full-information model makes use of the complete individual response patterns, one loses access to traditional model fit indices that are helpful in establishing whether the item responses are characterized by a single or multidimensional model" (Stucky & Edelen, 2015, p. 193).

Purpose of the Study

My current study explores how the STEM-CIS instrument can be used to assess STEM literacy; and, in doing so, I consider factor structures different from those considered in the design of the STEM-CIS. The purpose of the study is to offer an application of the two-tier bifactor model (Cai, 2010a) using the STEM-CIS data. Pre- and post-survey data are included in the analysis. I begin by testing multiple polytomous models — unidimensional, bifactor, correlated traits, and two-tier bifactor — using a CFA framework to confirm the pre-survey data performs best under the specified two-tier model. Next, I calibrate the set of items from the pre-survey administration to resolve theoretical and methodological concerns using IRT. Then, I apply the two-tier model to the modified set of items for the pre- and post-survey data to show, in CFA and IRT, the chosen model performs well for both survey administrations. Fit indices and parameters have not been fully developed for the two-tier bifactor model (Cai, 2010a). After I confirm model fit and calibration, I demonstrate ways to more comprehensively understand how the instrument performs under the two-tier bifactor model. I report item behavior (discrimination parameters, thresholds) and reliability measures. Last, I test changes in STEM literacy from to pre- to post-survey.

Rethinking the Meaning of STEM-CIS

I reconceptualized the meaning of the STEM-CIS in this work a priori using prior research (Betts, Pickart, & Heistad, 2011; Wilkins, 2010, 2015) and theory (e.g., Brown et al., 1989). STEM literacy is investigated as the construct of interest, both generally, and in terms of individual components that comprise STEM literacy. Bybee’s definition of STEM literacy (2010) coupled with relevant research on literacy in STEM disciplines provide the conceptual framework for STEM literacy offered for investigation in this study. The definition of STEM literacy I adopted for this study was:

> The “conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues” (Bybee, 2010, p. 31); the ability to engage in STEM specific discourse; a positive disposition toward STEM (e.g., Wilkins, 2000, 2010, 2015), including a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015); an understanding of the utility of applying STEM concepts to solve real world problems; and, an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change. (Chapter 2)

This definition of STEM literacy incorporates the acquisition and application of knowledge to STEM-related issues, utility of STEM disciplines, and engagement in STEM-related issues.

Unidimensional and multidimensional measurement models have been used to conceptualize literacy in STEM areas. For example, Betts et al. (2011) investigated a bifactor model for the Minneapolis Kindergarten Assessment to ultimately establish predictive validity of a measure of two specific factors of early literacy and numeracy uncorrelated with a primary factor of underlying academic achievement. Wilkins (2010) offered a model for quantitative literacy that accounted for a comprehensive view of literacy-cognition, beliefs, and disposition. Wilkin’s (2010) determined a hierarchical three factor model best represented data from the Second International Mathematics Study (SIMS), as a measure of quantitative literacy. Wilkins began with exploratory factor analysis with promax rotation, and used eigenvalues, scree plot, and parallel analysis as evidence for the three-factor solution. Subsequently, Wilkins applied CFA to the confirmed three-factor solution, and later a respecified model to improve model fit.

Similar to Wilkin’s (2010), the work here extends the conceptualization of literacy to beliefs and attitudes, but does so in terms of each STEM subject as opposed to mathematical literacy. This work adds to previous conceptualization by setting the stage for a survey that measures STEM literacy from a more integrated perspective, rather than STEM subject areas.

The purpose of this article is to use the STEM-CIS data as part of the STEM Camp survey data to investigate components related to STEM literacy — beliefs, disposition (Wilkins, 2010), and social factors. The five aspects of STEM literacy initially specified for the STEM-CIS items were: self-efficacy/perception of ability (12 items), attitude and interest (willingness to engage, career belief, disposition; 32 items), role and utility of STEM in society (10 items), sense of community (16 items), and family influence (14 items). While family influence is identified as a separate component to STEM literacy, it is hypothesized that family influence will not be relevant to the construct, and may, therefore, not make sense for inclusion in a modified version of the STEM-CIS. In addition to alignment to definitions of STEM literacy and research, there is overlap with the six-component conceptualization of STEM career interest initially intended for the instrument. The comparisons between factors by item are shown in Appendix A. Self-efficacy and interest items remain the same; additional items were classified as attitudes and interest to reflect an extended definition of attitudes and interest to include willingness to engage in STEM. Another involves the initial category, outcome expectation. These items were reclassified as either role and utility or family influence. The role and utility category reflects definitions of STEM literacy.

Two-Tier Bifactor Model

Bifactor models may be considered when conditional independence is violated between items that may be related in some explainable way using a subfactor where a single common dimension is still assumed (Cai & Hansen, 2013, p. 271). The two-tier bifactor model (Cai, 2010a) is a special case of the bifactor model (Gibbons et al., 2007; Reise, 2012). Cai (2010a) argued that the restriction placed on a single primary factor is not a necessary condition. The two-tier bifactor model draws from the correlated traits model and a traditional bifactor model. Dimension reduction is present with the two-tier model as it is with the bifactor model. However, rather than reduction to a single common factor, the two-tier model offers two levels of dimensions; primary dimensions, also called, primary factors, which are correlated, and uncorrelated specific factors, orthogonal to the primary factors. Consistent with bifactor model assumptions, each item will load on a primary factor and at most one specific factor. The two-tier bifactor model has been applied minimally to educational contexts (Cai, 2010a).

Method

The research questions for this study are: How can a two-tier bifactor model of STEM-CIS contribute to the understanding of STEM literacy amongst middle school students? How do measures of STEM literacy change from the beginning to end of summer STEM camp?

Participants

Pre-survey data were collected from middle school students (rising 5th - 8th grade) attending a week long STEM Camp on the campus of a large Southeastern University during Summer 2015 (n_1= 143) and Summer 2016 (n_2 = 215). All students who participated in camp and who had signed assent and consent forms on file were included in the analysis (*N* = 344). The target population is consistent with population targeted with the original STEM-CIS instrument, however the setting is different. For this study the STEM-CIS was administered in an informal environment. Demographic data including gender and race/ethnicity were also collected but was beyond the scope of the goals of this study.

Measure

The STEM camp pre-survey and post-survey consisted of 47 items. The 44 Likert-type items are the focus of this study. They are the same 44-items on the STEM-CIS instrument. Students were asked to report their level of agreement to each of the 44 items using a 4-point Likert-type format (1 *= strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree*). Students completed the pre-survey at the start of the first day of camp and the post-survey at the end of the last day of camp. Camp staff verified survey completion upon submission. Over the two years of administration less than 1% of the total data within and across cases obtained from 344 students were missing. The mode for each item over the two years was inputted for the missing data.

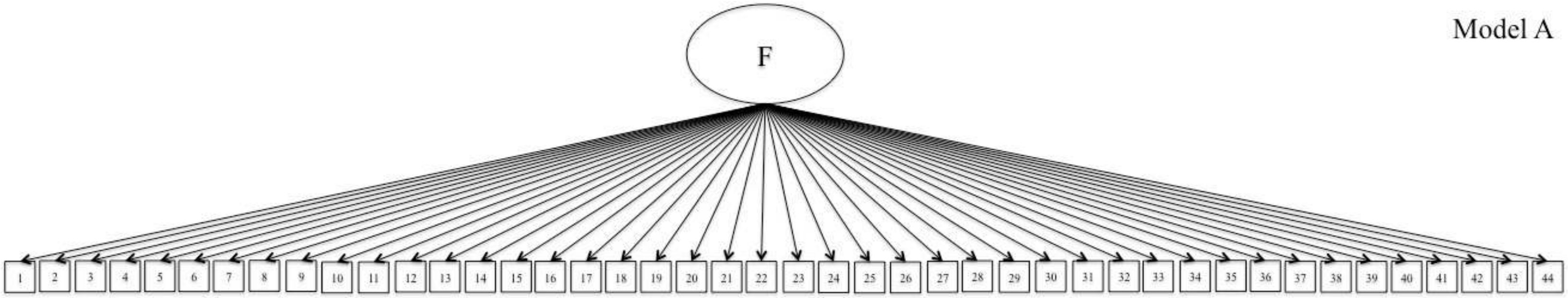
Factor Structures

The seven models considered (Table 3.1, Figure 3.1) were the unidimensional model (Model A); two correlated traits models, one consisting of five correlated factors (Model B) and the other consisting of four correlated factors (Model C); two bifactor models, one consisting of the general factor and four uncorrelated specific factors (Model D), and the other comprised of a general factor and five uncorrelated specific factors (Model E); and two two-tier bifactor models, one consisting of four primary factors and five uncorrelated specific factors (Model F), and the last consisting of five primary factors and four uncorrelated specific factors (Model G).

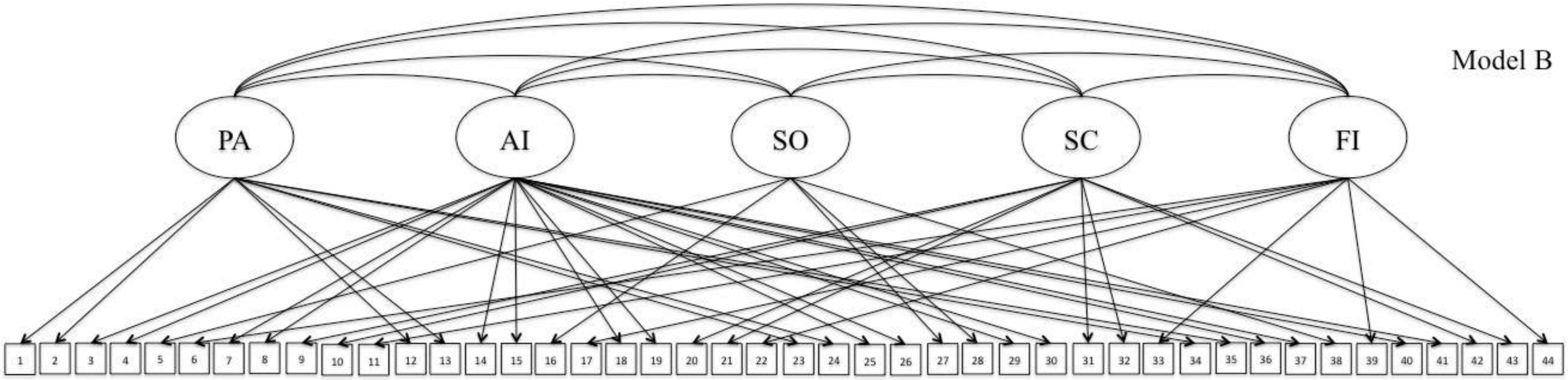
Table 3.1

Seven Considered Model Specifications for STEM-CIS

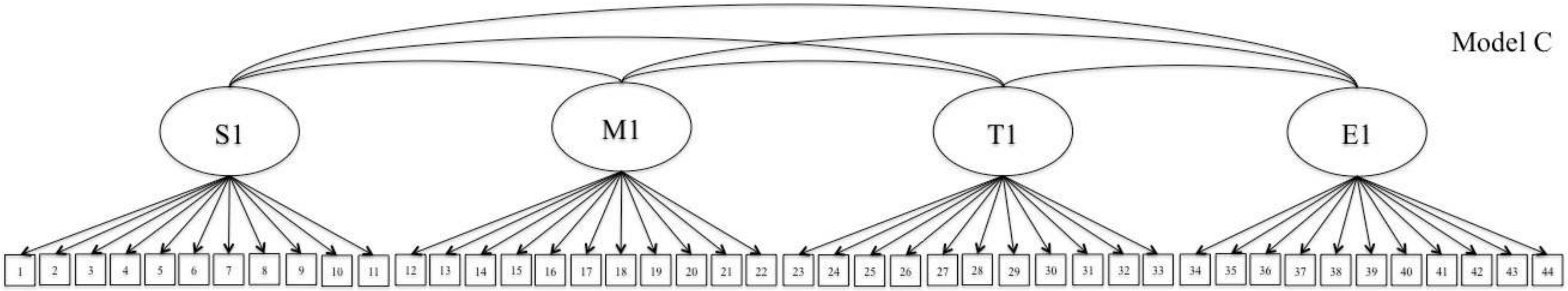
Model A	Unidimensional model where a single STEM literacy factor sufficiently explained the STEM-CIS structure
Model B	Correlated traits model where five correlated factors defined by components associated with STEM literacy
Model C	Correlated traits model where four correlated factors defined by the four STEM subjects
Model D	Bifactor model consisting of the general factor and four specific factors defined by STEM subjects
Model E	Bifactor model consisting of a general factor and five specific factors defined by components associated with STEM literacy
Model F	Two-tier bifactor model consisting of four STEM subject primary factors and five specific factors defined by components associated with STEM literacy
Model G	Two-tier bifactor model consisting of five primary factors defined by components associated with STEM literacy and four STEM subject specific factors



Model A

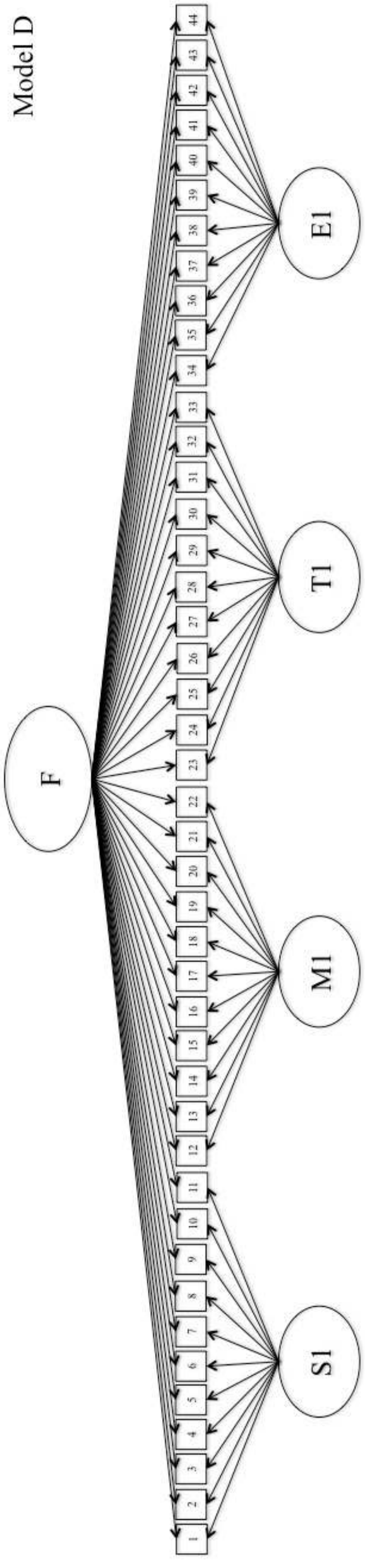


Model B

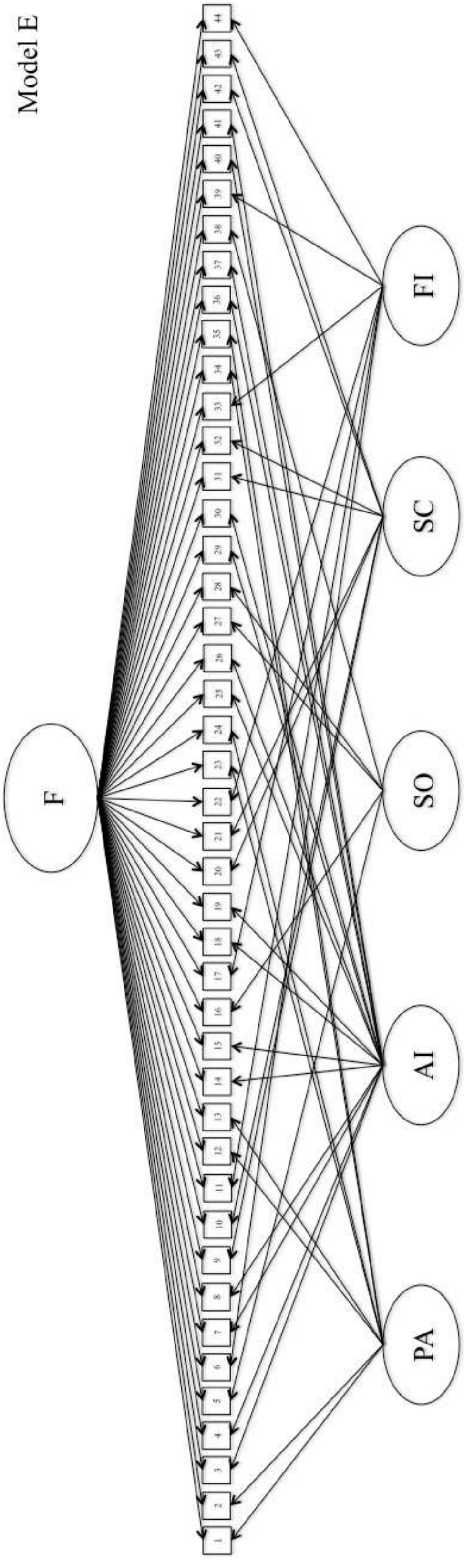


Model C

Model D



Model E



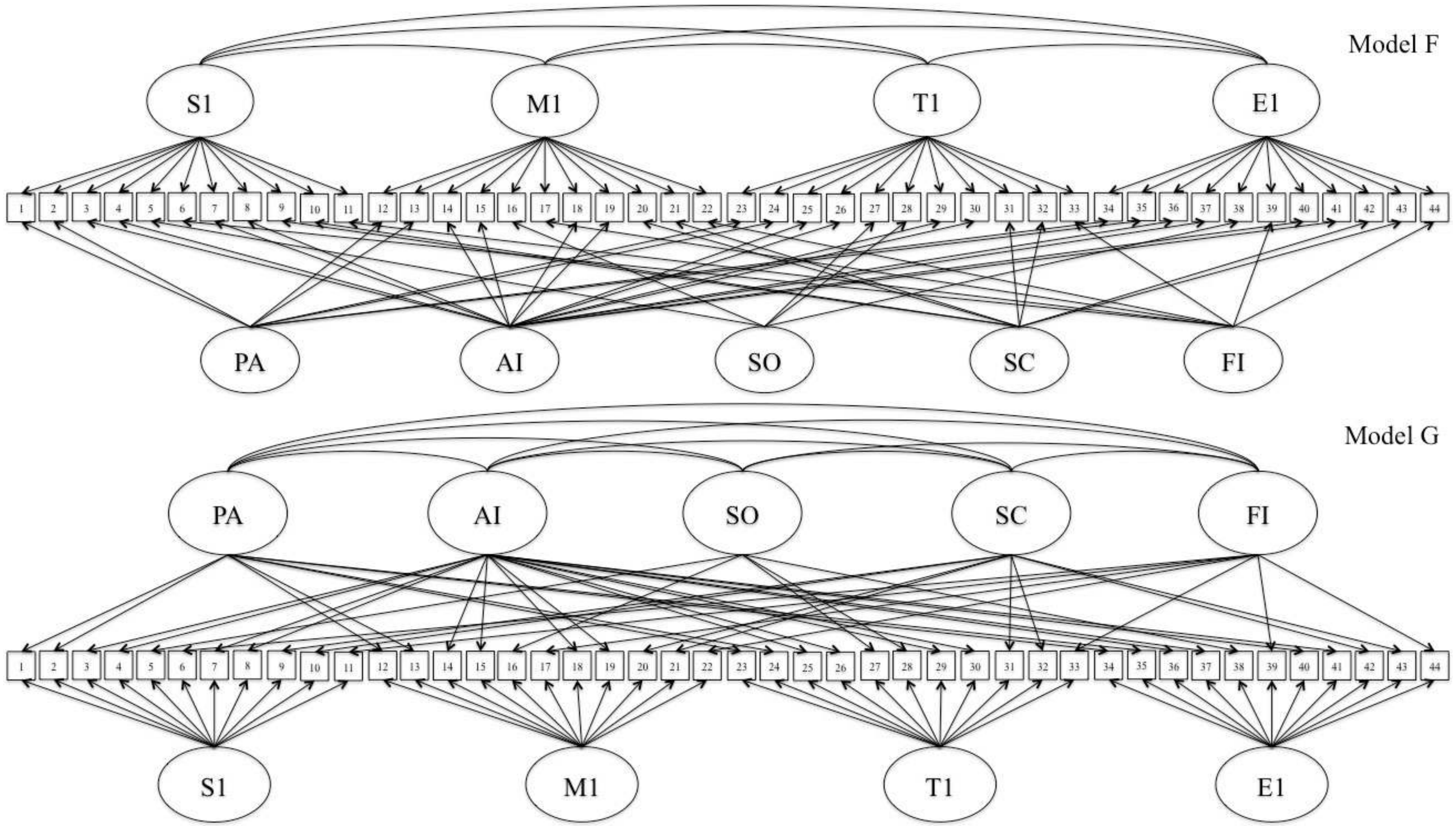


Figure 3.1. Seven latent trait models. Model A = unidimensional model; Model B = correlated traits model with five factors; Model C = correlated traits model with four factors; Model D = bifactor model with four specific factors; Model E = bifactor model with five specific factors; Model F = two-tier bifactor model with four primary and five specific factors; Model G = two-tier bifactor model with five primary and four specific factors; F = later trait; S1 = science literacy latent trait; M1 = mathematics literacy latent trait; T1 = technology literacy latent trait; E1 = engineering literacy latent trait; PA = self-efficacy/perception of ability latent trait; AI = attitudes and interest latent trait; SO = role and utility of STEM in society latent trait; SC = sense of community latent trait; FI = family influence.

Procedures

Investigating competing models in CFA. First, CFA using polychoric correlations was conducted to understand the factor structure of the STEM-CIS for the pre-survey data. Fit was assessed individually for seven models to identify the model that performed the best. The weighted least squares with adjusted means and variance (WLSMV) estimator in *Mplus v.7.11* (Muthén & Muthén, 2013) was used to investigate fit. Fit indices including the χ^2 index, comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA) with corresponding 90% confidence interval (CI) were assessed individually and compared for each of the seven models under consideration. Per Marsh, Hau, and When's (2004) recommendations, larger values for CFI and TLI, and smaller values for RMSEA were the general guidelines used to determine the better fitting model.

