“It’s What We Use as a Community”: Exploring Students’ STEM Characterizations In Two Montessori Elementary Classrooms

A THESIS
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

Alaina Hopkins Szostkowski

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF ARTS

Julie C. Brown

June 2017

Acknowledgements

My deepest thanks to Dr. Julie Brown, an unfailing source of support, ideas, and feedback throughout the process of conceptualizing and carrying out this project. I also acknowledge the members of my committee, Dr. Nina Asher and Dr. Bhaskar Upadhyay, for their insight and expertise. Katie Ibes provided me with vision, advice, and insight into the philosophy of Montessori STEM. Most of all, my gratitude to April Zoll Close and Erin Allen for their generosity and collaboration, and to all of the young people who shared their ideas and experiences with me. Last but not least, my housemates, STEM colleagues, parents, and partner Daniel Raskin, who made sure I had my all my fundamental human needs met.

Dedication

This thesis is dedicated to my grandparents, William and Dorothy Hopkins, whose love and generosity made so many other lives possible.

Abstract

Integrated science, technology, engineering, and mathematics (STEM) education promises to enhance elementary students' engagement in science and related fields and to cultivate their problem-solving abilities. While STEM has become an increasingly popular reform initiative, it is still developing within the Montessori education community. There is limited research on STEM teaching and learning in Montessori classrooms, particularly from student perspectives. Previous studies suggest productive connections between reform-based pedagogies in mainstream science education and the Montessori method. Greater knowledge of this complementarity, and student perspectives on STEM, may benefit both Montessori and non-Montessori educators. This instrumental case study of two elementary classrooms documented student characterizations of aspects of STEM in the context of integrated STEM instruction over three months in the 2016-2017 school year. Findings show that the Montessori environment played an important role, and that students characterized STEM in inclusive, agentive, connected, helpful, creative, and increasingly critical ways. Implications for teaching and future research offer avenues to envision STEM education more holistically by leveraging the moral and humanistic aspects of Montessori philosophy.

Table of Contents

List of Tables

List of Figures

Chapter 1 : Introduction

Since the turn of the millenium, integrated science, technology, engineering and mathematics education—known by the acronym "STEM"—has become a flagship initiative in science education reform (Honey, Pearson, & Schweingruber, 2014). Policymakers concerned about student achievement and declining participation rates in degree programs and careers have called on educators to engage young people in STEM (Committee on Science and Technology, 2008). Despite a dramatic increase in funding for programs and interventions, there remains limited consensus on the meaning of STEM (Bybee, 2013). Moreover, scholars are just beginning to operationalize conceptual models for STEM integration across school settings (Kelley & Knowles, 2016). Structural features, such as separate classes for each discipline, specialized teachers, and testing considerations, make multidisciplinary programs a challenge in secondary schools (Honey et al., 2014). Elementary classrooms in which teachers already teach multiple subject areas may be an ideal place to further develop STEM integration (Daugherty, Carter, & Swagerty, 2014). Furthermore, elementary school is a critical time for students to establish foundational knowledge and positive attitudes essential for future STEM success (Duschl, Schweingruber, & Shouse, 2007; Honey et al., 2014).

Students' engagement in science and related fields begins at a young age (Archer et al., 2010; Aschbacher, Li, & Roth, 2009; Honey et al., 2014). Studies conducted in the United States and England have shown early experiences leave a strong impression that shapes later academic and career choices: by age 11, children's interest in science could be directly linked to previous scientific experiences; by age 14, their future career goals were largely formed (Archer et al., 2010). School setting and peer and family relationships are social factors that play an important role in students' characterizations of science and scientists, as well as their own relationship to these concepts (Aschbacher et al., 2009). Students who express interest in their elementary years may not persist beyond middle or high school, particularly when they do not identify with the culturally-produced image of science celebrated in their learning environment or the wider society (Carlone, Scott, & Lowder, 2014). Examining how elementary children construct STEM understandings in particular classrooms may shed light on what motivates their engagement. As they are the intended beneficiaries of "top-down" integrated STEM initiatives (Johnson, 2013, p.367), it is worthwhile to understand what students themselves think about STEM. This is the purpose of the present study, which explores elementary students' STEM characterizations in two Montessori classrooms.

Stohlmann, Moore, and Roehrig (2012) recommend that research-based best practices in constructivist science, mathematics, and engineering teaching inform integrated STEM instruction. These include use of manipulatives, cooperative learning, building on prior knowledge, and learning through discussion and inquiry (Stohlmann et al., 2012). Classrooms in which such elements are already present may therefore provide a rich context for exploring student characterizations of STEM.

According to criteria identified by Stohlmann and colleagues (2012), Montessori classrooms are suitable environments for STEM integration. Anticipating the insights of constructivist learning theories that have dominated science education research since the mid-twentieth century (Taber, 2006), founder Maria Montessori believed that children make meaning through concrete experiences of phenomena. Children in Montessori "prepared environments" use specially designed materials to "explore until satisfied" (Rinke, Gimbel, & Haskell, 2013, p. 1525). They are able to follow their own interests and communicate freely with their peers.

The Montessori method is a child-centered form of education that emphasizes hands-on work in a collaborative learning environment (Cossentino, 2005). Italian physician Maria Montessori (1870-1952) viewed learning as a process of building the self, one she theorized took place in interactions between the child, her community, and her physical surroundings (Lillard, 2007). Dr. Montessori's work with intellectually disabled toddlers and young children living in poverty led her to adapt sensorial materials created by French physicians Jean-Marc Itard and Eduard Séguin to support her initial theory that spontaneous activity with concrete materials stimulated self-directed cognitive growth (Association Montessori Internationale, 2016b). Observations and successful pedagogical experiments later inspired her to apply her methods with children from a range of ability, cultural and socioeconomic backgrounds. Today, Montessori schools are found all over the world (Association Montessori Internationale, 2016a).

Practitioners recognize parallels between Montessori and STEM (Ibes & Ng, 2011; McNamara, 2016). However, there are no empirical case studies of prospective intersections between them. In fact, general scholarly investigation of Montessori schools remains limited (Whitescarver & Cossentino, 2008). Past researchers have examined the Montessori classroom environment and teachers' beliefs and practices (e.g. Cossentino, 2005). Several psychologists conducted quantitative analyses of student experiences (e.g.

Rathunde & Csikszentmihalyi, 2005). Research suggests that Montessori education leads to positive social-emotional and academic outcomes for students (Lillard, 2012), particularly in math and science (Dohrmann, Nishida, Gartner, Lipsky, & Grimm, 2007). At the time of this writing, however, there have been no studies exploring STEM integration in Montessori classrooms from student perspectives.

Rationale for Study

The overall purpose of this instrumental case study (Stake, 1995) was to examine Montessori students' characterizations of aspects of STEM. The study was conducted in two separate classrooms over a period of one semester in a single school year, in the context of instruction by teachers with extended training integrating Montessori and STEM education (Ibes & Ng, 2011). I examined the evolving characterizations of elementary children aged six through twelve, corresponding to grades one through six. Rather than measure student achievement or learning outcomes, I wanted to know how these students made meaning of their STEM experiences—what they viewed as the "Who, What, Where, When and Why" of STEM.

My focus on student perspectives is informed by a critical appraisal of STEM reform initiatives. While interdisciplinary curricula and opportunities to apply learning in real-world contexts may improve learning and benefit students previously marginalized in conventional science instruction (Honey et al., 2014), critics stress that integrated STEM should not be considered a reform "panacea" (Zeidler, 2016, p. 11). Policymakers, corporate partners, and researchers often justify STEM education initiatives with the aim of building a future workforce that can offset the United States' waning status as an innovation superpower (see the rationale in Cotabish, Robinson, Dailey, & Hughes, 2013 for example). Secondly, without an accompanying "humanistic perspective of scientific literacy" or attention to connections between the arts and the sciences, Dana Zeidler (2016) has claimed STEM education reifies "crypto-positivist…technocratic" views of science and engineering, which imply complex problems can be solved in a technological quick fix apart from their sociocultural contexts (2016, pp. 15-17). Lyn Carter (2016) further argues that even if STEM programs are ostensibly developed in the name of young people, a larger neoliberal economic agenda is driving the direction of reform. Thus, critics suggest that STEM education's economic development imperative may wind up outweighing its claims for educational equity and improvement.

Conversely, the primary goal of Montessori education is to create a more just and peaceful planet (Montessori, 2007). Each organism or Earth process that children engage with is conceptualized in service of that goal. As a doctor herself, Montessori (2000) was heavily invested in children developing a scientific worldview, but one compatible with a philosophical stance on the necessity of interdependence. The present study therefore examines Montessori elementary students' characterizations of STEM as a small step toward a larger research agenda: shifting STEM education discourse from an emphasis on international economic competition towards a more holistic understanding of the responsibilities humans have as scientific, engineering and mathematically-minded, technology-enhanced beings (Zeidler, 2016). I believe students can, and do, help shift this discourse. The inquiry detailed in this thesis was guided by the following research question: *How do Montessori elementary students characterize aspects of STEM?*

Theoretical Framework

Social constructivist theory framed my study design and analysis. Social constructivism is at its heart an epistemology, which views human knowledge as a dynamic process of making meaning through interaction and communication (Atwater, 1996; Ernest, 2010; Shapiro, 1994). Within educational research, social constructivism relates to older constructivist learning theories influenced by cognitive psychologists Jean Piaget and Lev Vygotsky (Fosnot & Perry, 2005). Rather than viewing linguistic expression and narrative as statements reflecting an objective reality, social constructivists stress that individuals' perspectives are interpretations informed by their history and experiences within communities. Thus, social environments substantially influence how people actively construct themselves and their understanding of the world (Crotty, 1998). In contrast to cognitive constructivists, social constructivists believe that constructions of reality do not develop in the mind alone (Ernest, 2010; Fosnot & Perry, 2005). For social constructivists, context is critical (Fosnot & Perry, 2005).

In educational research, a social constructivist approach has been applied to communication among students, between students and teachers, and between the researcher and the participants from whom she learns (e.g. Atwater, 1996). In terms of science education, a social constructivist epistemology implies that what counts as scientific knowledge is bounded by the worldview—including values and norms—of the knowers. As Mary Atwater (1996) argues, race, gender, culture, language are all factors that contribute to the particular bodies of knowledge from which learners draw as they construct themselves in interaction with others. Social constructivism therefore informs not only how a researcher approaches what her participants say and the behavior she observes, but also how various forms of difference shape her own involvement in knowledge production.

Significance of the Study

The instrumental case study recounted in this thesis contributes to two growing bodies of academic literature: studies on elementary STEM, and studies of Montessori classrooms. As nontraditional learning environments (Cossentino & Whitescarver, 2008), Montessori schools represent alternative sites to explore elementary STEM integration, potentially offering new insights. As Margaret Honey and colleagues (2014) suggest, it is necessary for researchers to examine STEM integration in a range of settings. The few studies that have been done on Montessori and science and engineering education suggest productive connections between these two areas, knowledge of which can be mutually beneficial for STEM and Montessori educators (Ibes & Ng, 2011; Rinke et al., 2013).