The relationship between the items and latent trait(s) was further investigated under each model using standardized factor loadings. Factor loadings are a measure of how much an item correlates with the latent trait. Larger values indicate the item responses can be distinguished from each other more than smaller values for the different levels of the latent trait. For the various bifactor and, by extension two-tier bifactor models, salient loadings on the primary factor(s), and stronger loadings on the primary than specific factors suggest the models may be reasonable (Reise et al., 2013).

From an IRT perspective, determining the latent structure was an important first step in IRT modeling to ensure the assumption of dimensionality was met. For multidimensional model, the dimensionality assumption states "the observations on the manifest variables are a function of a set of continuous latent person variables" (de Ayala, 2009, p. 288). Confirming the number of latent variables was sufficient to satisfy the dimensionality assumption, and a necessary precursor to calibration and further model-fit assessments.

Calibration of two-tier bifactor model under IRT framework. Item-fit statistics and parameter estimates could be misleading due to possible violations to local independence (Balazs & De Boeck, 2006; Chen & Thissen, 1997; Monseur, Baye, LaFontaine, & Quittre, 2011). As a result, it was necessary to calibrate the data prior to assessing model-data fit in IRT. It has been the case that researchers have turned to IRT modeling to calibrate data in coordination with CFA to evaluate psychometric properties of a scale (e.g., Crins et al., 2015; DeWitt et al., 2011; Edelen & Reeve, 2007; Stucky, Edelen, Vaughan, Tucker, & Butler, 2014).

flexMIRT was used for all analyses in this study that invoke IRT modeling. Estimation was done using the Metropolis-Hastings Robbins-Monro Algorithm (MH-RM) because Cai (2010b) indicated its use for “analysis with many items, many factors, and many respondents” (p. 310). MH-RM is a full information estimation procedure whose computational efficacy makes it a reasonable choice for high dimensional models (Cai, 2010b). In this study, 9 factors and 44 items were included in the most complex model evaluated; that being the two-tier bifactor model. I predicted Model F, specifically, would best represent the STEM-CIS as a measure of STEM literacy.

Calibration provided a way to improve upon the best fitting model for pre-survey data by reducing the set of items to those that made conceptual and theoretical sense, and whose inclusion were supported by psychometric measures. Psychometrically, calibration involved a sensitivity analysis in which local dependency (LD) χ^2 statistics (Chen & Thissen, 1997) were evaluated for violations to local independence (LI). It is appropriate to use Chen and Thissen's (1997) local dependence index with the two-tier model (Bonifay, 2015). LI is one of assumption of all IRT models, where, given a person's location, a person response to one item is independent of their response on another item (de Ayala, 2009, p. 20; Embretson & Reise, 2000). When LI is violated, inflation of parameter estimates and item-fit statistics can occur, leading to misspecification of a model. Items exhibiting large local dependency (LD) statistics ($|LD| > 10$; Cai, du Toit, & Thissen, 2011) were considered for removal. Item removal occurred systematically by removing items in pairs that occurred more often in terms of violating local independence. For example if LD X^2 statistics (Chen & Thissen, 1997) were large for item 1 and item 3 and for item 1 and item 6, then item 1 was removed. Recalibration occurred after each sequence of item removal. Upon recalibration, if removal of items suggested better model fit at the item level, analysis continued with the modified version of the instrument. Additionally, items involving family influence were considered for removal due to construct irrelevance. This choice was in line with what was done by Wilkins (2010) because items did not appear consistent with the relevant construct. The resulting pool of items was referred to as STEM-CIS Modified (STEM-CISM).

Assessment of global fit for STEM-CISM data. The initial assessment in CFA was repeated on the STEM-CISM data for the pre- and post-survey.

Assessment of IRT model-data fit for STEM-CISM data. Orlando and Thissen's S-χ^2 goodness-of-fit statistic (2000, 2003) can be applied to the two-tier model (Bonifay, 2015). S-χ^2 fit statistic for each item was analyzed to determine how well each STEM-CISM item was fit by model for the pre- and post-survey data, separately. Significant S-χ^2 values indicate poor fit of the model to the data. It was not possible to complement item-level fit with global fit using diagnostics such as the Akaike information criterion (AIC), Bayesian information criterion (BIC), -2 Log Likelihood (-2LL), or limited information goodness of fit statistics (i.e., M_2) because those statistics are not provided by flexMIRT when MH-RM is used as the estimator. Additionally, alternative full information estimators such as Marginal Maximum Likelihood (MML; Bock & Aitkin, 1981) would not converge in flexMIRT because "Bock-Aitkin EM algorithm can take an extremely long time to complete and may not be estimable at all due to computational limitations of the method" (Houts & Cai, 2015, p. 73). In reality, flexMIRT shut down when I tried to used alternative estimators to evaluate the two-tier bifactor models.

Additional Measures.

Item behavior. Item behavior was looked at using discrimination parameters (or slope), α, and category thresholds for pre- and post- STEM-CISM data. Discrimination parameters are provided by flexMIRT. For the two-tier bifactor model, two slopes are estimated for each item, one for the primary factor and a second for the specific factor. The discrimination parameter is an item level parameter measuring of the association between the item and latent trait (Irwin et al., 2010; Toland, 2014) where larger α values indicate a stronger relationship to the latent trait and they "do a better job of discriminating among respondents located at different points on the continuum than do items with smaller αs" (de Ayala, 2009, p. 19). Their meaning are analogous to factor loadings within a CFA framework.

The four response categories for all STEM-CIS items yield three thresholds. A threshold value is the point where the probability of responding above a response category given an ability level is .5 (Berkeljon, 2012; Embretson & Reise, 2000; Thorpe & Favia, 2012; du Toit, 2003;). When category threshold values are larger for k -1 threshold, a person ability level must be larger to have a probability of responding in the adjacent k response category greater than .5 (Toland, Sulis, Giambona, Porcu, & Campbell, 2017). Thresholds are not provided in flexMIRT but can be computed using the intercepts provided in flexMIRT:

$$b_i = \frac{-c_i}{\sqrt{\sum_k^m \alpha_{ik}^2}} \qquad (3.1)$$

where b_i is the threshold, in this case, for i = 1, 2, 3, obtained using the intercept, c_i, and the sum of the squares of the slopes for the primary and specific factor for an item (Bonifay, 2015; Reckase, 2009). Similar to the bifactor case, the loading of primary factors and one specific factor on each item result in thresholds that represent an additive composite of the two (Berkeljon, 2012, p. 32-33).

Single index reliability measures. Psychometric evaluations should be accompanied by a discussion of reliability. Reliability was investigated in this study by calculating indices for reliability in CFA and IRT. Large values for reliability suggest greater reliability in the measure. From a CFA perspective, reliability can be investigated using omega and omega hierarchical (omegaH) for the primary factor(s) and individual specific factors (omegaHS). The calculations of omega (ω), omegaH ($\omega_{H_{prim_i}}$), and omegaHS ($\omega_{H_{spec_j}}$) have not been developed for the two-tier case. In this study I assumed the set of items loading on a given primary could be treated as separate bifactor solutions, yielding four bifactor solution, one each for science literacy, mathematics literacy, technology literacy, and engineering literacy as a primary factor, with corresponding four specific factors. A bifactor calculator was used to complete the calculations (Dueber, 2016), based on the following equations from Rodriguez, Reise, and Haviland (2016):

$$\omega = \frac{(\sum \lambda_{prim_i})^2 + (\sum \lambda_{spec1})^2 + (\sum \lambda_{spec2})^2 + (\sum \lambda_{spec3})^2 + (\sum \lambda_{spec4})^2}{(\sum \lambda_{primary_i})^2 + (\sum \lambda_{sp1})^2 + (\sum \lambda_{sp2})^2 + (\sum \lambda_{sp3})^2 + (\sum \lambda_{sp3})^2 + \sum(1-h^2)} \tag{3.2}$$

for primary factor $i = 1, 2, 3, 4;$

$$\omega_{spec_j} = \frac{(\sum \lambda_{prim_i})^2 + (\sum \lambda_{spec_j})^2}{(\sum \lambda_{prim_i})^2 + (\sum \lambda_{spec_j})^2 + \sum(1-h^2)} \tag{3.3}$$

for primary factor $j = 1, 2, 3, 4;$

$$\omega_{H_{prim_i}} = \frac{(\sum \lambda_{prim_i})^2}{(\sum \lambda_{prim_i})^2 + (\sum \lambda_{spec1})^2 + (\sum \lambda_{spec2})^2 + (\sum \lambda_{spec3})^2 + (\sum \lambda_{spec4})^2 + \sum(1-h^2)}; \tag{3.4}$$

and $$\omega_{H_{spec_j}} = \frac{(\sum \lambda_{spec_j})^2}{(\sum \lambda_{prim_i})^2 + (\sum \lambda_{spec_j})^2 + \sum(1-h^2)} \tag{3.5}$$

Calculation of omegas determined whether summed score totals could be interpreted as essentially unidimensional (Rodriguez et al., 2016). While Rodriguez et al. (2016) applied the use of omegas for interpretability of total scale scores to the bifactor model in the same fashion as Reise (2012), this study assumed extension to the two-tier bifactor model was reasonable. While no specific cut-offs for omega and omegaH values exist, there is general agreement that large omegas suggest reasonableness in interpreting a single score (e.g., Reise, 2012, p. 690; Reise et al., 2013).

An alternative reliability measure, namely empirical reliability, was computed from an IRT perspective. A single index for reliability was calculated for each of the four primary factors from the EAP scores estimated using the two-tier bifactor model. Standard errors and observed scores were estimated using the EAP method. The sum of the squares of the standard error divided by the variance of the observed scores was subtracted from one to obtain the empirical reliability for each primary factor. It should be noted that Brown (2014) warned against the use of a single index for reliability in IRT due to potential issues with measurement precision arising from Bayesian estimation of observed scores and standard errors; and recommends the use of information functions for greater measurement precision in understanding reliability. I had hoped to obtain Fisher information values as described in the flexMIRT manual (Houts & Cai, 2015) to then graph the information function for the two-tier model using the software, R. However, it is indicated in flexMIRT that computation of Fisher Information values for high dimensional models is not yet available (Houts & Cai, 2015). As an alternative, I considered using Toland et al.'s (2017) strategy for computing information functions for a bifactor model where they allowed the theta for the primary to vary, but set the thetas for the specific factors equal to 0. However, I chose to use additional indices for reliability for alternative models. While reporting Cronbach's alphas for reliability is not recommended (e.g., Reise et al., 2013), the alphas have been included in the analysis for comparison to the CFA- and IRT-based reliability indices.

Investigating Change in STEM literacy.

Using raw scores. Garnering evidence of reliability allowed for a classical test theory (CTT) approach to be used to test the overall difference in STEM literacy. A repeated measures (RM) multivariate analysis of variance (MANOVA) was conducted to test whether the measures of STEM literacy amongst middle school students, specified by the four correlated primary dimensions (science literacy, mathematics literacy, technology literacy, and engineering literacy) identified in the two-tier bifactor model changed after participating in STEM camp. The RM MANOVA was conducted to reflect the effect of the sum of primary factors. Statistically significant MANOVA results were followed up with conducting a repeated measures (RM) univariate analysis of variance (ANOVA) results for each of the primary factors to test the effect for the individual factors. The F statistic associated with the Greenhouse-Geisser correction was reported. The univariate ANOVAs essentially serve as a post hoc investigation of the individual dependent variables (Huck, 2004) but should be interpreted with caution.

Fixed effects calibration. A fixed effects calibration was carried out in flexMIRT (Houts & Cai, 2015). This procedure applies fixed thetas from the pre-survey to the post-survey data. The resulting discrimination parameters for the fixed effects model of post-survey data indicate the average effect of the corresponding primary and specific factor for each item after controlling for person location from the pre-survey on the corresponding factors. As done for the raw scores, a RM MANOVA was performed to find any difference based on the combination of the four primary dimensions.

Limitations. The sample size for this study limits the interpretability of parameter estimates, particularly for more complicated models such as the two-tier model. That is because larger numbers of parameters require larger sample sizes to estimate parameters with accuracy (Embretson & Reise, 2000). However, the two-tier model allows both primary and specific factors to be investigated to understand all potential sources of variance within the model; as such the application of the two-tier is the goal of this study.

Results

The results of the confirmatory factor analyses, including fit indices and factor loadings estimated using WLSMV in *Mplus v.7.11* (Muthén & Muthén, 2013) offer a complex picture of determining an appropriate model to represent STEM-CIS survey data. Starting with pre-survey data, the two-tier bifactor model, specifically Model F, was confirmed as the best fitting model. Calibration of the pre-survey data in IRT resulted in a 34-item modified survey. Model fit assessment suggested the modified pre- and post-surveys performed well under the two-tier model. Additional measures, accomplished using complementary approaches in CFA and IRT, added to the understanding of how the two-tier model performed with pre- and post-survey camp data.

Pre-survey Model Fit and Calibration

Investigating competing models in CFA. None of the fit indices for the tested models fell within more restrictive guidelines offered by Hu and Bentler (1999), with the exception of the RMSEA for the Model F where RMSEA = .058, 90% CI [.054, .061]. However, thinking more flexibly about the meaning of fit indices from a comparative standpoint (Marsh et al., 2004) it was clear Model F had larger TLI and CFI values than competing models (Table 3.2). Based on the fit indices, the best to worst fitting models were generally two-tier bifactor, bifactor, multidimensional, and unidimensional. Based on the fit indices, amongst the two-tier models, Model F performed better than Model G; amongst the multidimensional models, Model C performed better than Model B.

Table 3.2

Confirmatory Factor Analysis Fit Indices for Unidimensional, Multidimensional, Bifactor, and Two-Tier Bifactor Models for 44-item STEM-CIS Pre-survey Data using WLSMV

	#pars	c2	df	TLI	CFI	RMSEA	90% Confidence Interval for RMSEA		WRMR
							LL	UL	
Unidimensional model									
Model A	175	5077.19	902	0.72	0.73	0.11	0.11	0.12	2.94
Correlated traits models									
Model B	185	4425.16	892	0.76	0.77	0.11	0.10	0.11	2.72
Model C	181	2950.00	896	0.76	0.87	0.08	0.08	0.08	2.03
Bifactor models									
Model D	219	3948.01	858	0.78	0.80	0.10	0.10	0.10	2.42
Model E	219	2852.84	858	0.86	0.87	0.08	0.08	0.08	1.92
Two-tier bifactor models									
Model F	225	1863.23	852	0.93	0.94	0.06	0.05	0.06	1.46
Model G	229	2230.72	848	0.90	0.91	0.07	0.06	0.07	1.64

Note. All models were significant, $p < .001$.

Factor loadings. All items loaded saliently on the general factor under the unidimensional model. However, 20 of the 44 items yielded loadings less than .60 (Table 3.3). Items loaded similarly on the general factor to Model A under each of the bifactor models, but more strongly under Model E. For Model D, four items loaded more strongly on the specific factor than the general factor. Three of those four items were part of the sense of community factor for STEM literacy. For Model E, 19 of the 44 items loaded more strongly on the specific factor. This pattern occurred more often for the science, mathematics and technology factors than the engineering factor. Stronger loadings on these STEM subject specific factors for Model E suggest that these specific factors account for the variance more so than the general factor; therefore, additional dimensions to model groups of items may be appropriate. All items loaded strongly on their respective factors under Models B and C. Additionally, factors were positively correlated, suggesting increases in level of one factor is expected to be associated with increased levels in another factor. For example, under Model C, mathematics and science factors, and technology and engineering factors were most strongly correlated with *r* = .671 and *r* = .740, respectively. The loadings on the primary factors for Model F were similar to the loadings for the correlated traits model (Model C). In both cases the latent traits associated with science, mathematics, technology, and engineering are correlated. It makes sense the loadings should be similar for these factors. Model F offers something additional, showing the additional unique contribution of the specific factors. For Model F, all items load more strongly on the respective primary factor than specific factor, except item 32 ("I would feel comfortable talking to people who work in technology careers") and item 43 ("I would feel comfortable talking to people who are engineers"). The loadings for similarly worded items for the mathematics ("I would feel comfortable talking to people who work in mathematics careers") and science ("I would feel comfortable talking to people who work in science careers") factors were minimally different from how strongly they loaded on the specific factor. All four items were included in the set of items I hypothesized to be represented by a latent trait involving sense of community.

While there are some concerns with Model F of how the items load on their respective factors, the specific factors shown an overall contribution to understanding the latent structure of the STEM-CIS, and therefore should be reflected in the model. While the fit indices suggest Model F is the best-fitting model, the items loaded similarly on the four subject specific literacy factors for Model C and Model F. Further comparison of the

Table 3.3

Standardized Factor Loadings for 44-Item STEM-CISM Pre-survey for Model A-Model G

		Model A	Model B					Model C				Model D					Model E					
												Primary	Specific				Primary	Specific				
	Item		PA	AI	SO	SC	FI	S	M	T	E	Gen	S	M	T	E	Gen	PA	AI	SO	SC	FI
Science	1	.57	.65					.70				.51	.49				.58	.39				
	2	.55	.62					.70				.49	.55				.55	.41				
	3	.73		.75				.86				.61	.65				.75		-.24			
	4	.48		.50				.62				.39	.61				.50		-.45			
	5	.67			.69			.81				.61	.51				.70			-.29		
	6	.53					.62	.66				.49	.45				.53					.40
	7	.64		.67				.77				.52	.63				.66		-.24			
	8	.48		.50				.61				.40	.55				.50		-.34			
	9	.54				.66		.67				.54	.29				.51				.32	
	10	.62				.73		.76				.65	.21				.52				.55	
	11	.46					.56	.57				.47	.24				.48					-.20
Mathematics	12	.59	.67						.71			.43		.66			.58	.53				
	13	.63	.73						.77			.45		.72			.62	.60				
	14	.71		.74					.82			.54		.65			.73		-.24			
	15	.64		.66					.78			.50		.62			.66		-.55			
	16	.70			.72				.83			.58		.59			.72			-.25		
	17	.59					.70		.71			.52		.47			.61					.21
	18	.73		.75					.86			.58		.66			.75		-.25			
	19	.55		.57					.68			.40		.63			.57		-.34			
	20	.54				.66			.66			.54		.29			.51				.34	
	21	.70				.82			.82			.71		.26			.60				.52	
	22	.54					.64		.65			.52		.30			.56					-.44
Technology	23	.63	.72							.75		.51			.64		.60	-.60				
	24	.65	.74							.77		.54			.61		.62	-.53				
	25	.69		.71						.80		.56			.63		.64		.50			
	26	.69		.72						.81		.63			.49		.69		.20			
	27	.62			.64					.73		.59			.38		.64			.30		
	28	.50			.51					.61		.44			.48		.51			.40		
	29	.52		.54						.64		.44			.52		.51		.27			
	30	.70		.72						.82		.59			.60		.64		.52			
	31	.50				.61				.61		.50			.30		.46				.35	
	32	.67				.79				.80		.71			.17		.54				.64	
	33	.47					.55			.56		.46			.26		.48					-.39
Engineering	34	.76	.85								.83	.73				.39	.75	-.39				
	35	.79	.88								.86	.76				.42	.79	-.30				
	36	.81		.82							.87	.59				.72	.68		.62			
	37	.74		.76							.83	.77				.23	.75		.12			
	38	.69			.70						.76	.70				.27	.71			.15		
	39	.63					.74				.71	.61				.35	.64					.49
	40	.80		.82							.86	.57				.74	.68		.61			
	41	.69		.71							.76	.63				.47	.67		.37			
	42	.50				.61					.58	.50				.30	.46				.35	
	43	.69				.82					.78	.77				-.01	.57				.64	
	44	.31					.37				.37	.30				.25	.32					-.27

Table 3.3 (Continued)

		Model F										Model G									
		Primary				Specific						Primary						Specific			
	Item	GFS	GFM	GFT	GFE	PA	AI	SO	SC	FI		PA	AI	SO	SC	FI		GFS	GFM	GFT	GFE
Science	1	.70				.33						.59						.47			
	2	.69				.40						.56						.54			
	3	.87					.18						.64					.63			
	4	.65					-.48						.41					.60			
	5	.82						.39						.67				.50			
	6	.67								.45						.60		.47			
	7	.77					.19						.54					.62			
	8	.64					-.24						.42					.54			
	9	.63							.32						.63			.36			
	10	.63							.60						.73			.31			
	11	.60								-.25						.58		.24			
Mathematics	12		.69			.46						.50							.64		
	13		.74			.53						.52							.71		
	14		.83				.19						.58						.62		
	15		.82				-.53						.52						.62		
	16		.84					.34						.64					.58		
	17		.73							.34						.63			.49		
	18		.87				.17						.61						.65		
	19		.70				-.15						.42						.63		
	20		.61						.34						.63				.34		
	21		.70						.62						.79				.36		
	22		.68							-.43						.64			.32		
Technology	23			.75		-.44						.60								.60	
	24			.76		-.35						.62								.59	
	25			.76			.37						.59							.60	
	26			.85			-.11						.67							.47	
	27			.74				.33						.65						.37	
	28			.64				.00						.47						.48	
	29			.66			.03						.47							.50	
	30			.77			.45						.63							.57	
	31			.57					.32						.57					.39	
	32			.65					.69						.80					.29	
	33			.59						-.34						.55				.33	
Engineering	34				.85	-.20						.84									.32
	35				.88	-.03						.87									.33
	36				.76		.55						.64								.68
	37				.87		-.15						.83								.15
	38				.78			.33						.78							.22
	39				.73					.56						.76					.37
	40				.75		.54						.63								.68
	41				.76		.19						.67								.43
	42				.55				.32						.56						.49
	43				.64				.66						.86						.14
	44				.39					-.27						.33					.40

Notes. Gen = General Factor, GFS = General Factor Science, GFM = General Factor Mathematics, GFT = General Factor Technology, GFE = General Factor Engineering, S = Science, T = Technology, E = Engineering, M = Mathematics, PA = self-efficacy/perception of ability (12 items), AI = attitude and interest (willingness to engage, consideration of science career belief, disposition; 32 items), SO = role and utility of math in society (10 items), SC = sense of community (16 items), and FI = family influence (14 items) two models in IRT involved correlations between the four latent traits estimated using EAP method (Table 3.4). While similar correlations between EAP scores indicate reasonableness of Model C in modeling the STEM-CIS data, for the purpose of this study the addition of specific factors to the model helped understanding of contribution of factors related to STEM literacy above and beyond the general literacy factors for the individual STEM disciplines.

Table 3.4

A Comparison of Correlations Between EAP Scores Under the Four-factor Correlated Traits Model and Two-Tier Bifactor Model for Pre-Survey STEM-CIS

	Model C				Model F			
	S	M	T	E	S	M	T	E
(S) Science	1				1			
(M) Mathematics	0.69	1			0.66	1		
(T) Technology	0.51	0.55	1		0.48	0.51	1	
(E) Engineering	0.63	0.59	0.80	1	0.61	0.57	0.77	1

Notes. Model C = correlated traits model where four correlated factors defined by the four STEM subjects, Model F = two-tier bifactor model consisting of four STEM subject primary factors and five specific factors defined by components associated with STEM literacy, S = science literacy, M = mathematics literacy, T = technology literacy, E = engineering literacy.

Calibration of Model F under an IRT framework. 11 items yielded LD statistics with an absolute value greater than 10 suggesting potential violations of local independence assumption of IRT modeling. Notably, clusters of item pairs exhibiting large residual covariance occurred largely in relation to the mathematics and science items, and for items across the four STEM domains where similar wording was used. Large residual covariance's indicated by large LD statistics suggest a number of items may be related to each other. The sensitivity analysis occurred in three steps to improve the performance of Model F for the pre-survey data. First, three items were removed: two items from sense of community factor-item 20 (“I have a role model in a mathematics career”) and item 31 (“I have a role model who uses technology in their career”), and one item from the family influence factor, item 44 (“I know someone in my family who is an engineer”). The instrument was recalibrated with the three items removed, yielding a RMSEA = .05, 90% CI [.05, .06], and CFI = .95.

A second iteration of item removal was done for item pairs whose local dependency issues were not resolved. Three additional items were removed, two from the family influence factor, item 6 (“My parents would like it if I choose a science career”) and item 17 (“My parents would like it if I choose a mathematics career”), and one item from self-efficacy/perception of ability, item 2 (“I am able to complete my science homework”). The instrument was recalibrated with the additional three items removed, yielding a RMSEA = .05, 90% CI [.04, .05] and CFI = .96.

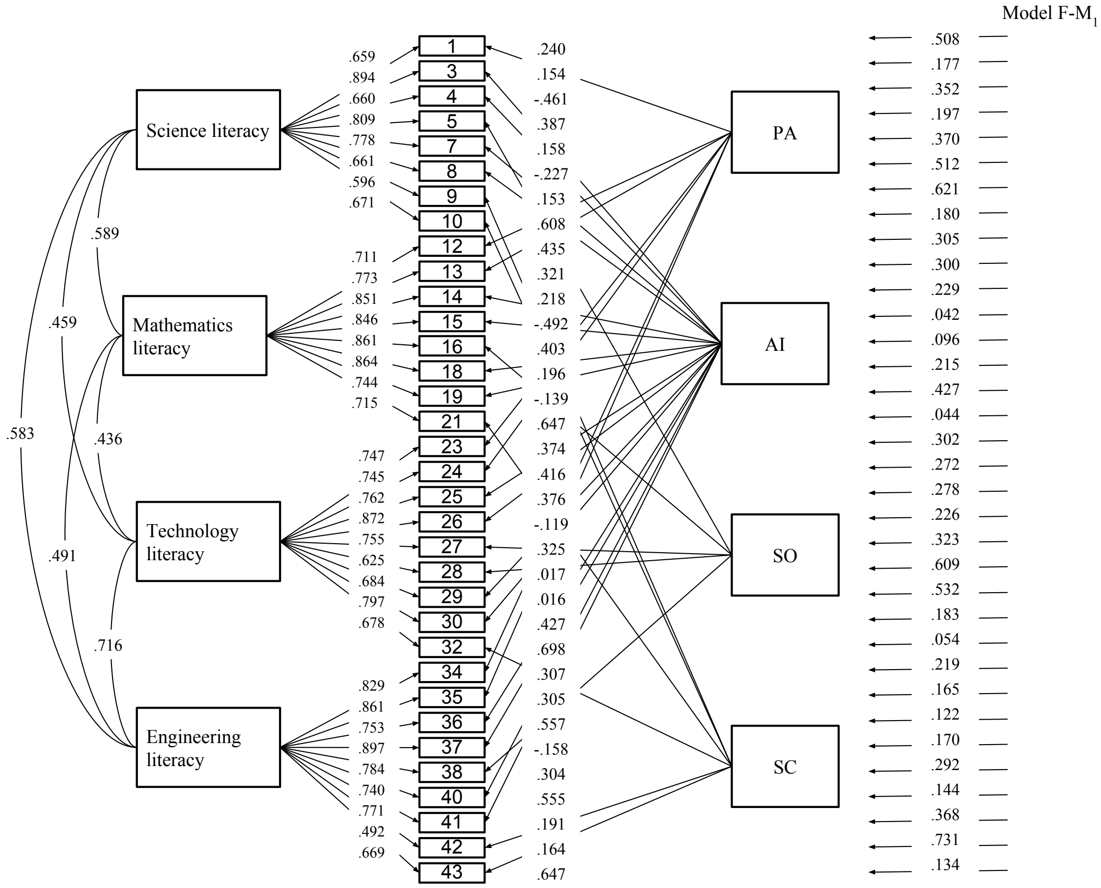
A third iteration of item removal was done, removing the remaining four items from the family influence factor, thus eliminating one of the five specific factors. The CFA results for the two-tier bifactor model with four primary and four specific factors yielded fit indices, RMSEA = .05, 90% CI [.05, .06], and CFI = .97, that suggest good fit. While there was minimal difference from previous recalibration, the final 34-item modified STEM-CIS (STEM-CISM) reflects the resolution of multiple violations of local dependency and removal of a specific factor that did not fit the construct, namely the family influence factor. While family influence may have made theoretical sense from a SCCT standpoint as intended by the designers of STEM-CIS, using the STEM-CIS to assess STEM literacy required an alternative conceptual perspective in which family influence items are not relevant to the construct of interest.

Assessing STEM-CISM for Pre- and Post-Survey Data

The two-tier bifactor model of the STEM-CISM consisting of four primary factors (science, mathematics, technology, engineering) and four specific factors (perception of ability/self-efficacy, attitude and interest, role and utility in society, sense of community) was fitted to pre- and post-survey data.

CFA results. A CFA was conducted on the 34-item STEM-CISM for pre- and post-survey data using *Mplus v.7.11* (Muthén & Muthén, 2013). For the modified pre-survey data, $\chi^2(487) = 918.56$, CFI = 0.96, TLI = 0.97, RMSEA = 0.05, 90% CI [.05, .06]. For the modified post-survey data, $\chi^2(487) = 1062.27$, CFI = 0.97, TLI = 0.96, RMSEA = 0.06, 90% CI [.05, .06] and WRMR = 1.26 indicating the items continue to perform somewhat well under two-tier bifactor model for the STEM-CISM. Factor loadings, residual variance, and covariance of primary factors for the pre- and post-survey are displayed in Figure 3.2. The results of the factor loadings are consistent with CFA results for the post-survey data consisting of the calibrated 44-item STEM-CISM.

IRT results. Nonsignificant values of the $S\text{-}\chi^2$ statistic (Orlando & Thissen, 2000, 2003) for all pre-survey items except item 23 ("I am able to do well in activities that involve technology") suggest the two-tier model fit the STEM-CISM data well, and reinforces conclusions of fit assessment from the previous CFA. Two of the 34 post-survey items ("I like my mathematics class" and "I am interested in careers that use technology") showed poor fit as indicated by $S\text{-}\chi^2$ values, $p < .05$ (Orlando & Thissen, 2000, 2003). All potential violations to the LI assumption, as indicated by large standardized LD χ^2 values, were resolved with the pre-survey STEM-CISM data. The number of LD pairs greater than 10, went from 17 to 7 by testing the two-tier bifactor model on the STEM-CISM post-survey data.



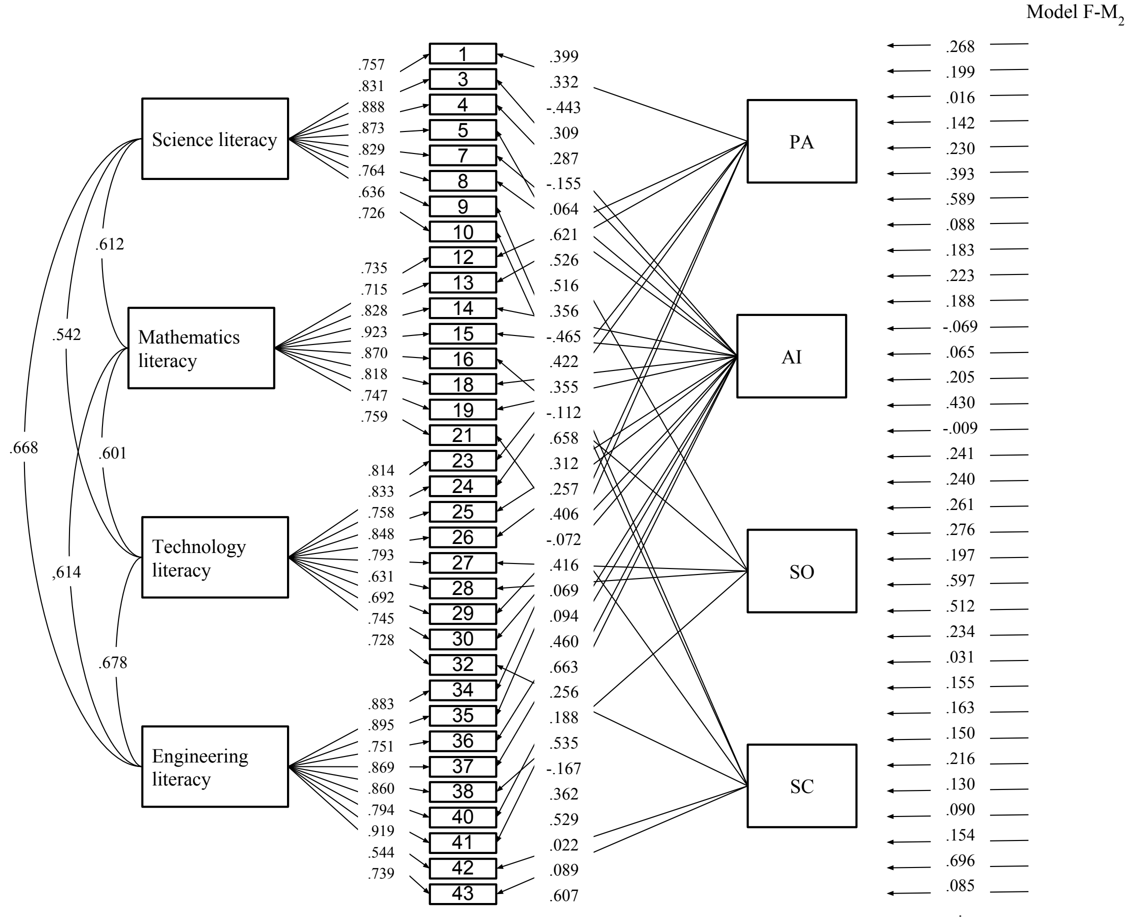


Figure 3.2. Confirmatory factor analysis for STEM-CISM. Model F-M$_1$ = two-tier bifactor model for pre-survey data; Model F-M$_2$ = two-tier bifactor model for post-survey data.

Item Behavior

The discrimination parameters for each primary dimension exceed 1 for the most part. Item 42 ("I would feel comfortable talking to people who are engineers") was the least discriminating item overall on the pre- and post-survey. Item parameter estimates are displayed in Table 3.5. Items that connect directly to the formal classroom setting (i.e., "I am able to get a good grade in my science class") were the least discriminating on the pre-survey, but were shown to be more discriminating for the post-survey. This could be a preliminary indication that students feel they are able to do better in the mathematics and science classes after participating in STEM camp. For the specific factors, the most discriminating items for the specific factors related to attitudes and interest, and sense of community. The least discriminating specific factor for the mathematics literacy was perception of ability/self-efficacy, the remaining three specific factors for this primary discriminated well among students with different levels of the latent trait. For the primary factors, mathematics literacy items and engineering literacy items were the most discriminating as primary factors. I identified the specific factors related to attitudes and interest, and sense of community as the most discriminating. However, given the broad range of discrimination parameters on the specific factors, I do so with hesitation. Interestingly, on the post-survey, for the primary factor related to technology literacy, I observed low discriminatory power for those items on their respective specific factor. In other places, discrimination parameters were generally consistent from pre- to post-survey.

Table 3.5 also shows the item category thresholds for 34 items for modified pre- and post-survey. However, it is not possible to distinguish between the influence of the primary and specific factor on item difficulty when interpreting thresholds for Model F. The results discussed are intended for an overall picture to inform future conversations. Among the threshold values, the first threshold for item 1 ("I am able to get a good grade in my science class") was strikingly different from other items. Upon examination of student responses, the extremely low threshold made sense because no students responded *strongly disagree*, 14 responded *disagree*, 157 responded *agree*, and 173 responded *strongly agree* to item 1. Two decisions that could be made include collapsing response categories for this item, or rewording the item to more accurately measure student latent levels. However, given the participants are middle school students, the

Table 3.5

Discrimination Parameters and Thresholds of the STEM-CISM

	Presurvey							
	Discrimination Parameters					Thresholds		
	Primary Factor	Specific Factors						
Item		PA	AI	SO	SC	b_1	b_2	b_3
Science Literacy								
1	1.55	0.24				-28.22	-2.33	0.24
3	3.98		0.99			-1.42	-0.34	0.72
4	1.75		-1.05			-3.63	-2.88	-0.15
5	3.29		0.00	1.61		-2.18	-0.85	0.36
7	2.83		0.85			-1.52	-0.53	0.82
8	1.52		-0.35			-2.27	-1.49	0.30
9	1.26				0.22	-1.74	0.17	1.62
10	2.18				2.21	-1.69	-0.67	0.82
Mathematics Literacy								
12	1.95	0.39				-2.88	-2.06	-0.12
13	2.34	0.06				-2.56	-1.94	-0.27
14	3.23		1.16			-1.70	-0.83	0.32
15	3.19		-1.51			-2.52	-2.10	-0.42
16	3.85		0.00	2.22		-2.47	-1.25	0.17
18	3.63		1.21			-1.32	-0.53	0.70
19	2.12		-0.14			-2.25	-1.29	0.22
21	3.09				3.34	-1.52	-0.80	0.58
Technology Literacy								
23	2.66	1.47				-2.29	-1.53	0.09
24	2.98	1.94				-2.33	-1.75	0.03
25	2.93		1.26			-2.09	-0.85	0.25
26	2.92		-0.44			-3.21	-1.46	0.19
27	2.02			0.36		-2.56	-1.69	-0.05
28	1.44			0.17		-3.63	-1.25	0.73
29	1.94		-0.12			-2.09	-1.26	0.30
30	3.99		1.91			-1.57	-0.65	0.39
32	2.3				2.78	-1.71	-0.84	0.58
Engineering Literacy								
34	3.18	1.51				-1.93	-0.99	0.52
35	4.07	1.48				-2.04	-1.19	0.50
36	4.27		2.65			-1.37	-0.23	0.66
37	3.35		-0.77			-2.35	-1.59	0.14
38	2.32			0.52		-2.40	-1.17	0.27
40	3.73		2.27			-1.31	-0.31	0.64
41	2.86		0.41			-1.74	-1.06	0.42
42	0.95				0.26	-2.18	0.20	1.60
43	2.23				2.50	-1.55	-0.70	0.60

Table 3.5 (Continued)

	Postsurvey							
	Discrimination Parameters					Thresholds		
	Primary Factor	Specific Factors						
Item		PA	AI	SO	SC	b_1	b_2	b_3
Science Literacy								
1	2.54	1.35				-2.28	-1.90	0.17
3	4.24		1.49			-1.16	-0.31	0.62
4	2.75		-1.74			-2.42	-1.82	-0.11
5	4.38		0.00	1.67		-1.41	-0.68	0.41
7	4.17		1.29			-0.95	-0.28	0.66
8	2.06		-0.69			-1.90	-1.22	0.27
9	1.63				0.19	-1.47	-0.03	0.90
10	2.48				2.78	-1.43	-0.66	0.51
Mathematics Literacy								
12	2.79	1.91				-2.07	-1.65	-0.04
13	3.10	2.43				-2.08	-1.63	-0.06
14	3.65		1.31			-1.24	-0.58	0.44
15	3.73		-1.98			-2.25	-1.89	-0.28
16	4.59			2.81		-1.58	-1.00	0.16
18	4.33		1.71			-1.01	-0.35	0.63
19	2.42		-0.40			-1.62	-1.05	0.16
21	2.23				2.51	-1.42	-0.71	0.47
Technology Literacy								
23	2.56	0.55				-2.19	-1.54	0.19
24	3.29	0.54				-1.91	-1.42	0.19
25	3.25		1.44			-1.30	-0.68	0.24
26	2.9		-0.13			-1.60	-1.17	0.29
27	2.42			0.57		-2.16	-1.33	0.04
28	1.43			0.12		-2.54	-1.24	0.55
29	1.99		0.31			-1.80	-1.16	0.23
30	3.87		1.98			-1.18	-0.53	0.38
32	2.97				3.40	-1.50	-0.76	0.24
Engineering Literacy								
34	3.90	0.78				-2.14	-1.25	0.32
35	4.72	0.78				-1.86	-1.15	0.33
36	4.14		2.8			-1.01	-0.17	0.67
37	3.88		-0.59			-1.79	-1.42	0.21
38	3.58			0.93		-1.63	-0.96	0.19
40	5.95		3.68			-0.88	-0.21	0.57
41	5.04		0.46			-1.28	-0.83	0.43
42	1.07				0.26	-2.05	-0.27	0.98
43	2.96				3.07	-1.40	-0.71	0.39

former decision could cause greater confusion in completing the survey (i.e., different response formats for different items). The second thresholds provided information of how difficult it was for an individual to endorse an item by selecting agree or strongly agree, given the level of the latent trait for an individual. Results indicate that the second threshold items were higher on the post-survey than the pre-survey with the exception of item 9 ("I have a role model in a science career"), item 23 ("I am able to do well in activities that involve technology"), item 43 ("I would feel comfortable talking to people who are engineers") and item 44 ("I know someone in my family who is an engineer"). This means for the post-survey, students generally needed higher levels of latent trait with respect to the corresponding primary and specific for a given item to select *agree* or *strongly agree*, than was needed for the pre-survey.

The results discussed are intended for an overall picture to inform future conversations. Grouping by primary factors, more difficult items for the pre- and post-survey were associated with engineering and science than mathematics and technology. For the pre-survey, the items with the highest second thresholds were item 42 ("I would feel comfortable talking to people who are engineers"), item 9 ("I have a role model in a science career"), and item 36 ("I plan to use engineering in my future career"). The five items with the largest second threshold for the post-survey were item 9, item 38 ("If I learn a lot about engineering, I will be able to do lots of different types of careers"), item 41 ("I like activities that involve engineering"), item 42, and item 7 ("I have a role model in a science career"). In general, the more difficult items dealt with student attitudes and interest and sense of community. Specifically, they were items that characterized student willingness to engage in STEM-related activities, namely pursuing a STEM career and those related to interactions with STEM professionals. Two of the items identified by the attitude and interest latent trait were the easiest items to respond agree or strongly agree. Those were item 4 (“If I do well in science classes, it will help me in my future career”) and item 15 (“I will work hard in my mathematics classes”) on the pre-survey; and item 1 (“I am able to get a good grade in my science class”) and item 15 on the post-survey. Looking back at post-survey student responses, 330 of the 344 (95.9%) students responded agree or strongly agree to item 1. This result was interesting because a number of items that related directly to aspects of formal school were less discriminating than other items.

Reliability

CFA and omega reliability. The omega, omegaH, and relative omegas for each specific factor on the corresponding primary factor are shown in Table 3.6, and provide evidence of reliability in the measure, and in using raw score totals to statistically test the difference between pre- and post-survey total scale scores for each primary factor. 92.0%, 96.2%, 94.3%, and 95.5% of the variance in total pre-survey scores can be attributed to the science, mathematics, technology, and engineering literacy factors, respectively. Even larger omegas were found for the post-survey survey scores. High omegaH for each primary factor relative to omegaHS for each corresponding specific factor suggests total scores can be interpreted as presenting the target construct. For example, 89.5% of the total score variance modeled on the modified pre-survey is due to the science literacy primary factor, 5.6%, 1.3%, 15%, and 1.9% to variation from self-efficacy, attitude and interest, role and utility in society, and sense of community, respectively. For

Table 3.5

Reliability Measures for STEM-CISM Pre- and Post-Survey Data

	Classical Test Theory		Confirmatory Factor Analysis														Item Response Theory	
	Cronbach's alpha		Omega/OmegaS[a]		OmegaH/OmegaHS[a]		Relative Omega[a]		OmegaHS[a]								Empirical Reliability	
									PA		AI		SO		SC			
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Two-tier bifactor model																		
S1			.92	.96	.90	.94	.97	.98	.06	.16	.01	.00	.15	.10	.19	.16	.86	.87
M1			.96	.97	.93	.93	.97	.96	.17	.30	.00	.00	.16	.18	.45	.43	.86	.85
T1			.94	.95	.91	.92	.96	.96	.18	.09	.04	.07	.04	.08	.49	.45	.85	.84
E1			.96	.97	.89	.94	.93	.97	.10	.05	.17	.07	.09	.13	.23	.17	.88	.87
Four Factor Multidimensional model																		
S1			.90	.93													.90	.86
M1			.94	.94													.91	.84
T1			.92	.93													.91	.85
E1			.94	.96													.93	.88
Four unidimensional models																		
S1	.84[b]	.87	.90	.93													.84	.85
M1	.88	.86	.94	.94													.84	.80
T1	.87	.87	.92	.94													.83	.80
E1	.88	.90	.94	.95													.87	.85
Bifactor model[c]																		
F			.98	.99	.78	.87	.80	.89									.85	.85
S1			.91	.93	.45	.32	.50	.34									.70	.73
M1			.90	.95	.45	.40	.50	.40									.71	.66
T1			.95	.93	.48	.38	.50	.38									.67	.69
E1			.99	.96	.50	.24	.50	.24									.74	.75

Note. F = primary STEM literacy latent trait; S1 = science literacy latent trait; M1 = mathematics literacy latent trait; T1 = technology literacy latent trait; E1 = engineering literacy latent trait.