Furthermore, little is currently known in the academic community about what STEM teaching and learning in Montessori classrooms looks like. Both teachers who participated in this study received extended training integrating science, technology, engineering, and math (STEM) education with Montessori philosophy (Ibes & Ng, 2011). While teachers and curricula were not my primary area of inquiry, descriptions of classroom activities in this thesis also provide insight on how two educators enact Montessori STEM education and work to improve their students' understanding. I therefore discuss my findings in the context of this larger issue in the science education literature, conceptualizing STEM (e.g. Johnson, 2013; Kelley & Knowles, 2016).

More importantly, my study takes a perspective on STEM education that has been little explored thus far: that of young children. Research on student views of STEM is currently limited (Amherst H. Wilder Foundation, 2016). The multi-age structure of Montessori classrooms enabled me to purposefully sample a wide range of students, to better understand how children across grade levels interpret shared classroom experiences. While "STEM" itself may seem a mysterious acronym to the uninitiated, I argue that students actively construct their own understandings of relationships between science, engineering, mathematics and technology. These understandings merit consideration by educators and researchers.

Overview of the Chapters

Chapter Two: Review of Related Literature, situates my thesis within the past and present scholarly literature. I first explore the influence of constructivism and social constructivism in elementary science education. I then introduce the Montessori method and discuss previous research in Montessori schools. Next, I critically examine current STEM education initiatives and discuss the rationale for integrated elementary STEM instruction. Lastly, I explore emerging research on STEM in Montessori classrooms.

In Chapter Three: Methodology, I explain the methodology guiding my thesis, the instrumental case study (Stake, 1995). After introducing the case study methods I used, I outline my overall study design. I include a description of the school site, participating teachers from both classrooms, and the students I interviewed and observed. I next provide a description of my data collection and analysis procedures. In closing, I discuss the steps I took to establish trustworthiness for my interpretations, explain my role as a researcher, and state the limitations of my study.

In Chapter Four: Findings, I offer a rich description of each classroom case to provide background information for the learning context. I then present results from each data source I analyzed and overarching assertions for each case I studied.

Finally, in Chapter Five: Discussion and Implications, I summarize my findings and contextualize them within the literature base. I offer lessons learned from the case, along with implications for teaching and future research. I then conclude my report of the study.

Chapter 2 : Review of Related Literature

In this chapter, I review literature relevant to my thesis. I begin by discussing the influence of constructivism and social constructivism in elementary science education. I then provide an overview of the Montessori method as a constructivist educational approach, and outline previous research in Montessori schools. I next discuss scholarly literature on STEM education, paying particular attention to integrated STEM at the elementary level and studies of students' views. Finally, I focus on the few scholars who connect the Montessori method, reform-based science and STEM education. This provides context for Montessori STEM and justifies the need for my study.

Further empirical research on Montessori schools is sorely needed, while research in integrated elementary STEM education is an expanding field of inquiry. Although there are several publications geared toward Montessori practitioners, mainstream academic journals do not often contain research on Montessori classrooms. Applying existing insights from STEM education scholarship to this novel context may raise questions capable of furthering both areas of study, while filling corresponding gaps in the existing literature on Montessori schools and elementary STEM.

Constructivism in Elementary Science Education

The basic idea behind social constructivism as a learning theory is that learners actively construct new knowledge in relationship to their existing knowledge and sensory experiences, within a social context that imbues these experiences with meaning (Atwater, 1996; Scott, Asoko, & Leach, 2007). Social constructivism is one strand in the larger fabric of constructivism, a "non-positivist" theory based in biological and psychological understandings of organismal development (Fosnot & Perry, 2005, p.11). Constructivism views development, and therefore learning, as an adaptive response to changing environmental conditions (Glasersfeld, 2005). Considered as a learning theory, an instructional approach, and an epistemology, constructivism has shaped research on to how students learn, how teachers teach, and the assumptions under which inquiry is conducted (Shapiro, 1994; Taber, 2006). Most science education articles today may not explicitly mention the word constructivist in their titles; however, its influence has been undeniable (Taber, 2006).

According to Keith Taber (2006) constructivist research in science education began in the late 1970s as part of the "alternative conceptions" research program (p.191). At that time, researchers considered learners' ideas of natural phenomena as "misconceptions", "prior conceptions", or "alternate conceptions" (Shapiro, 1994, p.20), with the intent to move learners toward more professional scientific understandings (Scott et al., 2007). In subsequent decades, this strand of research continued; however, the landscape of constructivist science education also became more complex and sensitive to linking learner conceptions of phenomena with cultural context and power (Atwater, 1996).

An early constructivist science education case study that examined children's views on their own terms was Bonnie Shapiro's (1994) research on fifth graders' understandings of light. Shapiro (1994) built on George Kelly's *personal construct theory* to develop in-depth portraits of how individual children understood science (Kelly, 1955, as cited in Shapiro, 1994, p.10). She engaged in multiple, lengthy conversations with six students regarding their feelings about science, their scientific activities in school, and how they understood basic explorations with reflection, refraction, and sight. Her results demonstrated the centrality of children's individual understandings, and their active efforts to make meaning of the world around them. However, the personal view of science Shapiro (1994) advanced does not take into account the social context of the learning community, nor the learner's wider social network or cultural background and how these features might impact their constructs.

Like Shapiro's (1994) multiple case study, later research on constructivism examined how students learn scientific practices and habits of mind beyond particular terms or concepts. A 2007 report by the National Research Council, *Taking Science to School*, synthesized existing research on how children learn science and provided recommendations for best practices in science instruction, professional development for teachers, and future research (Duschl et al., 2007). While the report emphasized teachers' key role in improving student learning, it also argued learners must participate in authentic scientific activities integrating knowledge and practices. The report took the position that children actively construct scientific understanding from the interaction between their prior knowledge and new experiences in the context of a learning community. The committee emphasized that the goal of science education was the normative transmission of practices, discourses, and habits of mind characterizing existing professional scientific communities (Duschl et al., 2007).

The influence of the community in learning cannot be understated, especially in critical appraisal of constructivist approaches to science education research. Taber (2006) pointed out that constructivism has faced substantial criticism despite its ubiquity: scholars have taken it to task for not being coherent enough, placing too much emphasis on learner's accounts, and lacking construct validity. Constructivists have also been criticized for relying on individual constructs of phenomena without accounting for the social context in which these conceptions develop (Crotty, 1998; Taber, 2006). This is why I take a social constructivist perspective in my thesis.

Social constructivism. Social constructivism emphasizes interaction and context. Ernest (2010) argued that social constructivism has its basis in Russian psychologist Lev Vygotsky's (1978) work on the relationship between thought and language, and the sociocultural construction of meaning. Vygotsky (1978) found that language and conversation provide the critical arena through which a learner internalizes the abstract "scientific" concepts presented in the school setting and comes to share their conventional meanings (p.84). He demonstrated that persons who already have access to these concepts, such as teachers or "more capable peers," can skillfully guide learners to acquire the public meanings of signs through scaffolding instruction (Vygotsky, 1978, p. 86). The learner is not the only builder of constructs; adults and peers are essential facilitators as well. Even when examining students' personal characterizations, the principles of social constructivism state that the teacher, community, and learning context help determine them.

Some social constructivists (e.g. Atwater, 1996) have explicitly taken a more critical approach to making meaning, which does not deny the importance of individuals' differing backgrounds. Situating social constructivism within a multicultural science education research agenda, Mary Atwater (1996) emphasized that power shapes the social construction of scientific knowledge, and calls on researchers to take into account the "stereotypes, prejudices, and discriminations" that influence learners' understandings of science and their own scientific selves (p.824). She also urged researchers to acknowledge how race, sex, class, culture and language impact communication in science classrooms. For social constructivists, culture –the dynamic and internally contested system of beliefs, meanings, and values underlying everyday community life—matters (Atwater, 1996).

Social constructivism and Montessori. I include culture in my discussion of social constructivism because Montessori education has its own set of characteristic values, rituals, and practices (Cossentino, 2005). A social constructivist perspective on Montessori education must therefore take into account not only the method's own constructivist theoretical underpinnings, but also how Montessori education itself is a context for learning particular meanings. As David Elkind (1967) argued, Maria Montessori's learning theory contains elements of multiple constructivist approaches. In Montessorian terms, constructivism has both a biological/psychological, and social component. Elkind (1967) writes, "For Montessori…the nature-nurture interaction has a dual character. In the case of mental capacities, nature plays the directive role and nurture is subservient, while just the reverse is true with respect to the content of thought," which is substantially influenced by environmental context (p. 539). In the next section, I explain the Montessori method in greater depth, and include findings from the empirical literature on Montessori student learning in order to better orient the reader to the culture of Montessori schooling.

The Montessori Method

The Montessori method is a holistic, student-centered educational approach that emphasizes hands-on work in a collaborative learning environment (Cossentino, 2005; Hainstock, 1986; Polk Lillard, 1996). Trained as the first female physician in Italy, Dr. Maria Montessori developed what she termed a *scientific pedagogy* in the early 1900s as a result of extended observations of children's activity patterns (Polk Lillard, 1996). From a historical standpoint, her work is akin to early applications of Jean Piaget's stage theory, in which children move through sequences of concrete-to-abstract activities considered appropriate to the *plane of development* they inhabit (Elkind, 1967; Montessori, 2000). However, Montessori's extensive advocacy for peace and children's rights demonstrates that she cared as much about social transformation as intellectual development (Elkind, 1967; see also Montessori, 2007).

Montessori believed children learn best through self-directed activity in a specially prepared environment (Lillard, 2007). While inspired by the work of earlier European physicians and educationalists such as Itard, Séguin, Froebel, Pestalozzi, and Rousseau, Montessori was also innovative (Hainstock, 1986). She designed original sequenced didactic materials to facilitate independent exploration of concrete phenomena in math, language, geometry, science and practical life skills (Polk Lillard, 1996). Claiming that older children flourish in social interaction with peers and doing meaningful work in the wider society, Montessori also established multi-age classrooms so that children could learn to function productively in community rather than rely on a teacher (Hainstock, 1986).

Angeline Lillard (2007) synthesized existing scientific research supporting Montessori, which she explained in the context of the method's essential elements. Characteristics of typical Montessori elementary classrooms include many elements shown to enhance learning, including self-paced and project-based activities combined with a high degree of choice, freedom of movement, and creative expression (Lillard, 2007). Students frequently engage in activities as diverse as chemistry experiments, advanced grammatical study, or animal care. The multi-age structure of the classroom facilitates peer instruction, and teachers give ample time to community-building activities and conflict resolution as well as independent planning for complex tasks. These essential features of Montessori have been shown to support students' social-emotional learning, executive functioning and academic achievement (Lillard, 2007).