[a] Omega reliabilities for the four factor multidimensional model and four unidimensional models were calculated using *Mplus v.11* (Muthén & Muthén, 2013); Omega reliabilities for the two-tier bifactor model and bifactor model were calculated using Dueber's (2016) bifactor calculator; both of which use formulae for omega from Rodriguz, Reise, and Haviland (2016).

[b] Cronbach's alpha calculated for the raw pre- and post-survey items are not model dependent.

[c] For the bifactor model, F represents the primary factor; S1, M1, T1, and E1 represent specific factors.

mathematics, technology, and engineering, sense of community contributed strongly to the total score variance modeled on the modified pre- and post-survey. The omegaHS for sense of community was unacceptably high for all primary factors, suggesting sense of community as a latent structure should be reconceptualized. These results are displayed in entirety in Table 3.5 for the modified pre- and post-survey.

Empirical reliability in IRT. The EAP scores of the four subject specific STEM literacy dimensions for the pre-survey estimated using the two-tier bifactor model range from -3.04 to 2.30 (*M* = 0.25, *SD* = 0.93) for science literacy, -3.11 to 2.09 (*M* = 0.21, *SD* = 0.95) for mathematics literacy, -3.28 to 2.16 (*M* = 0.28, *SD* = 0.93) for technology literacy, and -3.21 to 2.36 (*M* = 0.31, *SD* = 0.94) for engineering literacy.

For the science literacy scale, the standard errors computed using the EAP method and the variance of the EAP observed scores yield an empirical probability of .86 ($\rho = 1 - (.12/.86)$). For the mathematics literacy scale, the computed standard errors yield an empirical probability of .86 ($\rho = 1 - (.12/.90)$). For the technology literacy scale, the empirical probability is .85 ($\rho = 1 - (.12/.85)$). For the engineering literacy scale, the empirical probability is .88 ($\rho = 1 - (.12/.88)$).

The empirical reliabilities for each of the four primary dimensions for the STEM-CISM post-survey are similar to pre-survey values (Table 3.5). Notably, the range of observed scores is narrower on the post-survey than pre-survey; this difference is accounted for by the higher minimum theta and lower maximum theta for all four factors. The mean score is higher for each primary dimension on the post-survey than the pre-survey. There is a difference in the reliability estimates in CFA and IRT. This difference is expected as described by Brown (2014). Brown (2014) warned against the use of a single index for reliability in IRT due to potential issues with measurement precision arising from Bayesian estimation of observed scores and standard errors.

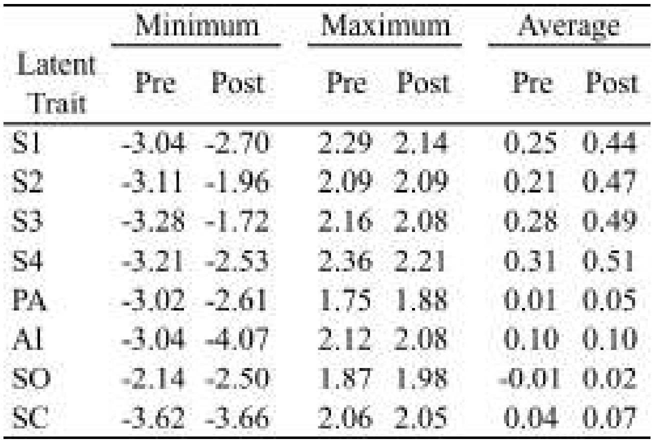
Investigating Change in STEM literacy

Raw score. A RM MANOVA was conducted to compare pre- and post-survey responses with respect to the multiple dependent variables — science literacy score, mathematics literacy score, technology literacy score, and engineering literacy score — which form the overall measure. The results from RM MANOVA indicate there is a statistically significant multivariate effect for the relationship, Hotelling's T^2, $F(3, 341) = 49.41$, $p = .006$. The RM ANOVA with a Greenhouse-Geisser correction results for this relationship indicate there is a statistically significant difference between pre- and post-survey for mean science literacy score, $F(1, 343) = 23.79$, $p < .001$, $\eta^2 = .065$, mean mathematics literacy score, $F(1, 343) = 12.69$, $p < .001$, $\eta^2 = .03$, mean technology literacy score, $F(1, 343) = 96.750$, $p < .001$, $\eta^2 = .047$, and mean engineering literacy, $F(1, 343) = 42.76$, $p < .001$, $\eta^2 = .111$. We can conclude that a one-week STEM camp positively effects middle school students' STEM literacy with respect to the four individual STEM subjects, treated as separate univariate measures, and as a single multivariate measure.

Fixed effects. Table 3.7 presents the descriptives for item parameter estimates contrast between pre-survey and post-survey. Discrimination parameters for post-survey are generally larger than those given by the fixed effects calibration.

Table 3.7

Descriptives for EAP estimated observed scores on pre- and post- STEM-CISM (N=344)



Latent Trait	Minimum		Maximum		Average	
	Pre	Post	Pre	Post	Pre	Post
S1	-3.04	-2.70	2.29	2.14	0.25	0.44
S2	-3.11	-1.96	2.09	2.09	0.21	0.47
S3	-3.28	-1.72	2.16	2.08	0.28	0.49
S4	-3.21	-2.53	2.36	2.21	0.31	0.51
PA	-3.02	-2.61	1.75	1.88	0.01	0.05
AI	-3.04	-4.07	2.12	2.08	0.10	0.10
SO	-2.14	-2.50	1.87	1.98	-0.01	0.02
SC	-3.62	-3.66	2.06	2.05	0.04	0.07

The items were able to distinguish between levels of the latent trait more for post-survey data estimated without pre-survey calibration. The results of the RM MANOVA to test the multivariate effect for the relationship between post-survey observed scores conditioned pre-survey calibration of observed scores and the post-survey score were not statistically significant, Hotelling's T^2, $F(3, 341) = 1.208$, $p = .307$, $\eta^2 = .111$. Therefore, we fail to reject the null hypothesis that there is no difference in the population mean of latent ability of the four dependent variables — science literacy, mathematics literacy, technology literacy, and engineering literacy — between the fixed effect post-survey scores and post-survey scores. We can conclude there is not enough evidence to suggest statistically significant gains in STEM literacy amongst middle grades students.

Discussion, Limitations, and Recommendations

Discussion

STEM literacy has been identified as a priority in education (e.g., DOE, 2016) to prepare an increasingly technological workforce (e.g., Bybee, 2010). Improving STEM education to help all students achieve STEM literacy has been a focus for K-12 stakeholders, yet how we interpret the levels of STEM literacy being reached by students is unclear. To achieve STEM literacy, it is vital to understand its meaning, and how it can be assessed in different contexts. No such scale appears to exist where an integrated perspective of STEM and STEM literacy is taken. For instance, items on the STEM-CIS (Kier et al., 2014) and T-STEM (Friday Institute for Educational Innovation, 2012) instruments approach STEM subjects from a siloed perspective. In this paper, STEM literacy was explored as a general latent trait, as the composite of science, mathematics, technology, and engineering, and in terms affective and social components related to STEM literacy (perception of ability/self-efficacy, attitudes and interest, role and utility in society, and sense of community). The STEM-CIS was originally intended as an instrument to measure STEM career interest (Kier et al., 2014); however, by reconceptualizing the STEM-CIS, I have argued for an opportunity to use it as a tool for assessing particular aspects of STEM literacy using a two-tier bifactor model, where STEM literacy is defined as,

> The "conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (Bybee, 2010, p. 31); the ability to engage in STEM specific discourse; a positive disposition toward STEM (e.g., Wilkins, 2000, 2010, 2015), including a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015); an understanding of the utility of applying STEM concepts to solve real world problems; and, an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change. (Chapter 2)

I viewed the two-tier model as an amalgamation of the bifactor and correlated traits models, but did not reflect the correlation between the primary factors in calculations of reliability indices. I attempted to supplement that aspect of the analysis by reporting on reliability of competing models.

The purpose of this paper was twofold. First, I used psychometric methods to confirm the reasonableness of using a two-tier bifactor model for data generated from administration of STEM-CIS in an informal learning environment, namely a summer STEM camp for middle school students. This was accomplished by conducting CFAs on competing models. I moved to an IRT framework to calibrate STEM-CIS for the two-tier case. The resulting 34-item STEM-CISM was shown to perform well for the pre- and post-survey data, but not without concerns. Doing so provided a picture of the relationship between STEM subjects and aspects which comprise STEM literacy that may be added in assessing STEM literacy in informal contexts.

Second, I used statistical procedures to show the difference between pre- and post-survey responses were statistically significant, where the four primary factors in the model were treated as four dependent variables taken together. While I garnered evidence for performing a RM MANOVA using the high omega reliability in CFA, I made assumptions about the applicability of omega calculations to the two-tier case. Reise (2012) and Rodriguez et al. (2016) used omegas obtained from bifactor models, in part, to interpret a summed score total. I understand correlation between primary factors could impact reliability of measurement, and thus interpretability of raw scores. The RM MANOVA results using raw scores indicated a significant difference between pre- and post-survey. As a preliminary conclusion, STEM camp was shown to change student levels of STEM literacy both in terms of individual STEM subjects and as an overall measure.

Under the confirmed two-tier bifactor model, the primary dimensions were moderately correlated (Figure 3.2), indicating the primary factors were related but not identical. Correlations were obtained in CFA using polychoric correlations. This was not surprising, but it does suggest students may not distinguish between STEM disciplines when responding to some items. This issue was most prevalent between mathematics and science items, and more specifically among items related directly to performance in the formal school setting such as “I can get good grades in mathematics” and “I can get good grades in science”.

The latent trait I identified as sense of community was represented by the data differently than I expected. I viewed items about having role models and feeling comfortable talking with STEM professionals as peripheral to the ability to engage in STEM specific discourse, which I identified in the operational definition of STEM literacy for this paper. The analysis suggests the set of items defined by sense of community as a specific factor may have a strong enough contribution to the overall latent structure of the STEM-CISM. Students more readily endorsed item 9 (“I have a role model in a science career”), and item 42 (“I have a role model in an engineering career”) on the pre-survey than the post-survey as evidenced by the thresholds. Both items involve students identifying the extent to which they have a role model in science and engineering, respectively. They were also two of the most difficult items for both surveys. It may be a good choice to have an item “I have a role model in a STEM career” rather than distinguishing between subjects. If the purpose is to develop STEM literacy, then to measure sense of community as a way for students to engage in STEM, and, thus develop STEM literacy, then sense of community related to STEM could be reflected more holistically in future designs of the STEM-CIS. Four testlet-based items with the sentence stem, “I would feel comfortable talking to people who work in… careers” loaded on the specific factor similar to, if not higher than, their individual loadings on their respective primary factor. The reliability measures provided additional evidence of possible misidentification of sense of community as a specific factor. Students with higher levels of latent traits related to primaries tended to have higher levels of latent traits related to sense of community items as evidenced by EAP scores on the pre- and post-survey.

Items related to attitude and interest were more discriminating on the primary related to engineering than the other primary dimensions. This is understandable considering students bring a range of experiences to camp. While all students have requirements to take mathematics and science during the academic school year, the same is not true for technology and engineering. I expected the technology factor to behave in a similar way, but it did not. Interestingly, the loading of items on specific factors within the technology primary factor was similar to mathematics and science. I had overlooked the daily informal interactions students have with various technologies. I suspect students have preconceptions of technology, and are often times so inundated with technology in their everyday lives that they are generally more able to endorse survey items related to technology. Across the primary factors, mathematics and technology items tended to have lower second thresholds than engineering and science items, with some exceptions, namely two science items with the lowest second threshold among all items.

There is much to understand about how student STEM literacy can arise in an informal learning environment. This analysis aimed at preliminary work to use data generated from the STEM-CIS to begin to understand how STEM literacy can be assessed in the context of a summer STEM camp. I approached this problem by investigating the performance of a newer measurement models in CFA and IRT, namely the two-tier bifactor model. This analysis has led me to consider further how the limitations of my study impact the conclusions I have made around measuring STEM literacy using the STEM-CISM. Additionally, I offer recommendations for next steps in assessing STEM literacy quantitatively.

Limitations

Important limitations to this study include small sample size and an absence of fit statistics specific to the two-tier bifactor model. The small sample size makes it difficult to interpret parameter estimates with confidence (de Ayala, 2009; Embretson & Reise, 2000), especially for the two-tier case where a large number of parameters were estimated. Additionally, small sample sizes can result in sparseness in the data. I had hoped to use this psychometric evaluation to create a short form of the STEM-CIS. I was able to reduce the pool of items from 44 to 34, but it is not enough. The sample size (N = 344) coupled with the large number of items led me to interpret the factor structure associated with STEM literacy with caution. There are a variety of guidelines offered for minimum sample size for reliable parameter estimates (MacCallum, Widaman, Zhang, & Hong, 1999). Muthén and Muthén (2002) pinpointed the potential issue with sample size stating, “A sample may be large enough for unbiased parameter estimates, unbiased standard errors, and good coverage, but it may not be large enough to detect an important effect in the model" (p. 599). Beyond sample size, the factor structure I confirmed was among the most complex models. This presented a challenge because I aimed to present an application of the two-tier model, but, in doing so, rejected more parsimonious models. The reader must weigh the stability of parameter estimates with the comparative model fit assessment to determine whether I effectively defended my choice of the two-tier bifactor model.

Our limited knowledge of the two-tier bifactor model led to additional limitations of the study. Cai (2010a) and Bonifay (2015) have identified a need to develop fit indices and limited-information goodness-of-fit statistics for the two-tier case. Thus far, the general approach has involved extending indices, diagnostics, and statistics for the bifactor solution to the two-tier bifactor model. Cai and Hansen (2013) investigated an alternative M_2^* limited information goodness of fit statistic for polytomous data, and found the statistic performed well. However, its performance for high dimensional models is still unknown. Additionally, limited-information goodness-of-fit statistics are not available in flexMIRT when MH-RM estimation is used, but MH-RM is the more appropriate choice for more complex models. Total information functions are recommended for evaluating reliability in IRT (Brown, 2014), but have not been conceptualized for the two-tier case. Techniques for calculating information functions for the bifactor model (Toland et al., 2017) may inform future applications to the two-tier model. I was aware of many of these limitations from the start and attempted to garner evidence for the two-tier bifactor model by using a number of indices, statistics, and diagnostics available when both CFA and IRT frameworks are used.

Recommendations

I think the results of the two-tier bifactor modeling can inform efforts to design a new scale for STEM literacy. I touched upon some considerations to make for the future design of the STEM-CIS above. Other aspects of the instrument that could aid in the process involves item wording. The items on the STEM-CIS are all positively worded. As a result, opportunities for construct validity were missed, but could be the focus of changes to the instrument. The reading level is appropriate for middle school students, but greater variation in the phrasing and fewer testlet-based items could resolve some concerns over the limitations of the instrument in its current form. I would additionally recommend the creation of items that incorporate the term “STEM” rather than strictly “science”, “mathematics”, “technology” and “engineering” whenever possible. A number of items for the original STEM-CIS exhibited large covariance, which suggested redundancy of items. STEM literacy, in part, involves an understanding of the use of the word “STEM” in society, and, therefore, pursuing “STEM” as a single term is valuable. The items “If I do well in … it will help me in my future career” were represented well by the latent structure. I suspect they would continue to add to the understanding of STEM literacy in future scale development around measuring STEM literacy.

The sensitivity analysis resolved violations of local dependency, but the CFA and IRT results do not suggest the STEM-CISM fully or accurately measures the intended construct under the two-tier bifactor model. The coordination of psychometrics and theory can aid in scale development. De Ayala recommended that, “To facilitate designing an instrument with specific estimation properties, we can specify *a target total information function* for the instrument” (2009, p. 33). I did not address total information function for the two-tier bifactor model, but, with a less complex model, I believe heeding de Ayala's recommendation could help align what is intended by the instrument with greater precision of the measurement for items.

The STEM-CIS can guide future work to develop an instrument to measure STEM literacy, as a complex construct across integrating subject domains and psychological components. Considering the presence of redundancy in measuring the construct for various item quadruplets, it is recommended that modifications to the STEM-CIS instrument go further than the 34-item STEM-CISM proposed in this paper to include consolidation of items. For instance, instead of four items such as "If I learn a lot about …, I will be able to do lots of different types of careers," if a revised item such as "If I learn a lot about STEM, I will be able participate in different types of careers" were included, then the latent trait related to role and utility of STEM in society could be more accurately measured. It appeared respondents did not distinguish between STEM subjects for all items; hence, the strong presence of shared variance on factors for items having similar wording.

Future Research

Further scale development and psychometric evaluation are, I think, are needed to create a quantitative survey that can reliably measure student STEM literacy. I have previously outlined some considerations that could be made in developing items. The scale development can be guided by literature on the topic (e.g., Benson & Clark, 1982; DeVellis, 2011). Additionally, future studies could involve investigation of group differences in STEM literacy amongst student participants, particularly potential differential item functioning (DIF) in gender, race/ethnicity, or grade level. I have an interest in understanding the impact of informal learning environments for populations that have been historically represented in STEM fields, but could not pursue such an evaluation from a measurement standpoint due to sizes of the groups of interest. Research on the impact of sample size on the ability to detect DIF has traditionally indicated that larger sample sizes are better (Li, 2015; Narayanan & Sawminathan, 1994; Swaminathan & Rogers, 1990). For Narayananand Sawminathan's analysis of various procedures to detect DIF for small sample sizes, sample size of 300 for each group was sufficient for reasonably detecting DIF (1994, p. 326). To meet this suggested minimum, a total sample size of 1250 is needed, given 25% of camp participants identify as an underrepresented minority and approximately 40-45% identify as female each year. While this work applies an approach that has recently been investigated for accuracy (Lee, 2017), it may be the case that more data is needed for more reliable interpretation of DIF results.

CHAPTER IV

ARTICLE 3: EMERGING STEM LITERACY: A DISCOURSE ANALYSIS OF STUDENT REFLECTIONS AT STEM CAMP

STEM literacy has been identified as a national priority (e.g., Asunda, 2012; Department of Education, 2016; National Research Council, 2011), namely in preparing a STEM-literate workforce (The Committee on STEM Education National Science and Technology Council, 2013). *STEM 2026* (DOE, 2016) offers a vision for improving STEM education, helping all students achieving STEM literacy in the United States. Questions must be addressed to achieve such a vision. How do you know when a student achieves STEM literacy? What contexts support the development of STEM literacy?

Definition of STEM Literacy

For this paper, I draw on a holistic integrated perspective of STEM literacy. I adopt the definition of STEM literacy I developed in Chapter 2. I define STEM literacy as the "conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (Bybee, 2010, p. 31); the ability to engage in STEM specific discourse; a positive disposition toward STEM (e.g., Wilkins, 2000, 2010, 2015), including a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015); an understanding of the utility of applying STEM concepts to solve real world problems; and, an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change. STEM literacy develops along a continuum. By engaging in STEM literacy practices in authentic environments, individuals become more STEM-literate; their level of literacy increasingly reflects that of an expert in STEM. Within a given context at a specific point in time, students who exhibit *emerging STEM literacy* place themselves in a position to engage in STEM related activities (i.e., attending STEM camp) and are able, to some varying extent, communicate their learning or experience within a situated STEM activity.

Purpose of the Study

The purpose of this study was to use discourse analysis to examine the ways rising middle grades students (grades 5 – 8) who participated in a summer STEM camp assign significance to targeted STEM learning experiences and the ways in which they enact STEM practices and identities during camp. Participants have multiple opportunities to actively engage in hands-on STEM learning experiences facilitated by STEM professionals. I explored how the style of language employed by students in written reflections of their experiences can be used to assess emerging STEM literacy amongst participants. Further, I aimed to show that by looking at how students communicate their learning and intent for future learning provides insight on the potential benefits of a short-term summer STEM camp.

Significance of the Study

Informal learning environments are one of the learning environments in which DOE's (2016) *STEM 2026* can be applied. However, in doing so, it is important to consider how access and identity (Gutiérrez, 2009) advance the framework by ensuring equitable opportunities for all students to develop STEM literacy. The design of the STEM Camp is argued to support equity in STEM as intended by camp leadership. This study is important because understanding when and how students build STEM literacy relies on understanding the context for enacting STEM practices and building STEM identities that support emerging STEM literacy. This study suggests that a summer STEM camp may be a productive context for supporting students’ emerging STEM literacy in informal settings. Further, it will add to current research into STEM literacy as an outcome by offering a qualitative approach for assessing STEM literacy in an informal setting.

The Relevance of Informal Learning Environments for STEM Literacy

Informal learning involves learning outside a formal classroom (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). Informal learning environments involve learning experiences outside the formal classroom environment (Gerber et al., 2001; Mohr-Schroeder et al., 2014; Olsen, Cox-Peterson, & McComas, 2001). Typically, informal learning environments include “learner choice, low consequence assessment, and structures that build on the learners’ motivations, culture, and competence” (Bell et al., 2009, p. 47). Out-of-school, informal, and afterschool learning environments provide opportunities to impact student academic and social outcomes (The STEM Education Coalition, 2016, p. 3). Informal opportunities that are “engaging, responsive, and make connections” lead to positive outcomes for participants (NRC, 2015, p. 2).

Participation in STEM summer camps (Bell et al., 2009; Elam et al., 2012; Fields, 2009; Kong, Dabney, & Tai, 2014,; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; Larkins, Moore, Covington, & Rubbo, 2013; Mohr-Schroeder et al., 2014; Weinberg, Basile, & Albright, 2011; Yilmaz, Ren, Custer, & Coleman, 2010) or other informal STEM programs (Afterschool Alliance, 2011b; Baran, Bilici, & Mesutoglu, 2016; Luehmann, 2009; Newell, Zientek, Tharp, Vogt, & Moreno, 2015; Sahin et al., 2014) have been shown to increase student interest in STEM areas. Collaborative and hands-on activities can be effective pedagogical approaches in fostering student interest (e.g., Elam et al., 2012).

Informal learning experiences can be designed to support aspects of literacy within and across STEM fields, such as reasoning and skills. Empirical studies on summer camps have shown improved scientific reasoning (Larkins et al., 2013; Sullivan, 2008) or other content knowledge increases related to STEM areas (Bell et al., 2009; Yilmaz et al., 2010). In some contexts, researchers have employed qualitative methods to measure gains in areas related to STEM literacy. For example, students who participated in the informal learning experience Robocamp completed a daily Engineering Notebook (Larkins et al., 2013), and students who participated in Louisiana's implementation of LA GEARUP created concept maps of their learning (Bhattacharyya, Mead, & Nathaniel, 2011). The concept maps were evaluated for terminology used and connections made to science concepts. In these two examples, researchers aimed to evaluate literacy components differently than the perceived and self-reported measures often used for attitudinal and content learning data. Additionally, they incorporated regular structured reflections. A 2011 synthesis of afterschool program evaluations indicated increases in STEM knowledge and skills (Afterschool Alliance, 2011b), more recently supported empirically by Newell et al.'s (2015) study on an afterschool science program.

There are numerous reasons why it is important to study the effects of informal summer learning experiences on STEM literacy including the need to assess STEM literacy to determine when it has been achieved and to counter the effects of summer learning loss. The majority of students' time is spent outside the classroom (Afterschool Alliance, 2011a) and after school, weekend, and summer programs are important (NRC,

1996) to help students take advantage of the substantial amount of time they are not it school. Students, especially those from underrepresented groups (e.g., Quinn, 2015), experience summer learning loss (Fairchild & Boulay, 2002; McCombs et al., 2011; Quinn, 2015) in the gap between formal learning that occurs during the summer, resulting in regression of content knowledge.

Informal learning experiences can bridge informal and formal learning STEM learning (Luehmann, 2009), helping to lessen the effects of loss, and possibly lead to achievement gains (McCombs et al., 2011; Mikulecky, 1990). This is especially important for underrepresented populations, where inequitable educational experiences contributing to differences in academic outcomes persist through schooling (Curran & Kellogg, 2016; Morgan et al., 2016). Underrepresented groups, in particular, benefit from informal learning experiences (e.g., summer camps; Burgin, McConnell, & Flowers, 2015; Weinberg et al., 2011), and have been the focus of research on the impact of informal learning environments (Elam et al., 2012; Hayden et al., 2011; Mohr-Schroeder et al., 2014).

In informal contexts, the learning experiences are not tied to the restrictions placed on formal school learning (Afterschool Alliance, 2011b; Bell et al., 2009; Meyers et al., 2013) such as scope and sequences, standardized testing, and shorter instructional periods of formal school, and thus can be more flexible in engaging students in STEM-related practices. Thus, informal learning environments spark student interest in STEM and make them aware of STEM careers (e.g., Afterschool Alliance, 2015) without added pressures typical of formal school environments. The hands-on STEM learning experiences central to the STEM Camp in this study offer a way to combat summer learning loss by providing informal opportunities for students to authentically engage in STEM activities. The focus on integrated STEM learning experiences can additionally support identity development (Honey et al., 2014).

The Meaning and Value of Discourse Analysis

Discourse analysis involves the analysis of *language-in-use* (Gee, 1999, 2005, 2011, p. 205) to understand the meaning in what people say and do. According to Gee (1999, 2005, 2011), when people use spoken and written language, they are engaging in the seven building tasks that offer insight into the person at a specific point in time and in a specific context (p. 121). The seven building tasks are: (a) significance, (b) practices, (c) identities, (d) relationships, (e) politics, (f) connections, and (g) sign systems and knowledge.

In performing a discourse analysis, patterns can be discerned from the language used by people in different contexts (Jorgensen & Phillips, 2002) as a consequence of the *reflexivity* between language and context (Gee, 1999, 2005, 2011), making it possible to understand a person relative to those building tasks. Those patterns give way to two forms of meanings - *situated meanings* and *cultural models* (Gee & Green, 1998). Gee's (1999, 2005, 2011) tools of inquiry can inform analysis of the ways a person carries out various building tasks (p. 26). Among the tools of inquiry are social languages, Discourses, conversations, intertextuality, form-function correlations, situated meanings, and figured worlds. In an ideal discourse analysis, a researcher "uses each of the tools of inquiry to ask questions about each building task" (Gee, 1999, 2005, 2011, p. 121).

There are different approaches that can be taken to complete a discourse analysis (Gee, 1999, 2005, 2011, p. 8). Consequently, there are a number of tools of inquiry appropriate at different times to employ different approaches to analyze *language-in-use*. When the aim of a discourse analysis is to examine the style or content of language, social language and situated meanings can be effective choices of tools of inquiry to apply. If the purpose involved examining the structure of language, tools of inquiry such as form-function correlations could be effective in communicating engagement in building tasks.

Discourse analysis is an appropriate methodological choice for understanding the ways discourses are used in a domain to enact practices and identities. Gee defined discourses as “sociohistorical coordinations of people, objects (props), ways of talking, acting, interacting, thinking, valuing, and (sometimes) writing and reading that allow for the display and recognition of socially significant identities” and are necessary for “cultural models, situated meanings, and its concomitant identities” to exist (1997, p. 255-256). By using discourses, learners convey their understanding of a domain in context (Jorgensen & Phillips, 2002). When STEM is thought of as a domain, discourse is a form of STEM practices (Bell et al., 2009), because individuals have opportunities to engage in STEM activities by speaking and doing in ways developed through cultural models in STEM.

The Relevance of Discourse Analysis in STEM Literacy

To unpack the relevance of discourse analysis in understanding STEM literacy, I examined approaches to discourse analysis that have been taken to study literacy and related constructs. I argue this relevance by looking, more generally, at how STEM literacy has been studied qualitatively. I am interested in the role of discourse analysis in understanding emerging STEM literacy as situated in practice where that practice is social practice. I aimed to justify my use of discourse analysis to assess emerging STEM literacy in an informal setting, and more specifically, my choice of three of Gee's seven building tasks — significance, practices, and identities (1999, 2005, 2011) — as the focus of analysis.

For any discourse analysis, theory and methodology must work together (Gee, 1999, 2005, 2011; Gee & Green, 1998; Jorgensen & Phillips, 2002) and the need to bridge theory and method as a "basic philosophical premises in order to use discourse analysis as their method of empirical study" (Jorgenson & Phillips, 2002, p. 4). Theoretical perspectives rooted in constructivist thinking have informed the work of educational researchers to offer discourse analysis as a way to study learning, literacy, and identity. Included, researchers have drawn on social constructivism (e.g., Jorgensen & Phillips, 2002), situated cognition (Taylor & Blunt, 2001), and socioculturalism (Reveles & Brown, 2008) to frame discourse analyses, where the aim has been understanding literacy.

Rogers et al. (2016) compiled the literature in education research from 2004-2012 that has applied discourse analysis, identifying common purposes which include: making comparisons between groups (gender, ethnicity, class), understanding how identities form and are negotiated, and understanding what informs accepted discourses in a domain. Bell et al. (2009) identified discourse analysis as one approach taken by science education researchers to characterize interest and willingness to engage in science in informal environments. The varied ways discourse analysis has been applied to educational research suggests flexibility in discourse analysis to study a broad range of questions about literacy.

In my literature search, I did not come across empirical studies where discourse analysis has been used to study STEM literacy from an integrated or holistic perspective. The literature on STEM literacy focused more so on the definition or application of STEM literacy, classroom teaching, and learning (e.g., Zollman, 2012) with the exception of Hayford, Blomstrom, and DeBoer (2014) and Jackson, Cavalcanti, Mohr-Schroeder, and Schroeder (2015). Hayford et al. (2014) and Jackson et al. (2015) qualitatively investigated STEM literacy as an outcome of informal learning experiences in a university setting. Both studies found that preservice teachers experienced gains in knowledge of STEM by participating in the experience.

However, discourse analysis has been used to study disciplinary literacy related to STEM subjects (Dunsmore, Turns, & Yellin, 2011; Wertz et al., 2013). Wertz et al.'s (2013) study was a content analysis of memos written by students in a first-year undergraduate engineering course, as part of an assignment, to create an argument for a new design of a living space. They performed the content analysis by first coding using qualitative themes, and then transforming the data to quantitative data. Pertaining to my current study, Wertz et al. evaluated specific skills related to information literacy, not accurate knowledge of engineering concepts. They found students utilized more lower-quality resources that did not sufficiently add to their argument. Assessing disciplinary literacy specific to STEM has been investigated using other qualitative methods as well (Dimmel & Herbst, 2015; Johanning, 2008; Kragten et al., 2013; Scharf, 2014), although empirical studies looking at the affective factors of disciplinary literacy related to STEM subjects have largely been quantitative (Fives, Huebner, Birnbaum, & Nicolich, 2014; Ozgen & Bindaka, 2011; Wilkins, 2015). Nonempirical research has also informed ways to think about STEM literacy and how to assess it (e.g., Krajcik & Sutherland, 2010; Meyers et al., 2013).

Related constructs, such as identity, have informed my study of assessing STEM literacy. Bell et al. (2009) synthesize literature relating participation in science activities and science identity where “the opportunities that learners have to encounter and make use of the ideas, images, communities, resources, and pathways that can lead to progressively greater involvement in the practices of science” (p. 75). The concept of identity related to STEM disciplines has been offered as a theoretical lens (e.g., Gee, 2004) to qualitatively explore engagement in STEM (e.g., Archer et al., 2010) and as a way to facilitate literacy development (e.g., Cobb, 2004; Reveles & Brown, 2008). Cobb (2004) referred to collaborative design experiments methodology as an opportunity to study students’ emerging mathematical identities, which leads to the development of mathematical literacy (p. 336). He identified a relationship between mathematical tasks, identity development, and mathematical literacy: “Students will come to identify with mathematical activity as it is realized in the classroom, and in the process develop mathematical literacies that have clout in wider society” (p. 39). Cobb seems to have acknowledged the importance of mathematical literacies as a way to participate in society.

Most relevant to my current study is how studying discourses have been used as a methodological approach to investigate student learning and literacy (Razfar, 2012), literacy development and identity (Reveles & Brown, 2008), and discourses and identity (Archer et al., 2010; Llewellyn, 2009) in STEM disciplines. While the findings of qualitative studies are not generalizable, the methods used by other researchers have helped inform the way that I chose to perform this discourse analysis. Further, in understanding the ways constructs of learning, literacy, and identity have been discussed, I was able to approach my data for analysis from a well-informed and research-based position.

Razfar's (2012) study – embedding discourse in mathematics instruction. Razfar (2012) aimed to inform integration of discourse into mathematics instruction. As part of his work, Razfar engaged doctoral students, university faculty, and inservice teachers in learning activities centered on discourse analysis to help participants understand how language and discourse can be embedded in mathematics instruction to support English language learners. One activity integrated baseball language in an arithmetic word problem highlighted how "mathematical meaning-making can be situated" (p. 55). In this activity, students, without knowledge of baseball language, faced a barrier to solving the mathematics problem, in a similar fashion as English language learners who struggle to access the mathematics language. In another activity, participants compared two examples, first presented by Gee (1999, 2005, 2011), of how social language can be enacted in discourse. Participants came to understand "differentiated learning and thinking" that can be interpreted from discourse as students demonstrate conversational versus academic fluency over a social language, and student acquiring secondary discourses, such as mathematics, is, in part, situated in the context of their primary discourse. Razfar's work relating learning and literacy via discourse has implications for how I chose to analyze student discourse in this paper. By extending Razfar's definition of mathematical discourse to all STEM areas, STEM discourse could be considered a "specialized secondary discourse developed by people for specific purposes" (p. 50). By enacting STEM discourse, students utilize STEM language as a social language at different levels. Those different levels suggest differential levels of reflection about their STEM learning experiences.

Reveles and Brown's (2008) study – connecting science identity to science literacy. In Reveles and Brown's (2008) study, the ways teachers explicitly integrated science discourse, in part through modeling the use of language, helped students use the science discourse appropriately in context. Meanwhile, discourses were supporting development of identity as science learners. Assessing STEM literacy from a situated perspective incorporates the role of social interactions in student learning. In Reveles and Brown's study, the role of the two teachers is central to their work. Providing students opportunities to access science by "doing science" and using the academic discourse helped students "develop academic identities as science learners to promote their use of discourse practices associated with developing scientific literacy" (p. 1023). Other researchers have noted that identity and literacy are related constructs, and additionally, connect to learning (e.g., Moje, 2011).

Studies connecting identity development and literacy using discourses. Llewellyn (2009) performed a discourse analysis with interview data for two preservice mathematics teachers to show how the two participants enacted difference beliefs related to mathematics through mathematical discourse, and how those similarities and differences inform how gender is prevalent in discourse. She examined interview data through three themes related to mathematical discourse: control (i.e., degree of taking ownership over math and understanding), choice (i.e., whether or not someone "opts out" or chooses to achieve at math, p. 419; different ways preservice teachers make use of social language of mathematics), and confidence (i.e., claiming not to be a math person). Llewelyn's discussion of confidence is relevant to the way I have used discourse analysis to interpret student identity and literacy. She indicated there is a relationship between confidence and identity, but multiple interpretations could be made to understand that relationship. For example, a person who feels she or he is good at mathematics can subsume a mathematical identity. In making her argument about confidence, Llewelyn (2009) cited Hardy (2009) identifying willingness to learn as a trait of a confidence person. Elsewhere, willingness to engage in STEM has been identified as a characteristic of a STEM-literate person (Bybee, 2013) and was included in the STEM literacy definition I adopted for this study.

Students can pursue different pathways for achieving STEM literacy. Those pathways are informed by the access to opportunities to engage in STEM activities and the context in which those opportunities arise. Archer et al.'s (2010) longitudinal qualitative study analyzed student discourse to understand how students come to identify as scientists by *doing* science and the differences in how students conceive being scientists based on social class, gender, and ethnicity. Students in the study who reported engaging in science in informal contexts (performing their own experiments at home) represented science as fun. This representation was distinct from those who practiced science in the formal school setting where the identities formed related to being good students (p. 624). Archer et al. recommended a disruption of "dominant discourses around science and the identity of the scientist...to consider how we might bridge the gap between children and young people's everyday identities...and the identities and messages conveyed by school and 'real' science" (p. 636-637). It is important, then, to consider the different ways students enact identities through their discourse. The need to shift away for instruction that reinforces dominant discourse has been suggested by subsequent research (Hanrahan, 2006). Later work reinforced barriers to students forming identities in STEM disciplines, and subsequently pursuing STEM careers (e.g., Archer, DeWitt, & Osborne, 2015), further suggesting a need to provide diverse pathways for students to form STEM identities. Included is the potential for STEM-related informal learning environments to support identity development (Weinberg et al., 2011).

Theoretical Framework

This work is grounded in the idea that literacy is a social practice (Barton & Hamilton, 2000) and that “situated meanings drive learning and practicing” (Gee, 1997, p. 243). Learning, literacy, and identity are related concepts, and have been studied as such through a constructivist lens. For example, situated or sociocultural lenses have been used to understand how people learn (Cobb, 2004; Gee & Green, 1998; Razfar, 2012; Smith & Semin, 2006; Taylor & Blunt, 2001). Gee argued for the relationship between learning and literacy, offering the application of the “mind, meaning, and learning” as situated and sociocultural to views of literacy (Gee, 1997, p. 235). His perspective of situated cognition is a coordination of situated and sociocultural perspectives on learning (1999, 2005, 2011). In taking on such concepts toward learning and literacy in this work, I assert that emerging STEM literacy develops through engagement in informal STEM learning opportunities in the context of a summer STEM camp. Further, it is possible to interpret the ways students draw meaning from the STEM learning experiences. In doing so, we can understand the ways students build significance, and enact practices and identities consistent with a trajectory of becoming STEM-literate.

In navigating theory and method to perform a discourse analysis on emerging STEM literacy, I thought about how literacy develops from a situated cognition perspective. I adhere to the conceptual treatment of literacy as social practice (Barton & Hamilton, 2000). Barton and Hamilton (2000) offered six propositions to understand the theory of literacy as social practice.

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

Each of the six propositions take shape within this work in some way, with a focus on the *literacy practices* enacted in student written reflections. The sixth proposition, *literacy practices change and new ones are frequently acquired through processes of informal learning and sense making*, is particularly relevant within this study because of the informal context in which the intended learning occurs. Specifically, the STEM learning experiences occur in the context of a summer STEM camp, outside of the formal school environment. Cobb (2004) recounted how research on learning mathematics in informal settings shifted views of mathematics from purely cognitive to situated, where the significance of the content comes from the context of social practices (p. 335). In this study, the significance that can be interpreted from the students' perspective is intertwined with the meaning behind the language used by students, whether that meaning is consciously or unconsciously known to individual students. The language is produced in response to participation in the informal STEM learning experiences.

I draw on Gee's perspectives on situated learning related to *situated meanings* and *cultural models* in this study. I believe students participating in STEM camp become part of a sociocultural group defined by a *community of practice* where the students are *legitimate peripheral participants* to the STEM community (Lave, 1991), and by engaging in hands-on, authentic STEM learning experiences, can enact STEM practices and STEM identities. The way students participate in the STEM content sessions is related to their prior experiences (Lemke, 1997, p. 48). Students come from multiple sociocultural groups that influence how they come to select meaningful patterns in STEM (Gee, 1997). For instance, a fifth-grade student who has never heard of the word "DNA" will experience a session on extracting DNA differently than an eighth-grade student who has previously been exposed to the term "DNA". A student whose first language is Spanish could attribute meaning to STEM words different from what is intended by the STEM context or demonstrate limited use of STEM language. Negative STEM socialization and stereotypes contribute to the disinterest and lower achievement in STEM areas among minorities and females more than ability (Byars-Winston, 2014; Valla & Williams, 2012). When asked a question regarding what they enjoyed or did not enjoy, the impact of stereotype threat could feed into how these students' experience and subsequently respond to such a question. If, instead, students feel a sense of belonging, they may become less vulnerable to stereotype threat (Spencer, Logel, & Davies, 2016, p. 424), and, thus, persist toward becoming a STEM-literate person.

James identified imitation as a human instinct (1899/2001). Vygotsky theorized the role of imitation in learning by suggesting imitation can lead to cognitive development (1935, 1978). I subscribe to this view of imitation in thinking about ways STEM literacy is initiated first through imitation by utilizing relevant Discourses of STEM areas. The Discourses members of the STEM community employ to facilitate learning of STEM content amongst students as legitimate *peripheral participants* provide a foundation for the cultural models that exist (Gee, 1997).

This discourse analysis is aimed at operationalizing Discourses, practices, and identities in the context of a summer STEM camp from a situated cognition perspective. At STEM camp, the socially significant identities being enacted by students are recognized in this work by how students write like STEM professionals. STEM professionals and educators provide the backdrop for Discourses to be built by modeling the ways STEM experts talk, act, interact, and think about STEM-related problems, and how they engage in solving STEM-related problems. The terminology used during STEM content sessions are associated with the practices of STEM professionals, and are thus examples of situated meanings that "tied together, are made understandable, not in terms of some generic genre label… but in terms of a cultural model of the production of work in the academic fields whose situated instances these are" (Gee, 1997, p. 250).

Methods of Analysis

This qualitative study used discourse analysis (Gee, 1999, 2005, 2011) to examine how emerging STEM literacy was situated in participation in hands-on, authentic STEM content sessions facilitated by STEM professionals. The research questions under investigation in this study were:

3. How can discourse analysis be used to understand emerging STEM literacy amongst middle grades students attending a summer STEM camp?
4. What STEM practices and STEM identities are enacted in student reflections of learning?

Discourse analysis allowed me to look at written text of the middle grades students as a way to understand how STEM identities and STEM practices were represented in student reflections on STEM learning experiences.

In 2013, as part of National Science Foundation's (NSF) Experimental Program to Stimulate Competitive Research (EPSCoR) initiative, a large public university in the midsouth received a five-year grant to implement a model for broadening participation via a summer STEM camp which would focus on engaging rising middle grades students (grades 5-8) in authentic STEM experiences, particularly to increase awareness and interest in STEM and STEM careers. Additionally, researchers aimed to broaden participation in STEM by purposefully recruiting females and minorities who are underrepresented in STEM to attend camp. As part of the five-day summer day camp, students participate in hands-on, authentic STEM sessions led by STEM faculty and supported by preservice and inservice STEM teacher leaders and graduate students.

There are multiple interpretations of what language and discourse can mean with respect to the moment and the prior knowledge (Razfar, 2012). My interpretation of written text is one possible way to use tools in discourse analysis to understand emerging STEM literacy, and, in doing so offer one possible representation of how students engage in building tasks. Interpretation of student responses was made based on my own interpretation of STEM, and knowledge of the how students were exposed to the STEM content, particularly the STEM practices and STEM language, which provided opportunities for students to subsequently enact those practices and STEM identity via their written responses.