It is important to note that Montessori's emphasis on choice, individualization, and student-driven learning also neatly map onto the "hidden curriculum of work" in the affluent professional and executive elite classrooms of Jean Anyon's landmark study examining social reproduction in class-stratified schools (Anyon, 1980). Although Montessori originally founded her schools to serve those who had been labeled mentally deficient or were underserved in wider Italian society (Hainstock, 1986), contemporary Montessori schools in the United States are typically private and serve wealthy families (Whitescarver & Cossentino, 2008), the majority of who are White (Lillard, 2012). Contemporary research suggests that even racially and socioeconomically diverse

Montessori public schools can reproduce the same structural inequities found in mainstream schools, albeit often to a lesser extent than their traditional counterparts (Debs & Brown, 2017). However, scholars argue, a belief in the transformational power of education also makes Montessori an important part of the movement for educational equity (Banks & Maixner, 2016).

Since the early 1900s, advocates of the Montessori method have claimed that her holistic educational approach is beneficial for students of all cultural, ethnic, or socioeconomic background (Brunold-Conesa, 2008). Some believe this is because the method responds to what Montessori deemed to be universal *human tendencies* of behavior, such as order, exploration, communication, repetition, and precision (Polk Lillard, 1996). Montessori passionately believed that her schools would improve the human species. This goal was particularly acute during the interwar period, when she travelled across the globe speaking to audiences about the importance of education for world peace (Montessori, 2007). And yet, despite Montessori's many connections to issues of central importance in education, including constructivism, social-emotional learning, and equity, her philosophy has remained at the margins of both the academy and the public school system (Whitescarver & Cossentino, 2008).

Research in Montessori Schools in the United States

Montessori schools have existed in the United States for just over a century. Keith Whitescarver and Jacqueline Cossentino (2008) of the National Center for Montessori in the Public Sector argue that for the most part it has been a century in limited dialog with mainstream public education. American Montessori schools tend to be privately run, a trend established since the reintroduction of the Montessori method to the United States in the 1960s. A unique training process and different standards of certification—whether through the Association Montessori Internationale (hereafter, AMI) or the American Montessori Society (hereafter, AMS)—also separates Montessori teachers from mainstream professional teacher education programs. Furthermore, independent Montessori schools remain largely insulated from the high-stakes testing and nationally standardized curricular reforms to which American public schools have become increasingly accountable. Since the mid-1990s, however, an increasing number of charter and public Montessori programs has prompted renewed examination of the method as an effective alternative to traditional public education (National Center for Montessori in the Public Sector, 2017). This has opened more doors to making Montessori accessible, and for researchers to examine teaching and learning in Montessori environments (Debs & Brown, 2017; Dohrmann et al., 2007).

Montessorians are often remarkably faithful to the teachings of the method's eponymous founder, and systematic investigation of Montessori education by outside scholars is rare (Cossentino, 2005; Whitescarver & Cossentino, 2008). Previous empirical studies are primarily in the field of psychology. There, scholars have focused upon Montessori students' cognitive achievement, motivation, executive functioning, and positive associations with school (Dohrmann et al., 2007; Glenn, 2000; Lillard & Else-quest, 2006; Rathunde & Csikszentmihalyi, 2005). Discussions of *how* Montessori students learn, however, remain primarily theoretical and restricted to reflections and analyses in professional practitioner journals or theses. One notable exception is psychologist Angeline Lillard's book *Montessori: the science behind the genius* (2007). Another is the new peer-reviewed *Journal of Montessori Research* (begun in 2015).

Two psychology studies claim measurable advantages for Montessori pre-school students ages three to five across a variety of tests (Lillard & Else-Quest, 2006; Lillard, 2012). Lillard and Else-Quest (2006) also found that students randomly assigned to public Montessori schools outperformed their peers on academic and social measures at age 12. In a comparative longitudinal study of high school students in the Milwaukee Public Schools who had attended Montessori programs between pre-school and fifth grade, Dohrmann and colleagues (2007) demonstrated a significant long-term effect for Montessori exposure in Math and Science, where the Montessori group outperformed their high-school peers. However, there was no difference for any other academic achievement factor. Furthermore, in this study gender, race/ethnicity, and socioeconomic status (SES) had a greater effect on achievement for this population, suggesting that they may later outweigh the benefits of Montessori (Dohrmann et al., 2007).

Quantitative studies typically use standardized achievement tests as a measure—as Montessori students do not normally take tests to assess their learning, such instruments may not be an accurate assessment of what they know (Lillard, 2007). In other studies Montessori students performed as well as, or better than, peers used to taking tests (e.g. Lillard, 2012). It therefore appears that while Montessori schooling is not detrimental by typical measures of achievement, and may be advantageous early on, more useful information may be gained by assessing students in other ways (Debs & Brown, 2017).

Previous research suggests that non-academic benefits of a Montessori education may in fact be more important than the academic ones (Debs & Brown, 2017; see also Lillard, 2007). Glenn (2000) conducted a longitudinal study for a private Montessori school in Oregon interested in learning about its alumni. Quantitative assessments found that students did not exhibit significant academic gains attributable to a Montessori education. However, analysis of qualitative self-assessments identified several characteristics that Montessori students favored in a learning environment, including experiential learning, collaboration, and conceptual understanding. Analysis of interview data demonstrated certain personality characteristics held in common among the students, including open-mindedness, societal, and environmental awareness (Glenn, 2000). Glenn's (2000) study dealt with a nonrandom sample from a single school, although the findings are worth noting in order to build a correlative relationship between characteristics associated with Montessori and those increasingly valued in science education. Dohrmann and colleagues (2007) also noted that previous studies found Montessori students to be more creative, experience a "greater sense of community" and perform better on conflict resolution exercises (p.207).

Why are there still so few studies of Montessori schools? Based on her ethnographic study of Montessori elementary lessons, Jacqueline Cossentino (2005) argued that the "ritualized" character of Montessori practices and the consistency of beliefs among educators in the community lend the schools a mystique, which renders them somewhat incomprehensible to unrecognized community members (p.213). In her analysis, Montessori as a *culture* in and of itself: without being inducted, a researcher may be hard-pressed to understand the significance of the lessons and how they impact students (Cossentino, 2005).

Furthermore, while Montessori has many advocates, previous research has not consistently shown outcome differences relative to public schooling. This is particularly true for students of color, as a recent literature review by Mira Debs and Katie Brown (2017) indicates. Inconclusive results (e.g. Dohrmann et al., 2007) can be attributed to limited generalizability due to small student sample size (e.g. Rathunde & Csikszentmihalyi, 2005); a lack of fidelity of implementation of the Montessori curriculum (e.g. Lopata, Wallace, & Finn, 2005); and the prevalence of single-school case studies (e.g. Glenn, 2000). Because many parents choose to enroll their children in alternative education, regardless of whether that choice is made possible by lottery or not, parental involvement may be an unexplored variable in student learning outcomes (Dohrmann et al., 2007). Overall, there is a need for diversification in the empirical literature on contemporary Montessori schools, as well as greater exchange between the Montessorians and the wider education community.

Research suggests that Montessori methods, if well implemented, support students' holistic development. However, few scholars have qualitatively examined the Montessori curriculum, or the relationship between specific practices and their identified educational outcomes, from student perspectives. Study designs must take multiple demographic variables into consideration and pay attention to cultural meanings constituting Montessori cosmology (Cossentino, 2005). Positive academic outcomes in the Math/Science curriculum area (e.g. Dohrmann et al., 2007), combined with findings on the holistic benefits of Montessori education (e.g. Glenn, 2000), suggest that a study on Montessori STEM taking students' understandings into account would contribute substantially to the literature. As I detail below, such a study also complements current research trajectories in elementary STEM integration.

Reform-based Science and STEM Education

To answer the rallying cry of "science for all" that has exemplified the past several decades of science education research, curriculum developers and policy makers have advanced *reform-based science* (hereafter, RBS) instruction (Carlone, Haun-Frank, & Webb, 2011). The characteristics of RBS include an inquiry approach; content integration; attention to the connection between science, technology, and society, and the inclusion of multiple perspectives within the umbrella understanding of science as a human endeavor (NGSS Lead States, 2013). The latest omnibus reform documents emphasize that students from all cultural and linguistic backgrounds must have authentic opportunities to engage in science and engineering practices, and develop scientific literacy in ways that are relevant to their everyday lives (National Research Council, 2012). In recent years, a particularly powerful tributary incorporating reform-based science has been integrating science, technology, engineering and mathematics under the acronym "STEM" education (Honey et al., 2014). While there is no single model for STEM, scholars often discuss this approach as some form of connected or multidisciplinary science instruction focused on solving problems in real-world contexts (i.e. Bybee, 2013; Kelley & Knowles, 2016). For many, engineering design challenges provide a motivating force to do so (Stohlmann, Moore, & Roehrig, 2012; Yoon, Dyehouse, Lucietto, Diefes-Dux, & Capobianco, 2014).

In 2014, the United States Committee on Integrated STEM Education compiled a report outlining an agenda for research in K-12 STEM education (Honey et al., 2014). Its publication complemented documents such as the Next Generation Science Standards (NGSS Lead States, 2013), which call for teaching engineering in science classes and greater integration of technology and mathematics. The report synthesized existing approaches in formal and non-formal education settings, as well as learning outcomes associated with disciplinary integration. The bottom line: effectiveness depends on *how* integration happens (Honey et al., 2014). The Committee did not believe evidence warranted that "integrated STEM …should replace high-quality instruction on individual STEM subjects" (Honey et al. 2014, p.10). They recommended that integration should be made "explicit"; students must be supported to develop competency in key concepts in each STEM discipline; and teachers should take a "measured, strategic" approach that compensates for trade-offs in cognitive load and instructional time associated with integrated curricula (Honey et al., 2014, p.5).

The publication of this report occurred amidst ongoing concerns among American policymakers and business leaders regarding the preparation of an innovative, technically competent and economically competitive future workforce (Honey et al., 2014). Indeed, economic competition has been a driving rationale behind STEM education programs around the world (Carter, 2016). Some scholars decry the emphasis on workforce preparation, and caution that uncritical celebration of innovation through science and technology masks the continuity of capitalist hegemony and "narrows [the] possibilities" for critical science education (e.g. Carter, 2016, p.31). I take this critique seriously, and hope to show that elementary STEM that does not overemphasize career preparation or view competition as the end goal can offer new directions for integration initiatives. Therefore, it is worth looking more closely at research on STEM at the elementary level.