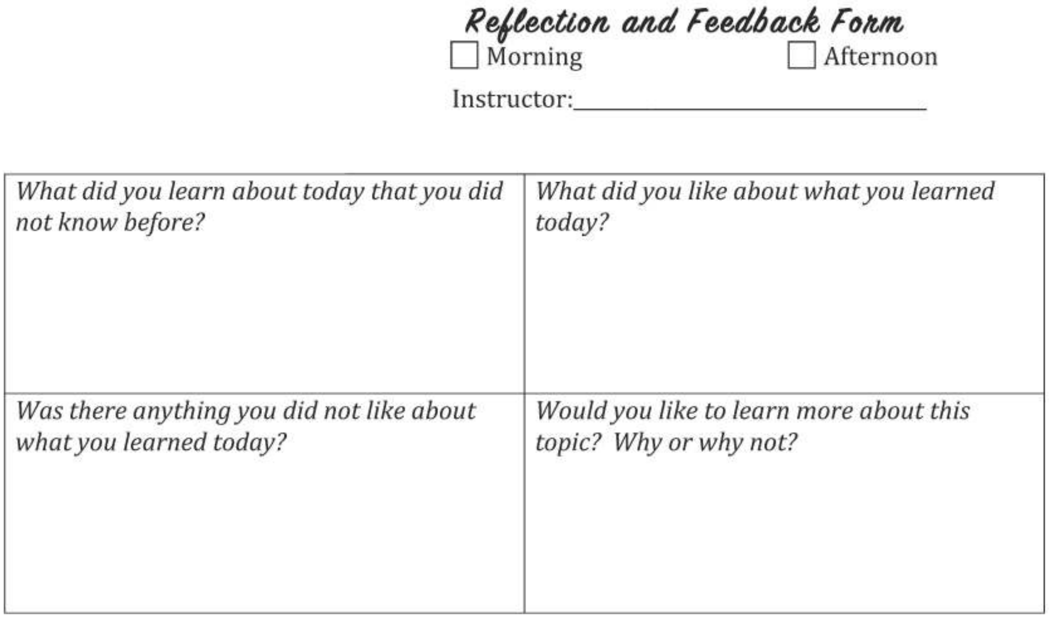
Participants and Settings

Participants. The summer STEM Camp was held on the university campus and was open to rising fifth- through eighth-grade students beginning Summer 2012. This study focused on data collected between summers 2013 and 2016. The number of students who attended camp has increased each year, starting with 138 in summer 2013 and increasing to 216 students in summer 2016. In 2013, camp was held on two consecutive weeks. Incoming 5th and 6th grade students participated the first week, and incoming 7th and 8th grade students participated the second week. All grade levels participated in camp during the same week in 2014 and 2015. In 2016, incoming 5th – 8th grade students chose one of two weeks to participate.   Students were assigned to groups based on their grade level, with rising 5th/6th grade students grouped together, and rising 7th/8th grade students grouped together. Students who had signed student assent and parent consent forms were eligible for inclusion in the study. Participants were not identifiable by the data presented in this study due to methods of inputting data.

Setting. Students participated in a different three-hour STEM content session each day of the five-day camp. During the other three-hour session of the day, students participated in robotics activities. During 2014 and 2016 iterations of the camp, students only participated in four STEM content sessions on the university campus; one of the five days was a field trip to the Center for Applied Energy Research to learn about energy. Students did not complete daily reflection forms for the robotics activities.

Data Collection

The data for this discourse analysis comes from the Student Reflection and Feedback Forms (Figure 4.1).



Reflection and Feedback Form

☐ Morning ☐ Afternoon

Instructor:__________________________

What did you learn about today that you did not know before?	*What did you like about what you learned today?*
Was there anything you did not like about what you learned today?	*Would you like to learn more about this topic? Why or why not?*

Figure 4.1. Reflection and feedback form.

Data gathered from the robotics activities were not considered for inclusion in the analysis because alternative methods were used to generate data on student experience with robotics activities, specifically pre- and post-surveys at the start and end of the camp week. Students were prompted to complete the paper and pencil reflection and feedback form following each STEM content session. Students were asked four questions:

- What did you learn about today that you did not know before?
- What did you like about what you learned today?
- Was there anything you did not like about what you learned today?

- Would you like to learn more about this topic? Why or why not?

After completing the form, researchers transcribed verbatim data exclusive of identifying personal information. This resulted in 2517 student responses on the Student Reflection and Feedback Form from 28 STEM content sessions collected from 2013 - 2016.

I needed to draw on full sets of reflections from STEM content sessions to provide robustness of data to the point of saturation. I began with STEM content sessions about which I knew the most given my personal experience with the STEM camp and knowledge acquired through my pursuit of a degree specializing in STEM education. I additionally considered sessions that were implemented over multiple years. While all STEM content sessions provided opportunities for students to interact with STEM content, not all reflections provided variations in the ways students engaged in the experience and what they learned. This is not to say they learned from or enjoyed those sessions less, but rather that the limited space to record their learning and enjoyment could limit analysis of those responses. These considerations resulted in the reflections from five STEM content sessions used in this analysis, consisting of a total of 473 student responses.

Table 4.1

Analyzed STEM Content Sessions at a Glance

STEM Content Session Title	STEM Content	Number of Sessions Analyzed	Year(s)	Session Description
Wonderful World of Engineering	Engineering	2	2013	Students toured engineering labs such as the anechoic chamber and the the concrete canoe student project. Students built and tested aluminum boats to understand concepts of buoyancy and optimization. Students explored electricity and used various materials to build motors.
It's a Small But Amazing World After All!	Nanotechnology	1	2014	Students explored applications of nanotechnology, including how nanoparticles can be used to create hydrophobic materials (i.e., fabric), "magic sand", and how nanotechnology exists in nature (i.e., peach fuzz).
Wonderful World of Engineering	Engineering	1	2015	Students toured engineering labs including the anechoic chamber, the UAV lab, the water resources lab, the concrete canoe student project, and the Solar Car student project. They learned about fields of engineering. Students explored engineering labs, students modeled waved using slinkies, investigated concepts of buoyancy and optimization by building aluminum boats, participated in an "are you smarter than your robot?" activity to explore motors, ultrasonic sensors, and color sensors.
What is your code?	DNA Modeling	1	2015	Student created DNA necklaces by first extracting their DNA from cheek cells, second observing characteristics of their DNA, and third linking nucleotides to build a DNA double helix.

Data Analysis

"A discourse analysis involves asking questions about how language, at a given time and place, is used to engage in the seven building tasks" (Gee, 1999, 2005, 2011, p. 121). For this study, I used discourse analysis to look at the *language-in-use* of middle school students immediately after participating in a STEM content session. This was accomplished by using select tools of inquiry to answer questions related to select building tasks (Gee, 1999, 2005, 2011). Specifically, situated meanings, social language, and Discourses are the tools of inquiry used to analyze how participants build significance and enact practices and identities related to engaging in STEM activities. By looking at student responses, the aim of this study was to assess the extent to which students are able to use STEM language, and, in doing so, develop vocabulary consistent with a STEM-literate person.

I took on a descriptive approach (Gee, 1999, 2005, 2011, p. 9) to this discourse analysis, focusing on the style of the language being used. For the full set of responses for each of the five selected STEM content sessions, I examined student responses to two questions: “What did you learn about today that you did not know before?” and “What did you like about what you learned today?” First, I established the context for each of the five STEM content sessions from a situated theory perspective. This included personal knowledge of the content of STEM content sessions.

Coding techniques.

What did you learn about today that you did not know before. I manually coded individual responses to the first question for sets of reflections using four qualitative themes: (a) level of reflective thinking (list of items, action or application of content), (b) use of vocabulary consistent with STEM professionals, (c) STEM vocabulary related to processes and practices, and (d) integration of STEM content. Through the coding process, I utilized techniques for quantitization of the data, namely by treating qualitative themes dichotomously during coding (Collingridge, 2013). For example, when a response to the question of interest indicated an action or application related to content explored during the STEM learning experience, I assigned “1” to that response for level of reflective thinking. Otherwise, specifically, if a response was a single word or list of items, a value of “0” was assigned to level of reflective thinking. Interpretation of student responses was made based on my own interpretation of STEM, and knowledge of how students were exposed to the STEM content, particularly the STEM practices and STEM language which provided opportunities for students to subsequently enact those practices and STEM identity via the student responses.

Analysis decisions were thoughtfully made regarding coding, with a strict focus on consistent coding and interpretation. For instance, in categorizing a response as including STEM language or not, the goal was to identify whether vocabulary was utilized as a social language indicative of STEM professional. This was accomplished by looking at evidence of STEM practices presented by level of reflective thinking and as a result of the content of STEM content session itself. The terms science, technology, mathematics, and engineering were not coded as evidence of STEM vocabulary, except in special cases such as using the term for the STEM disciplines as evidence of integration of STEM disciplines or using one of the terms alongside others to indicate more specialized knowledge. For example, “civil engineering” or “technology engineering” are terms used for a specific purpose as evidence by the content of a STEM content session. However, “engineering” alone is not indicative of using STEM language effectively.

What did you like about what you learned today. I repeated the previous steps for coding for responses to the questions “What did you like about what you learned today?”. Instead of using a priori code, open coding was utilized (Miles & Hubermann, 1994). The previous coding strategy could not be utilized because the goal of analyzing the second question was to make sense of the significance rendered by the students. Therefore, the ways in which the experience was relevant for students could only be understood through open coding to identify patterns and themes. Once those themes were identified, the themes were dichotomized to recode responses (Collingridge, 2013), as was done for responses to the first question.

Applying Gee's tools of inquiry to building tasks. Third, I evaluated Gee's tools of inquiry with respect to interconnectedness between language and context. Fourth, I examined each of the three selected building tasks specifically in relation to the three selected inquiry tools (Table 4.1; Gee, 1999, 2005, 2011). This yielded a total of nine questions used to support claims and hypotheses I made about how students used STEM language, and the meaning that can be interpreted with respect to emerging STEM literacy via a developing STEM identity embedded in social practice. Reliability was addressed by analyzing reflection responses for multiple sessions to the point of saturation. Validity was ascertained by maintaining coding sheets for each of the STEM content sessions included for analyses in this study.

Table 4.2

Questions Relating Selected Tools of Inquiry to Selected Building Tasks (Gee, 2011)

		Building Tasks		
		Significance	Practices	Identities
Tools of Inquiry	Situated Meanings	How are situated meanings being used to build relevance or significance for things and people in context?	How are situated meanings being used to enact a practice (activity) or practices (activities) in context?	How are situated meanings being used to enact and depict identities (socially significant kinds of people)?
	Social Language	How are social languages being used to build relevance or significance for things and people in context?	How are social languages being used to enact a practice (activity) or practices (activities) in context?	How are social languages being used to enact and depict identities (socially significant kinds of people)?
	Discourses	How are Discourses being used to build relevance or significance for things and people in context?	How are Discourses being used to enact a practice (activity) or practices (activities) in context?	How are Discourses being used to enact and depict identities (socially significant kinds of people)?

It is acknowledged that the time on task experienced by the students may limit the level of literacy participants are able to achieve. Claims were made with assumptions about the feasibility of achieving some level of STEM literacy within the context of a brief STEM learning experience. This assumption is theorized as reasonable for this study based on Vygotsky's definition of imitation. Vygotsky suggested imitation leads to cognitive development (1935, 1978, p. 344). Thus, by utilizing the language of STEM professionals directly after participating in a STEM learning experience, students are providing preliminary evidence of an emerging STEM literacy.

Discussion of Findings

As I examined reflection responses, it became apparent the highest level of enactment of STEM identities and STEM practices that could be argued could be described as emerging. *How can discourse analysis be used to understand emerging*

STEM literacy amongst middle grades students attending a summer STEM camp? What STEM practices and STEM identities are enacted in student reflections of learning? The findings are presented by examining the style of language within the context of selected STEM content sessions and understandings with respect to how students enacted STEM practices and STEM identities as markers for emerging STEM literacy, and second, the ways in which students made what they learned in the STEM content sessions significant.

Enacting STEM Practices and STEM Identities Toward Emerging STEM Literacy

Four qualitative themes were identified a priori to aid in the analysis of student responses to the question, "What did you learn about today that you did not know before?" following five STEM content sessions. Those themes were: (a) level of reflective thinking, (b) use of vocabulary consistent with STEM professionals, (c) STEM vocabulary related to processes and practices, and (d) integration of STEM content. These themes were generated from the evaluation of definitions of STEM literacy in the literature (e.g., Balka, 2011; Bybee, 2010) and as synthesized in the definition I posed in Chapter 2 which commonly focus on outcomes from engagement in STEM-related activities, combined with considerations of how the style of language from a situative perspective. Themes were dichotomized for interpretability. This discourse analysis reflects the interpretation of those themes around Gee's building tasks of significance, practices, and identities with respect to using situated meaning, social language, and Discourse as inquiry tools. Findings are suggestive of how participants work toward utilizing STEM language in relevant contexts. Students are able to engage in various levels of reflective thinking about their learning when they participate in authentic, hands-on STEM learning experiences. Those who demonstrated higher levels of reflective thinking more consistently utilized specialized language for the STEM content explored in the STEM learning experience.

Higher levels of reflective thinking are apparent in sessions where students had greater opportunities to interact with the STEM content hands-on and in collaboration with peers and STEM professions, thus signaling engagement in STEM practices as a precursor for emerging STEM identities, which, in turn, offers a pathway to emerging STEM literacy.

Reflective thinking and integrative STEM in engineering focused sessions. During the two 2013 engineering sessions, students investigated electromagnetism and surface area by constructing boats of varying sizes and materials, tested aerospace engineering shields in a soundproof room, and learned about various fields of engineering (Mohr-Schroeder et al., 2014). A professor of engineering who specializes in electrical engineering led the session with the help of engineering undergraduate and graduate students. The same content was explored during both weeks of camp during Summer 2013. Fifth and sixth grade students participated in the session during Week 1, and seventh and eighth grade students participated during week 2, resulting in 69 and 71 reflection responses, respectively. Since the same content was explored during both weeks, the responses were aggregated for a more comprehensive picture of *language-in-use* among STEM camp participants following a hands-on engineering session, with consideration of differences in response patterns by grade level across the two weeks. For the first and second weeks, 46 (66.7%) and 41 (57.8%) responses included STEM vocabulary, respectively (Table 4.2). The term engineering was not categorized as STEM vocabulary when it was written as a statement of the existence of engineering as a field or career. As part of the engineering-focused session students participated in 2013 and 2015, there were three aspects of the session that dominated (a) concrete and aluminum boats, (b) aerospace and soundproofing, and (c) existence of careers in engineering.

Table 4.3

Quantitized Data using Dichotomized Themes Related to STEM Language-in-use

		Themes				
STEM Content	Number of responses	Level of Reflective Thinking[a]	Use of STEM Vocabularly	STEM Vocabularly and Higher Reflective Thinking	Process and Practices of STEM	Integration of STEM Content or Concepts
2013						
Engineering, Week 1	69	41 (59.4%)	46 (66.7%)	37 (68.1%)	15 (21.7%)	5 (7.2%)
Engineering, Week 2	71	31 (43.7%)	41 (57.8%)	30 (42.3%)	17 (23.9%)	10 (14.1%)
Total	140	72	87	67	32	15
2014						
Nanotechnology	127	50 (39.4%)	103 (81.1%)	44 (34.6%)	9 (7.1%)	1 (0.8%)
2015						
DNA Modeling	70	35 (50.0%)	68 (97.1%)	35 (50%)	2 (2.9%)	0 (0.0%)
Engineering	136	86 (63.2%)	103 (75.7%)	80 (58.8%)	33 (24.3%)	18 (13.2%)

Student written responses following the engineering session reflected differences in levels of reflective thinking. While one student described learning “What engineers do,” (Week 2 Student A, 2013) another provided greater detail around the work of engineers, namely “That engineers could create special substances such as glass with strands that are smaller than hair” (Week 2 Student B, 2013). Week 2 Student A (2013) is an example of a response that exhibits a lower level of reflective thinking about the STEM content session and includes neither STEM specific language nor evidence of integration of STEM subjects. Week 2 Student B, on the other hand, recalled the applications explored during the engineering session. Week 2 Student B (2013) is an example of a higher level of reflective thinking about the STEM content session because the student describes a specific example of a possible function of an engineer. Additionally, the student made use of specialized STEM specific language with the context of process standards, although the level of enactment of social language is still that of an individual whose identity with STEM is emerging.

Another example of how students reflected on their experience involved reflections on the soundproof room.

- Week 2 Student C: I learned about the quiet room (no echo).
- Week 2 Student D: how more surface area can effect sound.
- Week 1 Student E: The spikes on the walls absorbs sounds
- Week 1 Student F: That spikes do not let sound waves bounce around as much as flat walls (2013)

Numerous responses identified factors impacting sound, with a focus on surface area during week 2 and "spikes" during the first week. During the session, student explored the relationship as part of the tour of the anechoic chamber (i.e., soundproof room). A clear distinction across the two weeks between the two ways sound was represented in the reflection responses suggests some differences in the way content was presented. Given the different grade levels for the two weeks, it makes sense the presenter differentiated student experience with the anechoic chamber according to what was developmentally appropriate. Specifically, the professor used more formal language connected to mathematics for the older students. This formal language is more consistent with the social language characteristic of that used by a STEM professional to describe the relationship under investigation.

The use of different forms of social language suggests varying levels of student ability to enact STEM practices and STEM identities. A response such as “how to make a motor” (Week 2 Student G, 2013) can be characterized as reflecting STEM vocabulary because of knowledge of how students engaged in learning about making a motor during this particular engineering session. However, “the motor thing” (Week 2 Student H, 2013) would not be characterized as reflecting STEM vocabulary just because the student used “motor” plus “thing” demonstrating more of a social language associated with the everyday than a specialized language of STEM professionals. In the absence of additional words such as “stuff” responses that did not utilize a higher level of reflective thinking were still considered as having utilized STEM language when more specialized terms were used whose meaning may only be interpreted within a STEM context such as *copper wire* or *copper pipes.*

Students were able to engage in various levels of reflective thinking about their learning when they participated in authentic, hands-on STEM learning experiences. Those who demonstrated higher levels of reflective thinking during the engineering session utilized specialized language for the engineering content explored during the session more often than those who used language representing a low level of reflective thinking. Across the years, while specifics may be absent, there is acknowledgement that different fields of engineering exist as well.

Integrative STEM learning. Similar content was presented during the World of Engineering session during STEM Camp 2015. In 2015, one week of camp was offered, during which time 136 students participated in the session and completed reflection responses. The session included activities around surface area in constructing boats from different materials, and the aerospace engineering shields as was previously implemented. The integration of STEM was more apparent during the 2015 session than 2013 session, especially with respect to mathematics. While there were only three fewer instances of integration of STEM during 2013 than 2015, the examples of integration from 2013 centered largely around the inclusion of the concept of *surface area*. With reference to the concrete and aluminum boat constructions, students connected learning to mathematics by (a) referencing the use of calculus as part of the work of an engineer, and (b) addressing calculations of density.

- Student I: I learned that calculus is in my future if I choose to become an engineer
- Student J: how to get the average on a calculator and what a concrete boat was
- Student K: how to calculate density (2015)

This shift in *language-in-use* between the two years of student reflections suggest a shift in instructional focus. The more recent direction for facilitating this STEM content session reflects the potential to revisit content in a different way. The depth of STEM concepts within engineering tasks is so extensive that students can have multiple opportunities to enact STEM practices even when variations to the situated meaning occur. The end result is consistent social language to build practices and identities, with opportunities to make connections to other STEM areas.

Differing discourses of DNA modeling. During the DNA Modeling session, students extracted DNA from their cheeks and then built DNA models of their DNA by linking their nucleotides together. Only rising seventh- and eighth-grade students participated in the DNA Modeling session. STEM vocabulary terms associated with this session were DNA, structure, double helix, cells, bases, chromosomes, ATCG, extract, structure, and organism. Of the 72 students, 68 students (94.4%) used at least one of these words, 35 (48.6%) used one of the words within context of a higher level of reflective thinking, and 29 (40.3%) students used at least one STEM-related term other than DNA. Concepts related to DNA are typically first introduced in the formal schooling setting during sixth grade where students learn all organisms are made up of cells that serve a specialized function. So, it can be assumed that students who participated in this session may have been exposed to the term, DNA, prior to the DNA Modeling session at STEM camp. While I do not have specific knowledge of this due to the variety of districts, schools, and classrooms students attend during the academic school year, the academic standards adopted by the state indicate introduction to some concepts related to DNA and cells.

Three key understandings about DNA were extracted from student reflections on new learning following the DNA Modeling session. Those include: (a) DNA has a structure; (b) DNA can be extracted/modeled; and (c) everyone's DNA is unique. Related to Gee's inquiry tools, the key understandings are argued to arise from the situated meaning in exploring concepts related to DNA, inclusion of STEM language associated with the session, and Discourse utilized by the STEM professional to facilitate learning.

DNA has a structure. Some students described learning about "the structure of DNA". Descriptions of DNA ranged from acknowledgement of a *structure* to specific description of its structure whether by utilizing social language consistent with related STEM professionals, or that of a more everyday vernacular. In the case of an acknowledgment of "the structure of DNA" (Student L, 2015), the level of reflective thinking is lower; however, the students who made such an acknowledgment did use appropriate STEM language given the context of learning for the DNA Modeling session. That is, while there was no further description of the structure, the term "structure" is consistent with how a STEM professional in biology or genetics would refer to the way DNA looks. In some cases, higher levels of reflective thinking were indicated even when the language utilized was not explicitly contextualized by the DNA Modeling session itself. One student learned that "DNA is twisted" (Student M, 2015) suggesting an emerging knowledge of the structure of DNA, more specific than "what DNA looks like" but more general than noting ATCG or the ladder structure of DNA. It would be interesting to know whether the term "twisted" was used during the session or if this is a student's own representation based on the STEM learning experience.