Elementary STEM Education

Notwithstanding critiques of "STEM-ification" and STEM-orthodoxy (Carter, 2016) in science education research, the past decade has seen an increase in scholarship on improving STEM integration. For the most part, the literature speaks to middle and secondary specialist science educators and assumes traditional disciplinary boundaries or "subject silos" (Bybee, 2013); however, success in enhancing secondary integration has been limited. Daugherty, Carter and Swagerty (2014) therefore claimed that elementary classrooms might represent the brightest future for integrated STEM education. Researchers' rationales for an early introduction to STEM have built upon the premise that young children are naturally curious, exploration-driven, and sensitive to design problems (Cotabish et al., 2013; Murphy, Murphy, & Kilfeather, 2011). Moreover, a study by Archer and colleagues (2010) found that by the time they entered middle school, British schoolchildren had formed their career aspirations and gendered dispositions around science. Thus, from developmental, economic, and gender equity perspectives, early exposure to, and positive associations with, STEM can have important impacts later on (Daugherty et al., 2014).

Because most elementary students in traditional Montessori schools do not have a lesson time or classroom specifically dedicated to "science", and regularly engage in activities in which science, math, the arts, geography, and history are connected (McNamara, 2016), I concentrate on scholarship on *integrated* elementary STEM. For elementary students, a small number of studies reported that connecting subject areas increases conceptual knowledge; however, performance gains were mainly in science (Cotabish et al., 2013), engineering, and technology (see also Yoon et al., 2014), and these outcomes were not consistent (Honey et al., 2014). Research also suggests that engaging interdisciplinary curricula with hands-on engineering design challenges and compelling story contexts have helped spark students' interest in STEM subjects (Lachapelle & Cunningham, 2014). After-school or extracurricular clubs in which middle school students had more open-ended opportunities to explore their own interests enhanced their motivation to learn and positive self-identification with science and engineering careers (Calabrese Barton et al., 2012). Finally, while subject integration demands increased cognitive load, scholars have argued that students may be more able to master challenging content when integrated STEM is taught through cooperative learning methods (Stohlmann et al., 2012).

Stohlmann, Moore, and Roehrig (2012) comprehensively outlined considerations for teaching integrated STEM, based on a synthesis of best practices for the following areas: math and science instruction, supporting students' knowledge construction, and enhancing teacher self-efficacy. Like many other researchers, they advocated for teaching STEM through problem solving, by using an engineering design process that models real-world situations. One recommendation made by Stohlmann and colleagues (2012) that is particularly relevant to this thesis is that STEM integration should be "student-centered"—building on prior knowledge, addressing preconceptions, offering opportunities for collaboration, and geared toward "understanding student capabilities" (p.33). As an extension of this recommendation, I believe it is also important that educators and researchers pay attention to how students themselves characterize different aspects of STEM.

The current literature indicates that integrated STEM education can positively impact elementary students' academic achievement, interest, and identity (Honey et al., 2014). For this to occur, engineering design, problem-based learning, and opportunities for collaborative projects are particularly important (Daugherty et al., 2014). However, the diverse goals of STEM education, and lack of cohesion in the nature and scope of integration (Bybee, 2013), suggest further documentation on what integration looks like in a range of settings is necessary (Honey et al., 2014). There is also a need for further research on STEM from student perspectives.

Student characterizations of STEM. Much research on STEM integration examines pre- and in-service teacher education and curriculum development (e.g. Stohlmann et al., 2012). Fewer studies have looked at student experiences of integrated STEM (e.g. Cotabish et al., 2013), and even fewer of these from the students' own perspectives (Honey et al., 2014). In part, this is due to the difficulty of assessing or asking young people about STEM as a unitary construct (especially when its definition remains ambiguous and plural among expert adults; see Bybee, 2013), as opposed to understanding student characterizations of individual STEM disciplines and relationships between them.

While there is no established literature base on student characterizations of the nature of STEM, a large body of extant scholarship examines students' views of the Nature of Science (hereafter, NoS) (e.g Lederman & Ko, 2004; Murphy et al., 2011; Walls, 2012; Walls, Buck, & Akerson, 2013). There are also several studies on students' conceptions of engineering and engineers (e.g. Capobianco, Diefes-Dux, Mena, & Weller, 2011). Attitude surveys have been used to measure student interest and engagement with STEM from a quantitative perspective; however, these are often directed towards older students and their interest in future STEM careers (e.g. Kier, Blanchard, Osborne, & Albert, 2014). Developing reliable assessments that match young elementary children's attention and literacy capabilities has been called a challenging task (Yoon et al., 2014). As Leon Walls (2012) pointed out, NoS studies are often conducted with secondary students and focus on measuring how informed or naïve students' views are, or how they relate to future education and career prospects, instead of viewing them on their own terms.

Two recent studies investigating student views of science and engineering guided data collection methods and informed the analytic framework of this thesis. Both used drawings, interviews, and questionnaires to assess elementary students' understandings of aspects of STEM. Working through a critical hermeneutics lens, Leon Walls (2012) used multiple instruments to analyze 23 African-American 3rd graders' views of NoS and of "themselves as users and producers of science" (p.1). This approach included data from the M-DAST (Walls, 2012), a modified version of a classic Draw-a-Scientist activity (Chambers, 1983); a semi-structured interview; a photo elicitation activity; and an open-ended questionnaire. Walls (2012) pointed out that few studies examine NoS from the perspective of young elementary children. He argued that the majority of NoS research has neglected to take race and culture into account when discussing students' views, assuming NoS to be a universal developmental process. According to Walls, it is important to intentionally include diverse perspectives in NoS research when examining students' prior knowledge. Rather than comparing students' responses to a "tenet list" (Walls, 2012, p.2), Walls used directed content analysis methods to generate open codes from the students in his sample, which he organized under major themes from the NoS literature.

Walls (2012) found that the African-American third graders he sampled expressed views of science that not only identified consensus definitions and practices already described in the literature, but also expanded upon them to include the importance of helping others and learning outside of school. Students in his study viewed themselves as participating fully in science and saw it positively. Most commonly, they thought of science as learning about the world and doing experiments, and the majority characterized scientists as male laboratory professionals. Walls (2012) concluded that his multi-instrument approach and modifications were effective at representing the complex conceptions held by young children. He suggested that his study become a "template" for future NoS research (Walls, 2012, p.30), a recommendation that I have attempted to honor by using his M-DAST protocol in this thesis.

Brenda Capobianco and colleagues (2011) conducted a similar study of elementary students' conceptions of engineers and engineering. Using a cognitive constructivist theoretical framework inspired by Piaget's scholarship on children's representations, they undertook content analysis of drawings of engineers made by 396 students in grades one through five. They purposefully sampled children from 20 different classrooms at one urban and one suburban school site. The demographics of their sample were similar to that of elementary students across the country, and they did not discuss race in their sample or results. Similar to Walls (2012), the researchers asked students to write about what their engineer was doing, and conducted 20 follow-up interviews to get additional information on students' explanations. The Draw-an-Engineer Test (DAET) was only administered once, before students had explicit instruction on engineering.

From inductive content and statistical analyses, Capobianco and colleagues (2011) found identified four primary conceptions of engineers, listed in order or prevalence within the sample: mechanic, laborer, technician, and designer. Over half the students depicted engineers as male, and female students drew most of the female engineers (18% of the sample). Students often depicted their engineer using artifacts like a hammer, tape measure, saw, or blueprints; some first graders drew machines as their engineers. Significantly more students in first, second, and fifth grades viewed engineers as laborers, but there were no statistically significant differences by grade for the other conceptions. Students who were interviewed often described engineers as men who fixed broken trucks, repaired everyday objects like toilets, or helped others. Older students were more likely to view engineers as designers.

On the basis of these results, Capobianco et al. (2011) concluded that engineering educators should support elementary students' competence in three dimensions: "the practice of problem solving," teamwork and communication, and "access to scientific and technological knowledge, skills, and tools" (p.322). They recommend that educators explicitly help students develop conceptions of engineers that emphasize creativity, problem-solving abilities, teamwork, use of science, math, and technology, and helping others. They suggest future researchers should look more closely at how students' conceptions might change over time, by age or culture, or in light of specific educational experiences (Capobianco et al., 2011). My own study, in which a range of students completed a Draw-an-Engineer task and were interviewed at two time points in the context of integrated STEM instruction, responds in part to this recommendation.

Previous studies of students' characterizations of STEM disciplines have focused on a single discipline, or addressed career aspirations with survey instruments (e.g. Kier et al., 2014). Scholars are just beginning to examine what students think about "STEM" as a unitary term. One report by the Amherst H. Wilder Foundation (2016), based on small-group semi-structured interviews with 44 fifth-graders who participated in an intensive STEM informal learning partnership program, shows that students' accurate understanding of "STEM" as an acronym for science, technology, engineering, and math was drawn primarily from their experiences with the program. Students remembered hands-on and group work experiences vividly, and expressed feeling like "real" scientists and engineers because of their activities (Amherst H. Wilder Foundation, 2016, p.8). Students' confidence in their own STEM abilities was mixed following participation in the program, due to their increased perception of interdisciplinary problem solving as cognitively challenging. However, most believed that STEM was valuable, and expressed interest in future careers. Findings from this study demonstrated elementary children both acknowledge mainstream definitions and construct their own understandings of the definition and purpose of STEM in the context of intentional integration experiences (Amherst H. Wilder Foundation, 2016).

The lack of empirical reports detailing how elementary students think about connections between multiple STEM disciplines indicates this thesis will add a much-needed perspective to the literature on STEM integration. This is also due to my exploration of STEM in an under-researched context: the Montessori classroom. As I show in the following section, the little research that has been done on STEM and Montessori indicates the two areas of study synthesized in this thesis have much to offer one another.

Connecting Montessori and STEM

Scholars who have examined science, engineering and technology integration in Montessori elementary classrooms argue that several aspects of Montessori philosophy and curriculum harmonize with the goals of STEM education (Elkin, Sullivan, & Bers, 2014; Ibes & Ng, 2011; Rinke et al., 2013). Montessori herself integrated natural and social science disciplines in her elementary curriculum, an approach she termed "cosmic education" (MacDonald, 2008). While this thesis does not directly compare STEM and cosmic education, the Montessori STEM lessons given by participating teachers were inspired by the cosmic education approach (Ibes & Ng, 2011). This section demonstrates how my thesis contributes to previous research connecting Montessori and STEM.

The only extant ethnographic case study on Montessori science suggests that the Montessori elementary environment fosters several foundational elements of scientific inquiry outlined in RBS education policy (Rinke et al., 2013). This study provides an example of why Montessori education and reform initiatives such as STEM are already complementary, even when teachers have not been intentionally STEM trained. Rinke, Gimbel and Haskell (2013) looked at five essential elements of inquiry science—asking questions; finding evidence; formulating explanations; evaluating these in light of alternatives; and communicating with others about these explanations—in three Montessori classrooms at two school sites, one public, one private. They organized these elements around three domains of activity: developing interest, communicating with others, and generating explanations.

Rinke and colleagues (2013) found that the Montessori environments they researched stimulated children's developing interest in the natural world and provided opportunities to communicate authentically about science. The children had access to natural objects they could observe, and used Montessori materials for exploration. Caring for classroom pets and plants helped students apply knowledge of other organisms. They were able to follow their interests and communicate freely with peers when conducting experiments or creating projects. The multi-age classroom also provided opportunities for mentorship and collaboration. Explanation, on the other hand, was mostly descriptive and in response to teacher direction, rather than in answer to student-generated questions. For example, students did not engage in as many activities requiring evaluation of evidence (Rinke et al., 2013). In conclusion, the researchers claimed that overall the culture of Montessori should be considered “highly compatible” with contemporary best practices in science education (Rinke et al., 2013, p. 1519). And yet, they note that the “humanistic” goals of Montessori education, which are “value-laden and morally-guided” rather than objective or content-focused, diverge from conventional science education imperatives (Rinke et al., 2013, p. 1521).

The same features of Montessori that foster an attitude of interest and communication in science can also be useful for engineering and technology integration. A qualitative case study by Elkin, Sullivan and Bers (2014) reported on a single lower elementary (grades one through three) Montessori teacher and her efforts to integrate robotics engineering into her elementary classroom following a professional development course. While the researchers did not discuss student learning, this study is relevant for its description of how STEM integration occurred and the type of activities the students undertook. In this Montessori classroom, STEM subjects were connected with games, art, performance, and history. The teacher, Diana, “focused on collaboration and using multiple modes…to cater to the different learning styles of her students” (Elkin et al., 2014, pp. 159-160). She sought to complement the lessons she was already giving on Ancient Greece, and used existing structures in her classroom culture such as the “Creative Basket of Joy” (a building materials station) and the “Community Meeting” (a whole-class sharing time) to help her introduce robotics into the class (Elkin et al., 2014, p.159). Students had ample unstructured time to build and program their robots in small groups, and Diana identified several older students already familiar with robots who could teach their peers. For their culminating project, students built a playground that combined robotics, simple machines and programming, which they presented to the public at the school's admissions Open House (Elkin et al., 2014).

Elkin and colleagues (2014) noted that because students were already comfortable using hands-on materials, working in groups with a variety of skill levels, and discussing multiple solutions to the same problem, elements of the Montessori approach helped them successfully engage with the new robotics curriculum. While results from a single case study are not generalizable, they felt that there were multiple areas of alignment between "fundamental engineering concept[s and] Montessori principles" (Elkin et al., 2014, p.165). This is a similar statement made by one developer of the "Montessori STEM" (hereafter M-STEM) Certificate program, Catherine Ibes (see Ibes & Ng, 2011).

In an unpublished conference paper exploring engineering in Montessori schools, Catherine Ibes and Yvonne Ng (2011) outlined the "perfect fit" between engineering and the Montessori method (p.2). Reporting on outcomes from the certificate program they developed, Ibes and Ng (2011) also provided an explanation of their vision for M-STEM. From their perspective, M-STEM maintains the foundational principles of Montessori philosophy. Its goals are to enhance the existing Montessori cosmic education curriculum with a series of presentations and hands-on activities that build students' STEM thinking and practices, and communicate science content in an up-to-date, accurate manner (C. Ibes, personal communication, 3/1/2017). The authors noted that "inquiry" and "design" are already central features of the Montessori environment, and that Montessori teachers regularly use features of the engineering design process, such as engaging context, hands-on exploration, and iterative activity (Ibes & Ng, 2011, p.1). My thesis does not report on the effectiveness of, or detail the specific curriculum for, this Montessori STEM certificate. However, both case study teachers participated in the M-STEM program. Ibes & Ng's (2011) paper therefore offers insight the teachers' learning context, which, according to constructivist principles, informed the experiences they provided for their students.

Ibes and Ng (2011) reported that M-STEM teachers valued the program's emphasis on integrating STEM into the traditional Montessori lessons, rather than as an "add-on" approach. Participating teachers claimed that the use of story, hands-on materials, and recurring or "spiraling" elements in engineering lessons appealed to their students (Ibes & Ng, 2011, p.18). However, they noted that students were more likely to "tinker" with building challenges than isolate variables and iterate their designs (Ibes & Ng, 2011, p.14). Ibes and Ng (2011) suggest that initial experiences they developed—such as the Mabel Marble incline challenge that appears in this thesis—be expanded to include more complex systems and further historical examples (Ibes & Ng, 2011).

Ibes and Ng (2011) concluded that the M-STEM program's success was substantially due to its alignment with the philosophy underlying the elementary Montessori curriculum, cosmic education (Montessori, 2007). Basic principles of cosmic education lessons include: proceeding from the big idea to the parts that compose it; moving from concrete experiences to abstract generalizations; beginning with what is known and adding in unknown elements one at a time; the recurring or "spiral curriculum", and the use of storytelling to spark children's imagination and create a meaningful context for learning (MacDonald, 2008; Montessori, 2007). I close this literature review with a brief discussion of cosmic education to provide the reader with relevant background information on the instructional practices of both traditional Montessori presentations and the STEM lessons that took place at the school site examined in this thesis. From a social constructivist viewpoint, it is critical to discuss this philosophy as another element shaping the learning context, and therefore potentially influencing students' characterizations of STEM.

Cosmic Education. Montessori educators have written extensively on the nature and purpose of cosmic education (e.g. MacDonald, 2008; Renton, 2002; e.g. Stephenson, 2015; Trudeau, 2002). Montessori AMI trainer Susan Mayclin Stephenson (2015) views this approach as a framework for sense making through experiential discovery and the use of the imagination. Maria Montessori created the cosmic education curriculum in collaboration with her son Mario during their exile in India, and it is traditionally associated with children ages six through 12. Cosmic education gradually introduces students to the history and organization of the universe through a series of Great Stories (Montessori, 2007). The physical, earth, and life science disciplines play a central part in this journey (MacDonald, 2008). Children are encouraged to develop gratitude for their part within this interdependent whole as they define their own cosmic task, the contribution they will make to achieve balance and harmony in the universe (Stephenson, 2015). According to Montessori, the curriculum allows children "to organize their intelligence…and give them better insight to their own place and task in the world," while simultaneously developing their "creative energy" (quoted in Polk Lillard, 1996, p. 75).

Today, Montessori science lessons are often presented in a narrative format complemented by demonstrations, a structure also characterizing the Montessori STEM lessons I observed for this thesis. Most teachers tell one or all of Montessori's five Great Stories each year. This series of narrative explanations weaves together the history of the universe and the solar system, the evolution of life on Earth, and the cultural achievements of human beings with crosscutting concepts in biology, physics, chemistry, astronomy, engineering, and archaeology (MacDonald, 2008). The Great Stories are accompanied by lessons on specific topics intended to engage students in independent inquiry: children typically complete laboratory experiments and observations on their own or in groups. As in all Montessori subject areas, students choose follow-up activities and learn at their own pace. Montessori philosophy recognizes the importance of teamwork, but also encourages children to pursue their own interests (Stephenson, 2015).

As I have argued, the Montessori method shares common elements with best practices in reform-based and constructivist science education, as well as integrated STEM. However, cosmic education integrates far more than the four STEM disciplines, and intentionally addresses students' social-emotional development, both aspects which critics note may be lacking in conventional STEM programs (Zeidler, 2016). Research on Montessori cosmic education and elementary STEM integration alike does not substantially address students' own characterizations of their experiences. While it is outside the scope of this thesis to analyze cosmic education in depth, my exploration of Montessori students' characterizations of STEM takes a step in this direction.

Conclusion

This chapter presented literature relevant to my thesis, including theory and research on constructivism and science education; the Montessori method; integrated STEM education with elementary students; and connections between STEM and Montessori. This review demonstrated that my thesis not only contributes to much-needed empirical documentation of contemporary Montessori schools, but it also adds to research examining STEM integration in elementary classrooms. In addition, the thesis attempts to address STEM from a little-studied perspective: the learner. In the next chapter, I detail the methodology for my study.

Chapter 3 : Methodology

This thesis reports on a study undertaken to explore Montessori elementary students' characterization of aspects of science, technology, engineering and mathematics (STEM) as they participated in a series of integrated STEM lessons over the course of three months in a school year. In this chapter, I explain how I carried out this research. First, I detail the methodology informing my investigation: the instrumental case study approach (Stake, 1995). I next outline my research design, describing the context and participants as well as each data source I collected and the analysis I undertook. I then discuss how I built trustworthiness throughout my inquiry. In closing, I explore my role as a researcher and limitations that I encountered.

Method

This thesis employed an instrumental case study approach (Stake, 1995). The case study approach is appropriate for qualitative research exploring and describing phenomena using multiple data sources (Plano Clark & Creswell, 2010). I examined two cases at a single school site, North Star Montessori[1], bounded at the classroom level[2] and by a three-month period of the school year. The first case was Carrie's ages six through nine classroom (first through third grades), hereafter referred to as E1. The second case was Erica's ages nine through 12 classroom (fourth through sixth grades), designated E2. Case study researchers strive for in-depth understanding of a particular complex teaching

---

1 All identifiable names appearing in this thesis are pseudonyms, chosen by participants whenever possible, to protect participant privacy and confidentiality.

2 Accredited Montessori classrooms consist of students in a three-year age group, a lead classroom teacher, and an assistant.

and learning environment, often through naturalistic inquiry (Lincoln & Guba, 1985). Naturalistic inquiry answers questions through observations of behavior in real-life settings, rather than intervention or experiment. The following overview of case study as a methodology justifies its appropriateness for my thesis.

The Case Study Approach

Since the late 1970s, qualitative methods have gained greater prominence in education research, particularly among scholars who embrace constructivist epistemologies (Plano Clark & Creswell, 2010). Qualitative researchers consider words and actions as their primary focus of study. They use observations, interviews, and documents as empirical data from the surrounding environment, and translate these into textual form. Reciprocally, natural language description and narrative are key reporting strategies. Qualitative educational researchers draw from many disciplinary traditions and use a variety of methodological tools. Case study (Stake, 1995) is one approach whereby scholars have woven these threads together to preserve the complexity of teaching and learning environments in the stories they tell. Case studies describe and interpret a phenomenon of interest through the in-depth exploration of one or more particular examples, called *cases*, which are bounded into units of analysis (Plano Clark & Creswell, 2010). A case could be one teacher, all students in the same classroom, or multiple schools. Boundaries could be physical (e.g., what takes place inside the school) as well as temporal (e.g., the course of a school year). Overall, the goal of case study is to understand a phenomenon in its real-world context through analysis of selected units within boundaries set by the researcher (Yin, 2014).