DNA can be extract and modeled. In addition to learning related to the structure of DNA and cells, student learning reflected their experience with building.

Student N: "learned how to create your own DNA"

Student O: "that you could make a DNA necklace and about all of the things in DNA"

Student P: ""that you can extract DNA from yourself" (2015)

The differing Discourses utilized by students offer different representations of the ways students enact STEM practices and STEM identities. When Student N's description of "creat[ing] DNA" is interpreted literally, it would appear inherently incorrect. However, when situated in the DNA modeling experience, Student N's description can be interpreted as extracting DNA to create a DNA necklace. Student O and Student P responses reflect this type of understanding more explicitly referring to *making* a necklace or *extracting* DNA. The connection to modeling and engaging in scientific practices were evidenced by reflections where the *language-in-use* was more precise, and more aligned to the social language of STEM professionals in biology and genetics. The range in level of precision can be seen in how students described the process the engaged in to create their necklaces. More non-STEM specific language such as "put your cells" or "taking DNA" contrast more STEM specific language such as "collect DNA" or "extract DNA." Interpretation of a range of styles of language suggests that while all students referred to the same experience, they utilized the language in a different way; subsequently, their enactment of STEM identities via written text varied. Another example of the different ways student experiences during the DNA Modeling session are reflected in Student Q and Student R's reflections.

Student Q: "That sports drinks absorb the cheek DNA"

Student R: "You can put your cells from your cheek in a bottle" (2015)

Both capture the process that was modeled and then replicated by students during the session. However, referring to "absorb the cheek DNA" (Student Q, 2015) in comparison to "cells from your cheek" (Student R, 2015) are two ways to represent understanding that DNA exists and can be extracted.

Everyone's DNA is unique. Students learning of the uniqueness of their DNA are suggested by response that incorporated language such as such as *my* or *your own* to describe DNA.

Student S: "what my dna [sic] is formed of and what my dna [sic] looks like"

Student T: "How to see your own DNA" (2015)

When such a connection between the existence of DNA and everyone's DNA being unique was made, students exhibited a higher level of reflective thinking. This type of language was not commonly used.

Synthesis of STEM as a Social Language. The language associated with individual STEM content sessions can be viewed as a social language, and by using the language in their written reflections, students, to some degree, applied what they learned (STEM practices), and doing so in a way that was influenced by the STEM professionals. The STEM identity of an expert is not the same as the emerging STEM identity of a student at STEM Camp. However, the ways students conveyed their new learning suggests a positive move forward in becoming STEM-literate with respect to the definition I adopted for this study.

Rendering Significance of STEM Learning Experiences as Supportive Pathways to STEM Literacy

The preliminary indications of what students may have thought significant from the STEM content sessions arose from what students chose to identify as new learning. It was necessary to move beyond the first reflection question around new learning to interpret the level of significance built around the STEM content sessions. The significance of STEM content sessions as STEM learning experiences was rendered by student written reflections around the question, "What did you like about what you learned today?". The significance attributed to the sessions fell largely into three themes: (a) students displayed extra enthusiasm for the experience (classified experience as experience using stronger descriptions than the term "like" posed in the reflection question); (b) the hands-on learning supported STEM learning; and (c) STEM-related activities are valuable. The first two themes that arose in this work reinforced previous findings of Mohr-Schroeder et al. (2014) around STEM camp increasing student interest in STEM. Here, the three themes were considered specifically in the context of the significance of the STEM content sessions that exists because of the way students reflected on their experiences in the sessions. Students' written reflections of what they liked about a given session establish the relevance of the STEM content sessions. Through coordination within the analysis of how practices and identities are enacted, the discourses students used suggest how emerging STEM literacy can be studied within the context of a summer STEM camp. This is possible to evaluate through a discourse analysis because "building with language is a *mutual* process" (Gee, 2011, p. 103) where the significance, practices and identities, as building tasks, work together.

The experience invoked extra enthusiasm. Twenty-eight percent (28%, n = 131) of the responses analyzed characterized the session as being "fun", "interesting", "cool", or "amazing" (18%) or wrote "everything" or something similar (10%). The positive adjectives to describe their learning experience can be interpreted as positive attitudes toward STEM learning. While many students did not specify what was "fun" or "interesting" or "cool" about the experience, the extent that students connected their belief and attitudes toward the learning to the learning experience itself varied. For example, a response of "I saw a lot of cool things" does not capture explicitly what those "things" are, but the action of seeing those "cool things" suggests engagement with the concepts through, at a minimum, observation. For the instances where students connected what was learning to favorable attitudes toward that learning, I interpreted students as willing to engage in STEM related activities. Such a willingness has been associated with literacy in STEM subjects. For example, a student in the engineering session in 2015 remarked “I thought it was cool that we got to build things” (Student U, 2015) Building is part of the processes and practices for learning STEM subjects. By describing the opportunity to build as cool suggests the student thought favorably about engaging in engineering practices. Beyond a positive attitude, some styles of language utilized by students went further to suggest excitement in the learning that occurred. For example, one student remarked “Concrete is my favorite material, and it floats!” (Student V, 2015). In this example, the student’s choice of an exclamation point as the punctuation mark coupled with inclusion of a positive adjective to describe some aspect of learning; thus producing a response suggestive of excitement toward the learning experienced. Responses interpreted as negative accounted for only 2% (n = 10) of all responses included in this study, suggesting the experience did not minimize the significance of participating in the STEM content session.

Hands-on learning supported STEM learning. Thirty-four percent (34%, n = 159) of students in the analyzed response sets referenced the hands-on nature of their experiences as what they liked. Student conveyed this generally in responses such as “hands on” or mention of activities or and experiments, or directly by noting how they actively engaged in building, making, experimenting, or programming. The Discourse commonly employed by students can be interpreted as the context for learning and is supportive of significance. The context was grounded in instructional choices centered around making the STEM learning experience hands-on and interactive for students. The enjoyment of the hands-on component was evidenced by responses such as:

Student W: “That I made something with my own 2 hands” (2013)

Student X: “I liked that were able to use our hands” (2015)

Student Y: “I liked the experiments so we could see how the conceps [sic] work” (2014)

Student Z: “I liked seeing the DNA and building a strand of DNA” (2015)

Student AA: “making electromagnets is fun, and we got to go to different labs and learn the science behind them” (2015)

The five examples represent these five students’ positive feelings about applying concepts during the sessions. They had opportunities to make, build, and create and engage in learning through experimentation and discovery. The notion of “seeing” DNA that Student Z (2015) described was a common characterization of what students liked about learning related to the DNA modeling session. Similarly, the idea of “building”, related to the aluminum and concrete boats, was a common way students expressed positive feelings toward learning by doing. Becoming STEM-literate requires students engaged in STEM-related activities to develop the relevant knowledge, skills, and dispositions to solve real world problems involving STEM areas. Students who identified some aspect of the hands-on nature of the sessions began to see themselves as participating in various STEM activities. So, by identifying the way they actively made, built, created, experimented, discovered, etc., those same students enacted STEM identities that support an emerging STEM literacy.

STEM-related activities are valuable. The theme of STEM as valuable was not as common as the other two discussed. Responses that were coded as such were those that noted the application of learning to other contexts.

- That forensic scientists can use engineering to benifit [sic] their research.
- It was interesting and proved that accidental scientific breakthroughs can

happen anywhere.

- I thought that it was very useful knowledge that people can use in everyday life.
- You can use it to make things at home.
- you [sic] can apply these things to real life.
- That there are multiple answers to every problem
- That Engineering is applied to everything.
- It will help me in science
- I will learn it in science next year
- I can use that information in my future.
- I can do some of these things at home.
- Applications to real life
- I learned to make beads to use on my garden
- that [sic] I can use it in the future
- very [sic] engaging & real world ideas behind them
- Robots are things that we use daily.

The utility of STEM was relevant for those students in reference to a variety of ways including: daily life, future career, problem solving, and scientific advancement. Otherwise, I argue, they would not have used the limited space and time to reflect on connecting learning to real life. It may be that those connections were explicit in individual sessions. However, the step of students writing down those applications as aspects they liked signal some form of significance students have drawn from the experience.

Gee (1999, 2005, 2011) asserted that speakers do not need to be fully aware of the significance for them to give significant to a person or context. For students in STEM camp, the aggregation of reflections on what students liked show how it is common for students to treat their experience in STEM content sessions as a significant or meaningful context for learning. Given student attempts at utilizing the STEM language introduced or explored during the sessions, it appears their significance may support student learning more broadly as emerging STEM literacy. The degree to which the learning experience may not be significant was considered by looking at responses to the question: “Was there anything you did not like about what you learned today?”. However, the majority of students responded “no” or “nothing” to this question, which may suggest the experience built significance rather than lessened it. I saw limitations in the widespread record of single word responses, and thus did not analyze those responses further. While I have highlighted the three themes most prevalent across the responses, students also responded citing specific facts from the sessions or enjoyment for learning about STEM career.

Conclusion and Implications

The problem that framed the inquiry was the need for qualitative methods for assessing STEM literacy. The need arises from the need to prepare future generations for STEM careers and to enable all students to have opportunities to achieve STEM literacy (DOE, 2016). Drawing on discourse analysis allowed for the exploration of how middle school students participating in a summer STEM camp enacted emerging STEM literacy through written reflections to STEM content sessions. This analysis was not aimed at determining which sessions best supported emergent STEM literacy. Rather, it was to understand the situated meaning of student reflections as they reflect individual learning in the selected STEM content sessions. Such a focus allowed a situated learning perspective to be employed throughout the discourse analysis approach to exploring STEM literacy amongst the students.

Central to engaging in this analysis was understanding the context first and foremost. The goal of STEM camp is to impact student interest in and awareness of STEM and STEM careers. Students who participate in STEM camp gain first-hand experience of STEM professions and STEM-related activities through interactions with STEM professionals. In that sense, engagement in STEM practices is a social practice, in that it is situated in the context of STEM camp. Through the process of examining *language-in-use* I was able to hone in on how students come to think about the significance of STEM, enact STEM practices from hands-on experience, and begin to build STEM identities by using situated meanings, social language, and Discourses. Doing so suggested that emerging STEM literacy is present within the context of the summer STEM camp being considered. Student responses appear similar to one another, signaling some sense of imitation in the STEM language utilized during the various sessions. However, it has been argued that doing so supports initial enactment of practices and identities via the use of the social language associated with STEM fields. Those may have been singular or integrated in the given context, but often times occurred alongside the addition of processes and practices associated with STEM fields. Those processes and practices place students in an active role in learning about what it looks like to engage in STEM-related activities. Even though written responses reflected a range of precision in using what would constitute as a social language related to relevant STEM professions, there was a clear attempt at responding to the question about what students learned that they did not know before, and doing so by including terminology that arose in the individual STEM content sessions.

While this discourse analysis attempted to provide robustness of evidence to support claims of emerging STEM literacy, the interpretation is not finite. With any discourse analysis, “analysts should be aware that the remaining questions still serve as an unfinished background to the analysis and it is fair game for any critic to raise one or more of them in questioning the validity of our analyses, which may mean we have to do more work” (Gee, 1999, 2005, 2011, p. 122). Interpreting student responses using the themes was a subjective process. While it is possible for another researcher to characterize a response differently than was done in this analysis, the approach taken in this research was implemented consistently within and across STEM content sessions. This analysis is not generalizable in understanding how to assess STEM literacy. However, it can serve as a framework for thinking about what students are learning using their own written reflections directly after participating in STEM activities in informal contexts. Student language suggested generally favorable attitudes toward the STEM learning experiences, but without additional sources of data the connection to learning could not be fully explored in this study. With additional inquiry methods such as ethnography, researchers could additionally explore learning within the STEM content sessions to link student responses. There is a larger need to explore how qualitative methods could be employed in the study of STEM literacy. This study can inform efforts to develop and validate consistent measures of STEM literacy (e.g., DOE, 2016) amongst students in informal learning environments using qualitative methodologies.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

The overall purpose of this study was to investigate the ways STEM literacy could be assessed in the context of an informal learning environment. In this study, I was able to first, focus on defining STEM literacy; second, investigate the use of a quantitative survey to measure constructs related to STEM literacy using CFA and IRT; and third, use discourse analysis tools to understand emerging STEM literacy amongst middle school students at STEM camp. This study was guided by the following overarching research question: How can STEM literacy amongst middle school students be assessed in the context of a summer STEM camp? In order to further investigate STEM literacy amongst middle school students in a summer STEM camp, ancillary questions were investigated within each article. I was interested in the extent current assessments utilized by the See Blue STEM Camp could detect STEM literacy and in what ways detection was possible. The basis of my chapters centered around situated learning theories, in which the importance of authentic learning experiences and interactions with STEM professionals create opportunities for students to develop STEM literacy during STEM camp in an informal learning environment (Figure 1.1). Students take on an active role in their learning through the experiences, and from the combined influence of the individual, social, and environment, interpretations of the meaning and extent of STEM literacy could be developed.

In this concurrent embedded mixed method design, the qualitative data were collected separately between pre- and post-survey administrations. This chapter triangulates the findings of the quantitative and qualitative analyses to develop overall conclusions (Clark & Creswell, 2008). While findings between the two studies align in some respects, the discourse analysis contributed uniquely to this dissertation in assessing STEM literacy related to knowledge and skills, specifically how students reflected about their learning and enjoyment around the STEM content sessions. Findings are additionally connected to the definition of STEM literacy I developed in Chapter 2.

Overall Findings

In Chapter 3 I argued for a complex two-tier bifactor model defined by four primary and four specific factors. The four primary factors grouped items by science, mathematics, technology, and engineering literacies. Doing so initially revealed a number of dependency issues between items that were resolved through sensitivity analysis in IRT, resulting in the STEM-CISM. Under the confirmed two-tier bifactor model, the primary dimensions were moderately correlated, indicating the primary factors were related but not identical (Bonifay, 2015). For the pre- and post-survey, the primary factors related to science and engineering, science and mathematics, and engineering and technology were the most strongly correlated. Given the required presence of mathematics and science in the middle school curriculum, the stronger correlation is of no surprise. As for engineering and technology, the items focused more so on engaging in engineering and technology activities. For instance, mathematics and science items were written as “I can get good grades in …” but for engineering and technology the items were written as “I can do well in activities involving…”. The discrimination parameters indicated some items were not able to distinguish between students at different levels of latent traits identified for the specific factors. The second thresholds showed that, in general, lower levels of the latent trait were sufficient to respond *agree* or *strongly agree* to items. Findings made based on parameters obtained in IRT mirrored those made from the CFA results. The CFA results showed a number of factor loadings of items on specific factors were large, most notably for the utility of STEM in society and sense of community latent traits. Descriptively speaking, the average observed scores for students for each of the eight factors estimated using the EAP method in IRT were higher on the post-survey than the pre-survey. Items that initially had low discriminating power such as item 42 (“I have a role model in an engineering career”) tended to poorly discriminate between laten levels on the post-survey. However, the degree to which any change was statistically significant was investigated with respect to the primary factors.

For each of the primary factors, the omega values were generally about .04 larger than omegaHs. The small difference in these values suggested each primary accounted for the majority of the total score variance with respect to each primary factor, allowing for a multivariate analysis using EAP observed scores for the four primary factors. The score variance for the specific factors was not consistently salient, indicating the respective primary factor accounted for much of the score variance and the specific factors did not need to be separately accounted for in the multivariate analysis. The difference between the pre- and post-survey in terms of the combined multivariate effect was statistically significant when raw summed scores were used for analysis. However, the results from the RM MANOVA involving pre- and post- survey EAP scores did not agree with the raw score results. Although the impact of STEM camp cannot be directly linked as the causative effect for the pre- to post-survey changes, the results are promising in considering future design of scales to measure STEM literacy.

The importance of the qualitative findings in reflecting the ways students were impacted by STEM camp were solidified by immediate completion following a STEM content session. The analysis centered on examining four themes (level of reflective thinking, use of vocabulary consistent with STEM professionals, processes and practices of STEM, and integration of STEM content) that arose in the context of five STEM content sessions. Among the four themes, use of STEM vocabulary was the most prevalent across student responses. The ways students enacted STEM practices and STEM identities as evidenced by the presence of identified themes suggested varying levels with which students can utilize STEM language in relevant contexts. Students were able to engage in various levels of reflective thinking about their learning when they participated in an authentic, hands-on STEM learning experience. Two hundred forty-three of the 473 students' responses (51.4%) exhibited a level of thinking, beyond listing items, to include an action or application of STEM content. Those who demonstrated higher levels of reflective thinking more consistently utilized specialized language for the STEM content explored in the STEM learning experience. Specifically, 226 (93.0%) of those responses additionally included STEM vocabulary akin to a STEM professional. Some students were able to articulate this more clearly than others. Just as some were able address learning in the context of the practices and processes associated with STEM. Processes, practices and integration of STEM content were not as prevalent amongst the analyzed responses, with 76 (16.1%) and 34 (7.2%) responses, respectively.

Findings by Specific Factors

Perception of ability and self-efficacy. Perception of ability was also described as self-efficacy in this study. Given the importance of self-efficacy in social cognition, I did not want to confuse the theoretical construct that guided my work by relying on terminology embedded in social cognition. However, the items identified as perception of ability or self-efficacy aligned to those labeled as such Kier et al. (2014) in the original design of the STEM-CIS. Willingness to learn has been identified as a characteristic of a confident person (Llewellyn, 2009). The aspects of my definition of STEM literacy that relate are “conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues” (Bybee, 2010, p. 31) and willingness to engage and persist in STEM (e.g., Wilkins, 2000, 2010, 2015). This latent trait remained relevant because self-efficacy has been identified as a factor influencing interest and success of underrepresented minorities (Museus et al., 2011) and females (Dweck, 2006; Hill et al., 2010; Wang & Dogel, 2013, p. 5) in STEM. However, the contribution of perception of ability/self-efficacy to the overall model was not reflected in CFA based reliability measures. That is, omegaHS values were generally low for perception of ability, indicating perception of ability could not be meaningfully interpreted apart from the corresponding primary factor. The largest omegaHS for perception of ability occurred on the post-survey where 30.2% of the subscale variance can be attributed to the perception of ability/self-efficacy latent trait after controlling for variance due to mathematics literacy. In this instance, we see a contribution to the total variance large enough to consider looking more deeply at how perception of ability exists as a latent trait to measure STEM literacy. Perception of ability/self-efficacy was less discriminating for technology and engineering items and was one of the two specific factors that yielded the smallest range of observed scores based on the EAP method. Perception of ability/self-efficacy was not a theme explored in the discourse analysis.

Therefore, the qualitative work did not add to understanding of how perception of ability contributes to a measure for STEM literacy.

Attitudes and interest. The findings related to attitudes and interest for the quantitative and qualitative analyses offer different ways this latent trait was assessed. Wilkins' (2015) work with modeling quantitative literacy informed the identification of the latent trait attitudes and interest in modeling STEM literacy. Specifically, the aspect of the definition developed in Chapter 2 that relates to attitudes and interest was written as a positive disposition toward STEM (e.g., Wilkins, 2000, 2010, 2015). Items related to attitude and interest were more discriminating on the primary trait related to engineering than the other primary dimensions. The three items least discriminating on attitudes and interest for the pre-survey were item 8 ("I like my science class"), item 19 ("I like my mathematics class"), and item 29 ("I like to use technology for class work"). Item 19 and item 29 were especially troubling on the pre-survey because each item loaded on attitudes and interest at less than .05, suggesting almost no unique contribution to understanding of the item beyond the primary factor. Additionally, item 19 was not fit by the model for the post-survey data. On the post-survey, discriminatory power among those items was still low, and loadings remained non-salient. These findings led me to conclude there are numerous items related to attitude and interest that should be reworded. Specifically, there needs to be a balance between items related to formal and informal learning environments. The qualitative methods could provide invaluable insight of the extent that students distinguish between learning in different environments and in different STEM disciplines. The diversity of student experiences may limit interpretation of levels of latent trait. Take item 29 as an example. A student may have limited opportunities to use technology in their middle school classroom, thus making it difficult to discern attitude and interest by student response to such an item.

All items related to attitude and interest that were least discriminating related to attitudes specific to the formal setting as evidenced by the smaller slopes yielded by the model in IRT. Student attitudes toward STEM subjects could be more of a reflection of the experience in formal school. Statistics for local dependency did not suggest any concerns over redundancy of the items on the STEM-CISM. The average EAP score for attitudes and interest was higher than the average for the other three specific factors for the pre- and post-survey, and EAP scores reflected a broader range of levels of attitude and interest. But, it is difficult to interpret those latent levels. With revisions to items related to attitudes and interest, I suspect the EAP scores could be interpreted with greater reliability.

For the qualitative data, it was clear students were positive about their experiences above and beyond simply liking the STEM content session and enjoyed the hands on aspect of the experience. These finding reinforce what Mohr-Schroeder et al. (2014) concluded when they analyzed student reflection data. Those findings are important to reinforce because of interest and engagement in STEM, but I aimed to further the research by connecting the outcome of student experiences to developing STEM literacy. Where students connected what was learning to favorable attitudes toward that learning, I saw student willingness to engage in STEM-related activities. Such a willingness has been associated with literacy in STEM subjects. For example, a student in the engineering session in 2015 remarked “I thought it was cool that we got to build things.” Building is part of the processes and practices for learning STEM subjects. A description of the opportunity to build as cool suggests the student thought favorably about engaging in engineering practices.

Utility of STEM. There are three aspects of the definition developed in Chapter 2 that relate to a theme — it is useful to engage in STEM. Specifically, those aspects are a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015), an understanding of the utility of applying STEM concepts to solve real world problems, and an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change. Within the items identified for the latent trait utility of STEM, those related to technology ("If I learn a lot about technology, I will be able to do lots of different types of careers" and "When I use technology in school, I am able to get better grades") were the least discriminating on the pre- and post-survey. The single science item ("If I do well in science classes, it will help me in my future career") and mathematics item ("If I do well in mathematics classes, it will help me in my future career") identified as utility of STEM were the most discriminating. The extent that students exhibit a disposition toward STEM related to the belief that STEM can help them with their future career could be understood by looking at student responses to the corresponding item. For future administrations of surveys aimed at assessing STEM literacy, these items can add to understanding of the construct. For the qualitative analysis, the theme of "STEM as valuable" was not as common as the other two discussed. Responses coded as such were those that noted the application of learning to other contexts. Three of the examples highlighted in Chapter 4 were "that there are multiple answers to every problem"; "I learned to make beads to use on my garden"; and "That forensic scientists can use engineering to benifit [sic] their research".