Case study is best considered a “genre” of research, rather than one strict method with a set procedure to follow (Hamilton & Corbett-Whittier, 2014, p. 8). Common characteristics of high-quality case studies include: 1) the collection of multiple forms of data such as interviews, observations, and artifacts/documents, the interpretation of which is triangulated by the researcher and member-checked with participants; 2) detailed, holistic description of each case generated over a considerable period of time; 3) the use of multiple perspectives; 4) analysis of themes and patterns across data sources; and 5) restriction of inquiry to bounded analytic unit(s) predefined by the researcher (Hamilton & Corbett-Whittier, 2014; Merriam, 1998; Plano Clark & Creswell, 2010; Stake, 1995; Yin, 2014). Within each case, the researcher often selects events or individuals for more intensive study (Merriam, 1998).

Approaches to conducting case study range from reflexive and interpretive (e.g. Stake, 1995) to objective and post-positivistic (e.g. Yin, 2014). I have drawn primarily from Robert Stake’s (1995) interpretive approach. This approach harmonizes epistemologically with both the constructivist and relativist qualities of the Montessori method—paralleling the views on learning expressed by the teachers in each case—as well as the social constructivist theoretical framework guiding the study. For Stake (1995), the goal of interpretive case study is to “facilitate reader understanding” of the case and its relationship to larger socio-political or historical issues (p.39). Sampling procedures are intentional, and analytic methods are inductive (see also Merriam, 1998). This approach results in an evolving, rather than static, inquiry.

According to Stake (1995), interpretive case researchers tend to hold constructivist epistemologies. They recognize that information is not "discovered" by the researcher (Stake, 1995 p.99); rather, it is synthesized from sensory experience, new and existing personal perceptions, and social influence. Interpretive case researchers are also "relativists": they respect alternative viewpoints while recognizing that some interpretations may offer greater insight than others (Stake, 1995, p.102). They work to empathize with participants, while remaining aware of their own frames of reference. They include raw data and report descriptions to enable readers to make their own interpretations. Throughout, they focus on meaning in context.

Instrumental case study. Stake (1995) delineates two types of cases: intrinsic and instrumental. An intrinsic case study seeks to capture as much information about the case as possible, whereas an instrumental case study focuses on a particular aspect or issue of interest to the researcher and participants. Multiple instrumental cases, or samples selected within an instrumental case, serve as instances that "maximize learning" for the researcher, participants, and reader (Stake, 1995, p.4). Stake asserts that unique qualities of selected participants, as well as the classroom or school case itself, often have greater research merit than a typical case—especially given preexisting limits in data collection time and access. Stake's (1995) intuitive and open-ended approach to case study complemented the exploratory aspects of my thesis. The instrumental type of case study facilitated my focus on student characterizations of STEM.

Given the dearth of contemporary educational scholarship on Montessori schools (Cossentino & Whitescarver, 2008) and the absence of any empirical studies of

Montessori elementary STEM integration, I had few similar studies I could reference. In addition, time and scope constraints made it practical to delimit my inquiry. Overall data collection activities enabled me to generate extensive background knowledge on what STEM looked like in each classroom. From there, I developed a research question that focused on a particular aspect: student characterizations of STEM. For each case, I sought to answer the following question: *How do Montessori students characterize aspects of STEM?*

Context of Study

Both classroom cases in this study were located at the same school site, North Star Montessori School. While I worked with the teachers throughout the 2016-2017 school year, I collected the majority of my data during a period of weekly site visits from September through December 2016. The following description of North Star is intended to orient the reader to some of the salient features of independent Montessori schools. In Chapter Four, I describe each classroom in greater detail to better contextualize my findings.

North Star Montessori School is an independent, non-profit Montessori school serving over three hundred children ages three to 15 years old. The campus sits on a corner lot in a mixed commercial-residential neighborhood of a midsized Midwestern city. Over 40 years in operation, North Star has built a reputation for authentic Montessori education. The school holds both regional independent school and international Montessori accreditation, and all classroom teachers possess a recognized Montessori credential. The majority of teachers at North Star have taught there for more than a decade, and several send their children to the school. At the time of writing, the school's demographics were similar to those of the surrounding neighborhood: 30% of families self-identified as people of color, with biracial as the predominant identity. Approximately 30% of families received financial aid to assist with the considerable tuition payments. The school provided additional in-house language support for emergent bilingual students, and individualized tutoring for students with learning needs.

The main North Star Montessori campus consists of a large nineteenth century brick building and surrounding property formerly occupied by a religious order. North Star also operates a 160-acre farm and field station in a rural area an hour south, where students travel for place-based, agricultural, and environmental education. The main campus is only a few minutes from a highway, but traffic on the surrounding streets was low during the day. I observed a marked increase in activity at meal times, as customers flocked to the trendy restaurants and coffee shops clustered within walking distance in both directions from the school.

North Star's outwardly imposing multi-story building has been renovated to meet the needs of a contemporary school, while maintaining vestiges of its original use. When I visited I noticed the building itself was ringed by a series of outdoor learning environments including a rain garden, a circle of stone benches, a terraced playground, a pergola, and a covered pathway. The interior facilities were kept up with care. Each classroom included a complete set of Montessori didactic materials, such as sensorial materials, geometric solids, impressionistic charts and fraction insets (Montessori, 1965). Students had access to a shared library, cafeteria, gymnasium and multiple common spaces for art, music, performance, food preparation, and physical activity. A sports field, play structures, and a small garden provided additional opportunities for outdoor exploration. In every classroom, large windows gave ample natural light. The original convent school blackboards and trim paneling complemented the child-size wooden furniture and potted plants characteristic of Montessori prepared environments (Polk Lillard, 1996). Student artwork was displayed on the hallway walls, along with posters promoting peace, human diversity, and care for the Earth. The students enjoyed considerable freedom of movement and activity throughout the building. During my observations, I commonly encountered children walking briskly in pairs on an errand to another part of the school, or heard them playing bells, xylophone or piano in the music room.

As in all accredited Montessori schools, students at North Star are divided into multi-age classrooms. There are multiple "children's house" (age 33 months – six years), lower elementary and upper elementary classrooms, as well as a middle school community (ages 12-14). The classrooms on which I focused were both led by experienced teachers credentialed at the level they taught.

Participants

Participants in this study included all consenting students in the E1 and E2 classrooms and two classroom teachers, one in each class. In each classroom, I purposefully sampled focus individuals (Plano Clark & Creswell, 2010), to provide the reader with information on a range of Montessori students' characterizations of STEM. First and foremost, I chose students on the basis of their extensive, unusual, or interesting responses to tasks. I strove for maximum variation in gender, ethnicity and grade level—however, particularly in the E2 class (where only 18 out of 28 students consented), I was constrained by which students from which I could select my sample.

Participant and site selection. Site and participant selection for this project was purposeful (Plano Clark & Creswell, 2010). I first sought out potential participating teachers based on their interest and willingness to collaborate. I complemented this strategy with predefined selection criteria so that the site I chose included salient characteristics of United States Montessori schools (Cossentino & Whitescarver, 2008) and represented a unique case of elementary STEM integration. My predefined criteria included: one or more forms of Montessori accreditation, signaling fidelity of implementation of the Montessori method; familiarity of both students and teachers with elementary STEM integration, so that I could observe existing practices in a naturalistic manner without intervention; student and family demographic characteristics that approximated the surrounding neighborhood; and independent interest from participants, so that the findings from the research undertaken in this project would be applicable to the school context. I prioritized nearby schools so that I had flexible access, allowing for lengthy engagement with the field site (Stake, 1995). While North Star is in many ways similar to other independent Montessori programs, there are few schools in which teachers explicitly seek to integrate STEM and have undertaken extensive professional development to do so.

The summer prior to beginning this study (June, 2016), I participated in a weeklong Montessori STEM training through a local university, where I met participating teachers Carrie and Erica. Both teachers had completed the same multi-year Montessori STEM certificate program (see Ibes & Ng, 2011). They expressed interest in reflecting on and improving their STEM teaching, so I asked them if they would be willing to partner on this research project. Following an informed consent process (see Appendix D for Internal Review Board Exemption letter), they agreed to work with me during the 2016-2017 school year. My study actively focused on students; however, statements in interviews and my observations suggested that each teacher influenced student characterizations. This was not surprising, as several scholars have argued that teachers are perhaps the most influential factor in classrooms (e.g. Bryan & Atwater, 2002). The following description of the two classroom teachers serves to contextualize students' experiences.

Carrie, E1 teacher. Carrie, a White female, has been a Montessori teacher for over twenty years. The majority of these have been spent at North Star, where her children were current students and alumni. She previously taught upper elementary for five years, and had been in her current position at North Star as a lower elementary teacher for sixteen. In addition to Elementary I-II (grades one through six) certification through AMS and AMI, Carrie holds a Master's in Montessori Education, as well as a state Elementary teaching license. Carrie considered Montessori philosophy to be the "consistent heartbeat" of her teaching (Personal communication, September 1, 2016). She approached her work with an attention to detail and accuracy in convention and terminology, but regularly took time to tell stories or make jokes about herself and her students. Her serious demeanor communicated high expectations for student accountability and independence, but she also engaged in frequent conversations about their families, interests, and lives outside of school.

Carrie completed M-STEM training almost three years prior to this study, but continued to seek additional professional development to help STEM "take on a life of its own" in her classroom (Personal communication, September 1, 2016). These experiences provided her with a framework for STEM integration as "a series of lessons that address gaps that we have in the Montessori albums" (Personal communication, September 1, 2016). Carrie aimed to cultivate wonder in her students through the traditional Montessori practice of impressionistic lessons, and did not aim to give the same STEM presentations to every child. She viewed M-STEM as one aspect of an overall learning process, and did not emphasize repetitive opportunities for practice or product creation. STEM, for her students, was one set of stories among many.

Erica, E2 teacher. Erica, a White female, taught at North Star for the past eight years since her Montessori training, and it was the only school at which she had been a lead teacher. She was also parent to a child currently at North Star. While not initially formally educated as a teacher, Erica worked as an Assistant in a Montessori classroom as well as a substitute, summer program leader, and one-on-one aide. She obtained her Montessori Elementary I-II teaching credential through AMI. Erica described her teaching role as a "guide" of the "whole child's social, emotional, and academic growth" (Personal communication, January 18, 2017). She felt that individual attention and student choice were central strengths of the Montessori method, and did not expect every student to participate in all of the same lessons. Instead, she encouraged independent exploration by communicating her own enthusiasm about the material, and regularly elicited students' stories with questions about how certain topics related to their lives. When not giving lessons, Erica was an unobtrusive presence against the background of considerable student activity, her voice rarely heard over the hum of conversation unless she made an announcement to gather students' attention.

Erica also completed an M-STEM certificate three years prior to this study, attending the same cohort as Carrie. She credited this program with her introduction to the idea of STEM education, and explained that it made STEM feel "accessible" and "liberating" (Personal communication, September 1, 2016). Erica placed a premium on student interest and teamwork in her approach and provided many opportunities for "learning by doing" (Personal communication, January 18, 2017). She wanted STEM to be fully integrated into other disciplines, and noted that unless student engagement and motivation was high they would not follow through. Erica was a strong proponent of what she called "Big Work," or student-directed mini-projects, and devoted weekly time to allow students to pursue them. STEM in her classroom often took the form of investigations organized by small groups of the students themselves in response to a lesson that she posed. Erica aimed to provide students with a firm grounding in specific scientific concepts so that they had knowledge guiding authentic choices to follow up.