Student responses suggested that utility of STEM was relevant for those students in reference to a variety of ways including: daily life, future career, problem solving, and scientific advancement. The fact that students recorded those applications additionally signaled some form of significance students drew from the experience.

Sense of Community. The sense of community construct relates to the ability to engage in STEM specific discourse because of the focus on social interactions to support STEM literacy. Social interactions are important. For the reflection data, that importance is implicit in the significance students attributed to the sessions. The omegaHS for sense of community was high for all primary factors indicating a substantial amount of the total variance can be attributed to the sense of community specific factor after controlling for the respective primary factor. Students more readily endorsed item 9 ("I have a role model in a science career"), and item 42 ("I have a role model in an engineering career") on the pre-survey than the post-survey as evidenced by the thresholds. Both items involved students identifying the extent to which they have a role model in science and engineering, respectively. Four testlet-based items with the sentence stem, "I would feel comfortable talking to people who work in…careers" loaded on the specific factor similar to, if not higher than, their individual loadings on their respective primary factor. Students with higher levels of latent traits related to primary factors tended to have higher levels of latent traits related to sense of community items as evidenced by EAP scores on the pre- and post-survey. Sense of community could be reconceptualized by specifying the model differently, namely so items load on sense of community as a primary rather than specific factor. However, I offer this conclusion with some hesitation. If students were not distinguishing between STEM subjects, then the information provided by a student response to a science item could be redundant to a student response on a similarly worded mathematics, technology, or engineering item. The result would be inflated reliability measures, leading to inaccurate analysis of the overall contribution of sense of community. It would be interesting to reword items to reflect STEM careers and role models more broadly (i.e., "I have a role model in a STEM career").

The use of different forms of social language suggested varying levels of student ability to enact STEM practices and STEM identities. Students who demonstrated higher levels of reflective thinking during the engineering session, for example, utilized specialized language for the engineering content explored during the session than those who used language representing a low level of reflective thinking. The range in levels of enacting social language occurred during the DNA modeling session as well. Descriptions of DNA ranged from acknowledgement of a DNA having a structure to specific description of its structure whether by utilizing social language consistent with related STEM professionals, or that of a more everyday vernacular. As legitimate peripheral participants, students gained initial entry into the STEM content based on their prior experiences with STEM. Consequently, the way students communicated their learning was influenced by those experiences coupled with the direct social interaction with STEM content and STEM professionals during camp. Student efforts to communicate their experience within the STEM content sessions showed engagement with STEM content, thereby reflecting emerging STEM literacy.

Conclusions and Implications

The findings of this study led to more questions than answers. How can students come to engage in STEM in a way that supports the development of STEM literacy?

How can instruments be developed that measure STEM literacy? And, how can those instruments be implemented broadly to enable a standardized measure for STEM literacy? Berkeljon (2012) concluded the “principle problem for the clinical researcher is unifying a quantifiable method with phenomena resistant to quantification. That is, finding a standard of measurement to capture illusive phenomena” (p. 51) such as, in this case, perception of ability or self-efficacy, attitude and interest, belief of utility of STEM in society, and feelings of a sense of community. The balance of quantitative and qualitative methods in assessing STEM literacy in an informal environment can provide a more comprehensive picture of the complexity of STEM literacy as a construct that could not have been achieved using a single measure. I did not see assessment of the knowledge and skills components of STEM literacy as possible in the context of STEM camp without being at odds with essential components of informal learning environments to not be school-like. Sources of data that were qualitative in nature filled in those gaps in measuring knowledge and skills related to STEM literacy, thus strengthening the reliability of quantitative results related to the affective components. The conclusions that can be made from this study relate to how STEM literacy is conceived, and how the informal learning environment offers pathways to emerging STEM literacy.

STEM Literacy as a Continuum

“Literacy itself refers to a continuum of skills—it is not a condition that one has or does not have (i.e., literacy or illiteracy), but rather each person’s skills place them in a particular place on the literacy continuum.” (Lemke et al., 2004, p. 2). The view of literacy offered by Lemke et al. (2004) should be considered further to understand how to assess STEM literacy, namely by acknowledging that literacy exists along a continuum.

Students exhibited levels of STEM literacy along a continuum and were able to differentially articulate new learning after participating in STEM content sessions. The meaning interpreted from how students enacted STEM identities and STEM practices were invaluable to building the argument for the way student STEM literacy emerged. The ways students conveyed their new learning suggest students moved toward becoming STEM-literate. IRT and CFA were valuable in investigating the latent constructs associated with STEM literacy, because each assumed the latent construct can be represented as a continuum. The statistically significant difference between the pre- and post-survey using raw scores led me to conclude that student latent traits did increase from the beginning to end of camp. Students moved forward along the latent continuum for STEM literacy defined by eight latent factors. More students had higher levels of the latent traits with respect to the eight factors on the post-survey than the pre-survey. However, the changes were not statistically significant over and beyond what was expected by the calibrated model. The difficulty in understanding this difference quantitatively could be more telling of the instrument than the impact of STEM camp on levels of STEM literacy. STEM literacy can be thought of more broadly than connections to performance and confidence in the formal school setting to develop a measure that reflects a full continuum of STEM literacy. If items reflected that broader perspective, then the impact of STEM camp on levels of the various latent traits could be interpreted with greater confidence.

Informal Learning Environments as a Platform for Emerging STEM Literacy

The design and structure of camp aligns to Gutiérrez’s dimensions of equity (2009), namely access and identity. Engagement in STEM practices is a precursor for emerging STEM identities, which, in turn, offers a pathway to emerging STEM literacy. While the STEM identities enacted by students did not elevate students beyond *legitimate peripheral participants*, opportunities arose for students to enact STEM identities as they participated in STEM content sessions facilitated by STEM professionals. The STEM Camp allowed students to access STEM content through authentic, hands-on learning experiences. The hands-on aspect of the STEM learning experiences was particularly significant for students. Higher levels of reflective thinking were apparent in sessions where students had greater hands-on opportunities to interact with the STEM content, and in collaboration with peers and STEM professions. Students came to see STEM-related activities as valuable and exhibited positive dispositions toward STEM learning. While I can conclude that attitudes and interest for mathematics and science items were discriminating, that was not the case for technology and engineering. Therefore, it was difficult to interpret latent levels of attitude and interest toward the collective STEM amongst students. While social interactions were essential within the situated learning perspective I adopted for this study, it appears I underestimated the importance of role models in identifying model specifications for the STEM-CIS. By using that language in their written reflections, students, to some degree, applied what they learning, doing so in a way that was influenced by the STEM professionals.

The integrated STEM content and foci on practices and processes are components of STEM camp not fully realized in this study. There was some evidence students valued the integration of STEM disciplines in learning STEM content, but connections between STEM subjects were not widespread in student responses. There are a number of reasons this finding may have occurred. The connections between STEM disciplines could have been highlighted in STEM content sessions, but did not directly translate to new learning many students could articulate in the limited space and time of a written reflection. The current STEM-CIS could not add to interpretations about students' beliefs related to integrated STEM learning experiences. There were no items that were integrated in nature, hence the identification of four primary factors defined by science, technology, mathematics, and engineering literacy. There appears to be an absence of a measure to detect student ability to make connections across STEM disciplines.

There were notable attempts by student to enact relevant Discourses in STEM when responding to the question about what students learned that they did not know before. But, the connection to processes and practices was not strong. The processes and practices place students in an active role in learning about what it looks like to engage in STEM-related activities. The connection to modeling and engaging in scientific practices were evidenced by reflections where the *language-in-use* was more precise, and more aligned to the social language of STEM professionals in biology and genetics. The connection to the processes and practices were not consistently made by students, and analysis could not be complemented by analysis of the STEM-CIS. As with integration, STEM-CIS did not reflect processes and practices.

Limitations

The STEM-CIS was originally designed to measure interest in pursuing STEM careers. I attempted a bold reconceptualization of STEM-CIS as a measure of affective factors associated with STEM literacy. The literature supported relationships between persistence in STEM and STEM literacy to justify this new direction for the STEM-CIS. However, the restriction to essentially psychological constructs in measuring STEM literacy using the STEM-CIS could be considered a limitation to fully covering the knowledge, skills, and dispositions associated with STEM literacy. The precision of measurement that could be obtained with the high dimensionality, number of items, and resulting parameters may not allow for conclusive findings of the STEM-CIS as a tool for measuring STEM literacy. Its use is in the potential to inform efforts to design a new scale for STEM literacy with a conceptualization of STEM literacy related to situated learning and the global impact of individuals achieving STEM literacy.

It is possible that with additional sources of data, distinguishing across those levels could be accomplished more precisely. Multiple sources of data were available for the STEM camp but I decided to limit this study to two of those sources. This choice arose from an early examination of how different sources of data were linked to specific students and others were not, and different data sources could be used to help accomplish my intended purpose. I remain committed to that decision but understand the value in considering alternative approaches in future research.

Recommendations

This study was conducted immediately following the publication of *STEM 2026*, a framework for transforming STEM education (DOE, 2016). STEM camp is one type of learning environment where the framework can be applied to help deliver on key components of the framework while advancing equity in STEM. While the outcomes and focus of the STEM camp were conceived over five years ago, their work is relevant to aligning to *STEM 2026*. My work most immediately used research tools to investigate ways to assess STEM literacy in an informal learning environment. Ultimately, I hope my work can help advance equity in STEM by bridging the opportunity gap (Flores,

2007) through recommendations for establishing consistent measures for STEM literacy in informal learning environments. STEM literacy is just one of the relevant constructs that instruments should be developed around as policies and initiatives are developed to advance DOE's framework and evaluate how the framework is being applied consistently to best serve all students. This extends to a need to be explicit about where STEM literacy fits in within a framework for transformative STEM education because STEM literacy has been identified as valuable and important for preparing a STEM workforce (e.g., NSB, 2015) and ensuring all people can achieve STEM literacy (e.g., DOE, 2016).

The STEM-CIS provided an opportunity to assess STEM literacy, although from a siloed perspective, where science, mathematics, technology, and engineering were treated separately. If the STEM-CIS could be redesigned using the recommendations discussed extensively in Chapter 3, then it could reflect an integrated perspective of STEM literacy. Additionally, adding a third time point at the start of the academic school year could be useful in planning for longitudinal studies of the impact of camp on student STEM literacy or other constructs of interest to meet the goals outlined by camp leadership. Scale development should be supplemented by qualitative measures to assess knowledge and skills related to STEM content. Student reflections are a good starting point because it provides an aggregated view of the learning that occurred related to specific STEM content sessions. However, the context could be better developed by adding an ethnographic component to connect student learning to comprehensive details of the content and how students engaged in the STEM learning experiences. Interviews have been conducted during STEM camp since 2014. If they are to be used for triangulation to analyze STEM literacy, I recommend linking students to reflection data.

Once measures of STEM literacy are developed and validated, they can be implemented in similar informal contexts. DOE (2016) summarized the importance of measures of learning:

> Although it will remain important in the future, as it is today, to assess the extent to which students are equitably developing facility with and mastery of core content knowledge, the future measures of learning…also value the enduring skills and personal qualities that demonstrate academic tenacity and competence, and other lifelong learning skills that will remain relevant in 10 to 20 years. (Duckworth & Yeager, 2015, p. 21)

The implication of establishing such measures can inform continuous improvement of efforts to improve STEM education. Consistent, valid, and reliable measures of STEM literacy can help stakeholders remain mindful of how learning experiences are designed and implemented to improve outcomes for all students. Then, STEM literacy for all can become a reality.

Appendix A

Original and Reconceptualized Item Classification for STEM-CIS

	Item	Reconceptualized Classification	Original Classification
1	I am able to get a good grade in my science class.	Self-efficacy	Self-efficacy
2	I am able to complete my science homework.	Self-efficacy	Self-efficacy
3	I plan to use science in my future career.	Attitude and interest	Personal goal
4	I will work hard in my science classes.	Attitude and interest	Personal goal
5	If I do well in science classes, it will help me in my future career.	Role and utility of STEM in society	Outcome expectation
6	My parents would like it if I choose a science career.	Family influence	Outcome expectation
7	I am interested in careers that use science.	Attitude and interest	Interest in science
8	I like my science class.	Attitude and interest	Interest in science
9	I have a role model in a science career.	Sense of community	Contextual support
10	I would feel comfortable talking to people who work in science careers.	Sense of community	Personal input
11	I know someone in my family who uses science in their career.	Family influence	Contextual Support
12	I am able to get a good grade in my mathematics class.	Self-efficacy	Self-efficacy
13	I am able to complete my mathematics homework.	Self-efficacy	Self-efficacy
14	I plan to use mathematics in my future career.	Attitude and interest	Personal goal
15	I will work hard in my mathematics classes.	Attitude and interest	Personal goal
16	If I do well in mathematics classes, it will help me in my future career.	Role and utility of STEM in society	Outcome expectation
17	My parents would like it if I choose a mathematics career.	Family influence	Outcome expectation
18	I am interested in careers that use mathematics.	Attitude and interest	Interest in science
19	I like my mathematics class.	Attitude and interest	Interest in science
20	I have a role model in a mathematics career.	Sense of community	Contextual support

	Item	Reconceptualized Classification	Original Classification
21	I would feel comfortable talking to people who work in mathematics careers.	Sense of community	Personal input
22	I know someone in my family who uses mathematics in their career.	Family influence	Contextual Support
23	I am able to do well in activities that involve technology.	Self-efficacy	Self-efficacy
24	I am able to learn new technologies.	Self-efficacy	Self-efficacy
25	I plan to use technology in my future career.	Attitude and interest	Personal goal
26	I will learn about new technologies that will help me with school.	Attitude and interest	Personal goal
27	If I learn a lot about technology, I will be able to do lots of different types of careers.	Role and utility of STEM in society	Outcome expectation
28	When I use technology in school, I am able to get better grades.	Role and utility of math in society	Outcome expectation
29	I like to use technology for class work.	Attitude and interest	Interest in science
30	I am interested in careers that use technology.	Attitude and interest	Interest in science
31	I have a role model who uses technology in their career.	Sense of community	Contextual support
32	I would feel comfortable talking to people who work in technology careers.	Sense of community	Personal input
33	I know someone in my family who uses technology in their career.	Family influence	Contextual Support
34	I am able to do well in activities that involve engineering.	Self-efficacy	Self-efficacy
35	I am able to complete activities that involve engineering.	Self-efficacy	Self-efficacy
36	I plan to use engineering in my future career.	Attitude and interest	Personal goal
37	I will work hard on activities at school that involve engineering.	Attitude and interest	Personal goal
38	If I learn a lot about engineering, I will be able to do lots of different types of careers.	Role and utility of STEM in society	Outcome expectation
39	My parents would like it if I choose an engineering career.	Family influence	Outcome expectation
40	I am interested in careers that involve engineering.	Attitude and interest	Interest in science
41	I like activities that involve engineering.	Attitude and interest	Interest in science
42	I have a role model in an engineering career.	Sense of community	Contextual support
43	I would feel comfortable talking to people who are engineers.	Sense of community	Personal input
44	I know someone in my family who is an engineer.	Family influence	Contextual Support

Appendix B

34-Item STEM-CISM

1	I am able to get a good grade in my science class.
3	I plan to use science in my future career.
4	I will work hard in my science classes.
5	If I do well in science classes, it will help me in my future career.
7	I am interested in careers that use science.
8	I like my science class.
9	I have a role model in a science career.
10	I would feel comfortable talking to people who work in science careers.
12	I am able to get a good grade in my mathematics class.
13	I am able to complete my mathematics homework.
14	I plan to use mathematics in my future career.
15	I will work hard in my mathematics classes.
16	If I do well in mathematics classes, it will help me in my future career.
18	I am interested in careers that use mathematics.
19	I like my mathematics class.
21	I would feel comfortable talking to people who work in mathematics careers.
23	I am able to do well in activities that involve technology.
24	I am able to learn new technologies.
25	I plan to use technology in my future career.
26	I will learn about new technologies that will help me with school.
27	If I learn a lot about technology, I will be able to do lots of different types of careers.
28	When I use technology in school, I am able to get better grades.
29	I like to use technology for class work.
30	I am interested in careers that use technology.
32	I would feel comfortable talking to people who work in technology careers.
34	I am able to do well in activities that involve engineering.
35	I am able to complete activities that involve engineering.
36	I plan to use engineering in my future career.
37	I will work hard on activities at school that involve engineering.
38	If I learn a lot about engineering, I will be able to do lots of different types of careers.
40	I am interested in careers that involve engineering.
41	I like activities that involve engineering.
42	I have a role model in an engineering career.
43	I would feel comfortable talking to people who are engineers.

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Educational Institutions

University of California Los Angeles
Master's in Education, 2006

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Professional Positions

- Graduate Research Assistant, Experimental Program to Stimulate Competitive Research (EPSCoR) NSF Grant, University of Kentucky Lexington, KY *(August 2014-Present)*
- CS*Uteach* Master Teacher-Mathematics, College of Education and Human Services, Cleveland State University, Cleveland, OH *(August 2011-May 2014)*
- Center for Innovation in STEM Education Assistant Instructor, Great Lakes Science Center, Cleveland, OH *(2012-2013)*
- High School Mathematics Teacher, Parkway Academy of Technology and Health, Boston Public Schools, Boston, MA *(September 2006-July 2011)*
- Summer Bridge Program Instructor, Wentworth Institute of Technology, Boston, MA *(Summer 2008)*
- High School Mathematics Teacher, Centinela Valley Union High School District, Leuzinger High School, Lawndale, CA *(2005-2006)*

Scholastic and professional honors

- University of Kentucky College of Education John Edwin Partington and Gwendolyn Gray Partington Scholarship (2016-2017)

Professional publications

Delaney, A., Albers, S., Williams, M., **Calvalcanti, M.,** Chadd, E., Thomas, O. T., Jackson, C., & Mohr-Schroeder, M. J. (revise and resubmit). Using games to foster algebraic reasoning. Submitted to *Mathematics Teaching in the Middle School.*

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Jackson, C., Mohr-Schroeder, M. J., **Cavalcanti, M.,** Albers, S., Poe, K., Delaney, A., Chadd, E., Williams, M., & Roberts, T. (accepted). Prospective mathematics teacher preparation: Exploring the use of service learning as a field experience. To appear in *Fields Mathematics Education Journal*.

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Professional Presentations

Mohr-Schroeder, M. J., Jackson, C., **Cavalcanti, M.,** & Delaney, A. (2017, February). *Increasing STEM literacy of preservice and inservice teachers via an informal learning environment*. Paper presented at the annual conference of the Association of Mathematics Teacher Educators, Orlando, FL.

Schroeder, D. C., Jackson, C., Mohr-Schroeder, M., & **Cavalcanti, M.** (2016, October). *Motivating and inspiring students' interest in STEM.* Paper presented at the annual School Science and Mathematics Convention, Phoenix, AZ.

Mohr-Schroeder, M. J., Schroeder, D. C., Jackson, C., Walcott, B., **Calvacanti, M**., Delaney, A., & Evans, M. (2016, May). *Broadening participation of underrepresented populations.* Video presented at the NSF 2016 Video Showcase. Available at http://stemforall2016.videohall.com/

Cavalcanti, M. & Mohr-Schroeder, M. (2015). *Mobilizing STEM education through leadership, partnership, and apprenticeship: A doctoral student's perspective*. Presented at annual convention of the School Science and Mathematics Association, Oklahoma City, OK.

Cavalcanti, M. & Mohr-Schroeder, M. (2015, October). *An application of the Rasch model to the parent attitudes toward mathematics (PATM) survey*. Presented at the Ohio River Valley Objective Measurement Seminar, Lexington, KY.

Albers, S., Poe, K., Mohr-Schroeder, M. J., Schroeder, D. C., **Cavalcanti, M.**, Blyman, K., & Roberts, O. T. (2015, April). *Using informal learning environments to prepare preservice teachers to work with struggling mathematics learners.* Paper presented at the annual meeting of the Kentucky Mathematics Educators Development (KMED), Richmond, KY.

Mohr-Schroeder, M. J., Schroeder, D. C., Walcott, B., Jackson, C., Evans, M., & **Cavalcanti, M.** (2015, May). *Informal STEM learning communities to broaden participation of underrepresented populations in STEM.* Poster presented at the annual Kentucky EPSCoR Conference, Lexington, KY.

Schroeder, D. C., Jackson, C., Mohr-Schroeder, M. J., Powers, L. B., Albers, S., Poe, K., Roberts, O. T., Blyman, K., **Cavalcanti, M.**, & Speler, L. (2015, April). *Tapping the potential of struggling learners of mathematics: Instructional strategies.* Gallery workshop presented at the annual meeting of the National Council of Teachers of Mathematics, Boston, MA.

Jackson, C., Mohr-Schroeder, M., Schroeder, D. C., Roberts, O. T., Blyman, K., & **Cavalcanti, M.** (2014, November). *Preparing prospective teachers to work with students who struggle in mathematics.* Paper presented at the annual convention of the School Science and Mathematics Association, Jacksonville, FL.

Schroeder, D. C., Jackson, C., Mohr-Schroeder, M. J., Blyman, K., Roberts, O. T., & **Cavalcanti, M.** (2014, November). *Motivating and inspiring middle level students' interest in STEM via STEM Camp.* Paper presented at the annual convention of the School Science and Mathematics Association, Jacksonville, FL.

CSUteach Leadership Team (2012, June). CS*Uteach: A STEM teacher preparation program*. Poster presented at the Teacher Quality Partnership Project Director's Meeting at the Department of Education, Washington D.C.