Students. To answer my research question, I collected a combination of whole-class and individual focus student data, purposefully sampled for maximum variation and theoretical interest (Plano Clark and Creswell, 2010). Consenting students represented two genders in all three grades in each class. While largely racially homogeneous (70%

of E1 and 78% of E2 students are White), each classroom sample included students from multiple linguistic and ethnic backgrounds, including two emergent bilingual students in E1. I did not collect extensive demographic data on the whole class samples to protect students' identity and confidentiality[3]. Table 3.1 below provides basic information on the overall classroom sample of students who consented to participate in the study.

Table 3.1
Consenting sample demographics, E1 and E2, North Star Montessori

		Number of students		
Class	Grade	Female	Male	Total
E1 (*N*=27*)	1st	5	3	8
	2nd	4	4	8
	3rd	6	5	11
E2 (*N* = 18)	4th	3	4	7
	5th	4	2	6
	6th	3	2	5

**Note.* 27 out of 29 total students consented in E1 and 18 out of 28 consented in E2. Samples do not necessarily reflect the demographics of the entire classroom.

Each student participant in this study received a code corresponding to class level (LE for E1 and UE for E2), grade, gender, and student number from a class list created by the teacher. In this way, documents would not be linked to student names and confidentiality would be maintained. For example, a second-year male student might have the code LE2113, and a fourth-year female student might have the code UE4024. All non-focus student quotations in this thesis hereafter use these student codes.

---

3 I have relied on teacher report of student demographic information including race, ethnicity, linguistic background, and gender identification; therefore, this information represents external assessment rather than student self-identification. I provide this information for descriptive and contextual purposes, but did not analyze student demographic variation in depth in this thesis. For example, while I use the indicators "male" and "female," these reflect teachers' reports and are not meant to reify a binary understanding of gender.

E1 students. The E1 class included 29 students aged six through nine, corresponding to first through third grade. Rather than by grade level, students in this study are identified by their year in the elementary program. While some students had been in the E1 classroom for two years prior to beginning the study, others had just completed kindergarten. Out of 27 consenting students (29 total in class), in this thesis I have highlighted four whom I interviewed twice: Tuna, Max, Julia, and Elexor.

Tuna (LE1008) was a biracial African-American female first-year student, focused and driven to succeed in school. Tuna was also one of the few members of E1 I interviewed who knew someone in a STEM career: her father was an engineer. While she was always serious and attentive in lessons, I observed that Tuna participated increasingly confidently and frequently as the fieldwork progressed. During my observations, Tuna moved between activities independently and with purpose, but was also comfortable consulting older students to ensure that she knew what to do or how to spell a word accurately.

Max (LE2103) was a biracial Asian-American male second-year student. He had an older brother in Erica's classroom. Max was skilled and careful; a rapt listener in all the lessons I observed, he regularly remembered specific details or vocabulary words. He worked with his male peers on projects such as animal reports and survey data collection for a bar graph, but also displayed considerable concentration in independent activities. Max especially liked to challenge himself mathematically.

Julia (LE3005) was a White female third-year student. Polite and talkative, she liked to take the lead in projects such as a group play on the origin of engineering in early human communities. She was comfortable sharing her opinions in lessons. Younger students often came to Julia for help or information on classroom routines. Julia was one of the few students I observed using print resources to seek out information on how to conduct a science experiment.

Elexor (LE3002) was a White female third-year student. Highly animated and artistic, during my observations she often moved around from work to work, checking in with her peers and asking them what they were doing. She was somewhat reluctant to do assignments she didn't perceive as relevant, and occasionally rushed through a task. She prided herself on her creativity, and talked extensively in both interviews about her outside of school pursuits with toy making and imaginary play.

E2 students. The E2 class included 28 students aged nine through twelve, corresponding to fourth through sixth grade. Some students had been in the E2 classroom for up to two years prior to beginning the study, and many had attended North Star in lower elementary as well, although not all had come from Carrie's class. Out of 18 consenting students (27 total in class), I chose four focus students.

Ruthie (UE4024) was a White female fourth-year student. Thoughtful and imaginative, in lessons, she often listened quietly, preferring to watch rather than be at the center of the action. During my observations, she often sat with one or two friends and talked with them about stories they were composing. She enjoyed making books and drawing.

Jake (UE4123) was a Latino male fourth-year student. Conscientious and active, in lessons, he liked to engage in hands-on explorations with whatever materials were at hand. He embraced opportunities for full-body participation, such as when Erica announced that students could race across the recess field to collect data on their velocity. During the work cycle, he regularly visited with his peers to see what they were working on. Jake followed current events critically and passionately, and expressed a deep desire to make the world a better place for marginalized people and endangered animals.

Courtney (UE5004) was an Asian-American female fifth-year student. Curious, creative, and humorous, she often helped her peers with projects or tasks, and liked to laugh and joke with them in the process. Courtney worked with friends on multiple STEM investigations over the course of the fall, including testing various paper plane designs, writing the script for a play on early human tools, and collaborating on a poster about challenges to natural pear and apple tree pollination in China. In our interviews, she made puns, asked lots of questions, and confidently shared her out-of-school engineering pursuits with LEGOS and Rubik's Cubes.

Jordi (UE6101) was a White male sixth-year student. Talkative and quick-witted, he liked to be involved in the whatever conversations were going on, although he was more likely to call across the room before walking over to find out what his peers were discussing. Jordi never hesitated to share his opinion on a conversation or ask a question, but was polite and agreeable with a willingness to hear others' reasons. In his written responses and interviews he expressed a clear big-picture worldview, stating, "everything humans do is to acquire power" (UE6101.OctIn).

Research Design

The aim of this project was to explore and interpret the meaning of Montessori elementary children's characterizations of science, technology, engineering and mathematics (STEM) as they engaged in STEM activities and lessons over the course of three months in the school year. To answer my research question, *How do Montessori elementary students characterize aspects of STEM?* I undertook an instrumental case study approach with two cases, one for each classroom. This allowed me to holistically represent a range of views in two learning contexts at a single school site. Table 3.2 on the following outlines my research design; Table 3.3 illustrates the timeline of my data collection activities.

Table 3.2
Research design, including research question, student data source, and analysis approach

Research Question	Data Source	Analysis Approach
How do Montessori elementary students characterize aspects of STEM?	Montessori Modified Draw-A-Scientist Test (or Engineer) (MM-DAST(E))	Descriptive coding (Saldaña, 2016); Direct interpretation, categorical aggregation (Stake, 1995)
	STEM Questionnaire (STEMQ1/STEMQ2)	1st cycle: Elemental coding methods using descriptive and process codes (Saldaña, 2016) 2nd cycle: Categorical aggregation (Stake, 1995); Pattern coding (Saldaña, 2016); matrix data display (Miles, Huberman & Saldaña, 2014)
	Semi-structured follow-up interviews	1st cycle: Direct interpretation, Elemental coding methods using descriptive, process and in vivo codes (Saldaña, 2016) 2nd cycle: Pattern/category coding (Saldaña, 2016) Development of themes and assertions (Stake, 1995)

Data Sources

I collected multiple forms of student data over the course of my fieldwork. Lengthy engagement with the field site helped me triangulate student data and build familiarity and rapport with participating teachers, thus contributing to the trustworthiness of my inquiry (Lincoln & Guba, 1985). Within constraints of my own class schedule and observations, as well as North Star field trips and special events, I collected data from both classrooms on the same timeline (see Table 3.3). Participation in the project was voluntary over the course of the study. Due to student absences, response numbers varied between the M-MDAST(E) administrations and STEMQ1 and STEMQ. On the following page, I discuss in greater detail the primary and secondary data sources I collected during this time period.

Table 3.3
Timeline of student data collection activities

Date	Participants	Activity
September 14-20, 2016	Whole class (N_{E1} = 27) (N_{E2} = 18)	MM-DAST(E)1 STEMQ1
October 3-7, 2016	Focus students (N_{E1} = 4) (N_{E2} = 4)	Semi-structured interview
November 28 - December 2, 2017	Whole class (N_{E1} = 25) (N_{E2} = 17)	MM-DAST(E)2 STEMQ2
December 5-14, 2016	Focus students (N_{E1} = 4) (N_{E2} = 4)	Semi-structured interview
September, 2016 – December, 2016	Whole class (N_{E1} = 27) (N_{E2} = 18)	Classroom observations

Note. During my observations, I audio-recorded lessons, wrote field notes, debriefed with teachers and took photographs of student work. These activities are not included as data sources as they were not actively analyzed for this thesis.

Primary data sources. Two tasks were administered to all students in both classes (E1 and E2) twice during the study. The first was the Montessori Modified Draw-A-Scientist Test (or Engineer) (hereafter MM-DAST(E)). This task was based on an instrument used by Walls (2012), modified from Chambers' (1983) DAST. The second task was a researcher-generated written questionnaire about science, technology, engineering and mathematics (hereafter, STEMQ). Both tasks were designed to provide multiple representations of the students' views on scientists and engineers, and to help gather a range of views from all grade levels over a period of time.

As shown in Table 3.3, each task was administered by the classroom teacher at two time points: once prior to beginning STEM lessons for that year, and then following the conclusion of each teacher's STEM lesson series. This was done in order to document changes that occurred over the course of the fieldwork. Each teacher was responsible for administering both tasks without myself present, in order to minimize additional bias or discomfort introduced by an outside observer and to make the tasks a more authentic part of the students' activities (Lincoln & Guba, 1985). I provided protocols to Carrie and Erica beforehand in order to elicit their feedback on the appropriateness of the reading level and address questions or concerns about logistics.

MM-DAST(E). The MM-DAST(E) was a modified version of the M-DAST (Modified Draw-A-Scientist Test) (Walls, 2012). Based on the classic Draw-A-Scientist instrument (Chambers, 1983), the M-DAST has been used to provide information about children's views of the nature of science (NoS), scientists' work, and their identities as science learners (Walls, 2012). A similar task adapted for engineering, the Draw-An-Engineer-Test (DAET), has been used to gather information about student conceptualizations of the work of engineers (e.g. Capobianco et al., 2011). According to the protocol of the MM-DAST(E) (see Appendix A), children are given a piece of paper and drawing materials and are asked to produce a detailed drawing of a scientist or an engineer. They are verbally encouraged to include specific information in their drawing, and to write a short story captioning their drawing. They are also reminded that there is no correct answer and that the purpose of the instrument is to see what they think.

The MM-DAST(E) followed the same four changes that the M-DAST made to the classic Draw-A-Scientist Test (Walls, 2012): 1) students were given access to drawing materials allowing them to represent a range of skin colors; 2) they were verbally asked to give their scientist a name; 3) they were verbally asked to provide additional information about their scientist, and 4) to identify the skin color, race or ethnicity of the figure they drew in a follow-up interview. According to the protocol, students completed the drawing as a whole class activity at the same time. The follow-up interview took place after the researcher has reviewed student drawings and observed the classroom (see *Interview*, below). For the purposes of this study, I modified the observation and interview sections of the M-DAST administration protocol provided to me by Leon Walls (L. Walls, personal communication, November 27, 2015) to include questions about the STEMQ and reflect the observations I had already planned to do in the classroom.

STEMQ. The second task, the STEMQ, asked students to answer questions about science, technology, engineering, math, and STEM (Appendix B). Questions on the STEMQ were adapted from existing literature (Carlone, 2012; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman & Ko, 2004). This questionnaire was intended to elicit self-reports on how Montessori elementary children describe and define distinct aspects of STEM, such as the terms “science,” “engineering”, “technology” and “math.” Because many Montessori lessons involve activities in which students define and classify objects, and the questionnaires were to be delivered to students with a wide range of literacy skills, questions were posed in the simplest, most general possible form (e.g. “What is [science]” rather than “What do you think [science] is?”).

The STEMQ was also designed to provide evidence for how students report on their classroom STEM activities and their attitudes toward STEM. They were queried as to whether they “do” science, use technology, do engineering, or use math in their classrooms, and if so, what they do. In Montessori E1 and E2 classrooms, there is no designated time for learning “science”, “technology” or “engineering,” and science lessons are named by the concept presented or the subfield addressed (e.g. botany or zoology) instead of the overarching term “science.” I therefore selected these words for the questionnaire in part to determine if students demonstrated familiarity with the terms, and to see if they would associate their classroom experiences with specific disciplines and/or the idea of “STEM”.

Finally, students were asked which subject they liked, and why people might consider STEM to be important. Based on students’ first STEMQ responses, the final questions were altered during STEMQ2 to ask if students thought STEM was helpful to people and/or the Earth. The purpose of these questions was to provide some insight into students’ attitudes toward STEM. To keep the questionnaires as short as possible and allow for open-ended responses, I reserved follow-up questions for interviews.

The classroom teachers administered the STEMQ the same week that students completed MM-DAST(E). In order to let students to work at their own pace, Erica copied questions from the STEMQ on a class whiteboard and allowed students to answer over the course of one week; Carrie also allowed students to answer at their own pace, or to dictate their answers to a peer or classroom assistant. Consistent with expectations for assignments in Montessori classrooms, students were responsible for answering the questions and turning in their own questionnaires as independently as possible.

Student interviews. From the larger sample of drawings and questionnaires, I selected students from each grade level in each class for semi-structured follow-up interviews, using the purposeful sampling strategies described earlier in the Participants section of this chapter. Semi-structured interviews ensured that responses across individuals were comparable, but also allow for participants to elaborate on ideas (Plano Clark & Creswell, 2010). This is particularly important when research participants are young children who may not be able to fully explain their thoughts in writing.

I began the interview protocol by asking students to verbally explain their M-MDAST(E) drawing, and to provide information on what scientists/engineers do, and who can become a scientist/engineer (Walls, 2012). Questions asked early in the interview included: “The follow-up asked you to draw a scientist/engineer. Can you tell me a little bit about what you drew?” and “Who do you think could become a scientist?” The protocol then addressed STEMQ responses. I asked students to reflect on their responses in relationship to their classroom experiences, in order to gauge their familiarity with STEM. Questions in this part of the interview included, “Can you tell me a little bit more about what you meant when you wrote…" or "Is there any answer you wrote before that you would like to change now?". Throughout the interview, student drawings and written responses served as prompts and grounding reference points. Individual interviews lasted between nine- and twenty-one minutes, and an average of fifteen minutes. I transcribed student responses from each interview verbatim.

Secondary data sources.

Observation field notes. I used field notes from my classroom observations as a secondary data source in order to characterize the learning context in depth. This provided me with an etic perspective on students' self-reported experiences of STEM and helped establish trustworthiness for my interpretations (Lincoln & Guba, 1985). Over the course of the fieldwork period, I visited North Star one to three times each week, typically staying for two and a half hours. Observations in each classroom ranged from twenty minutes (the length of a typical lesson) to approximately one hour (including a lesson and follow-up). I maintained a peripheral stance during this time, and did not interact with students unless explicitly invited to do by teachers or students themselves.

STEM lessons. Prior to the start of the 2016-2017 school year, I asked Carrie and Erica to determine a series of STEM lessons[4] approximating what each teacher would normally deliver in a full semester. Both teachers identified a short lesson sequence in a

---

4 While the individual lessons were not explicitly aligned to national or state standards for science education, the content approximated many ideas encapsulated in the Next Generation Science Standards (NGSS Lead States, 2013). It is important to note that such a predetermined schedule was somewhat of a departure from the more organic manner in which both teachers told me they usually set a sequence. As the teachers decided whether or not their sequence design was feasible, the lesson strands and presentation schedule evolved over the course of the fall.

topic area of their interest, which they presented at an average rate of two lessons per week between October third and November 16, 2016. Most lessons were drawn from teaching albums the teachers obtained through their Montessori STEM training (Ibes & Ng, 2011). My observations were concentrated on these lessons, which I describe in greater detail in Chapter Four.

Analysis

Stake (1995) provides general guidelines for data analysis in case studies. He states that case study researchers use *codes* to develop the evidence patterns that warrant their subsequent assertions and themes, but does not detail specific coding techniques. I therefore consulted Jonny Saldaña's (2016) coding manual for a more thorough treatment of different coding methods. Saldaña (2016) writes that coding is a "heuristic—an exploratory problem solving technique" that helps researchers connect data with one another and endow them with meaning (p.8). This process is adaptable to each researcher; one may just as easily develop, hybridize, or apply coding methods depending on the study (Saldaña, 2016). Coding involves making decisions about goodness of fit between research questions, data sources, coding methods, and study purpose. It is rigorous, but also subjective. Saldaña (2016) notes that coding is part of analysis and one way to analyze data, not something that has to happen with all data collected for the study.

My primary analytic work was spent on questionnaires and transcripts, as they revealed the most information on how E1 and E2 Montessori students characterized aspects of STEM. Field notes served as a secondary data source. In analyzing the student data I followed a recursive process. As my analysis progressed, I coded each source multiple times and compared within and across data sources as well as individual students. This constant comparison sensitized me to patterns in the data and helped me identify emerging analytic categories, which I then used to organize the themes synthesized from my coding procedures (Miles, Huberman, & Saldaña, 2014). From the interplay between the questions I asked and students' response patterns, I organized my analysis by the following aspects of STEM:

- *Who* can be/become a scientist or engineer? (MM-DAST(E), interviews)
- *What* does it mean to do S-T-E-M? Where and when do these activities take place? (STEMQ, Interviews)
- *Why* is "STEM" important? What is its purpose? (STEMQ, Interviews)

I began by analyzing the MM-DAST(E), then moved on to the STEMQ and student interview transcripts. I analyzed each case separately and sequentially, beginning with E1 and moving next to E2. My data matrices, code lists, and draft analyses were made available to both Carrie and Erica at multiple time points during my analysis process, and I discussed my overall findings with both teachers during member checking meetings (Stake, 1995) in March and April, 2017.

MM-DAST(E). I began analysis by holistically examining students' MM-DAST(E) drawings for information on who can be a scientist or engineer. I laid out all the drawings and wrote short descriptions of each, detailing what the characters looked like, what gender markers or skin color they had, and the actions in which they were engaged. This allowed me to characterize "Who" students saw as being scientists/engineers, a key feature of their descriptions of STEM. I described each drawing from guidance in the literature (see Walls, 2012 and Capobianco et al., 2011) and entered my descriptions into a spreadsheet organized by students and color coded by gender and scientist or engineer. I followed this procedure for all drawings for both cases, E1 and E2, for the data collected at the beginning and end of my fieldwork period.

After I had entered all drawing descriptions into the spreadsheet, I physically sorted and coded the student drawings from each round of the M-MDAST(E) into four features of interest: student gender, character gender, skin color, and attributes of scene. Saldaña (2016) calls this process of coding for content or topics *descriptive coding*. Describing drawings and looking for patterns also corresponds to Robert Stake's (1995) concepts of "direct interpretation", in which a researcher looks at an instance and asks what it signifies, and "categorical aggregation", which involves finding correspondence between codes and instances to create a class of interpretations (p.74). Because I was interested to know whether any patterns appeared by gender and/or race and ethnicity, I disaggregated drawings according to gender marker and skin color, as well as by scenic attributes, such as "in the lab". I performed the sort repeatedly, comparing my interpretations of the drawings against my spreadsheet coding to confirm or revise my initial codes. This served as an internal audit of my analytic process (Lincoln & Guba, 1985).

For example, after doing this process multiple times I identified fewer gender amorphous characters. In some cases, students depicted multiple figures or figures where features were ambiguous. I identified my interpretations of gender according to a combination of conventions such as student report, name, dress and hair length. In cases where multiple figures appear in the drawing, I counted each figure for gender and skin color, but all as part of the same scene. For instance, three students each time (LE1104.Sep, LE2001.Sep, LE3002.Sep and LE1109.Dec, LE2001.Dec, and LE3002.Dec) depicted engineers in a group of two or three characters, sometimes with variation in skin color and gender within them. In September, a female first-year (LE1001.Sep), one of three English language learners in E1, depicted her scientists in a group of three characters: male, female, and gender amorphous and in bright colors; however, in December she only depicted one character. Another student (LE2105.Dec), made a drawing with three gender amorphous figures for his scientists, each with a different skin color.

STEMQ. Next, I approached the STEMQ data because I wanted to interpret how E1 and E2 students characterized their own STEM activities in and out of the classroom ("What"). The STEMQ also provided information on students' views of the purpose and value of STEM ("Why"). I began with a holistic read-through of student responses. To analyze the questionnaire results, I transcribed all students' handwritten responses and entered them into spreadsheets organized by question and student ID number, with separate spreadsheets for STEMQ1 and STEMQ2. When transcribing students' words I kept the original syntax and punctuation, but matched spelling to Standard English for clarity of expression. I then inductively analyzed student responses for patterns around each question.

For the first cycle of coding, I assigned descriptive codes to capture the primary topic of student responses (Saldaña, 2016). When possible, I used students' own words, a technique known as *in vivo* coding (Saldaña, 2016). To create codes, I compared responses across each classroom case so that codes would be as inclusive as possible. For example, for the STEMQ question, "What is engineering?" early codes included: *creating or making stuff, problem solving,* and *fixing.* Figure 3.1 (below) illustrates an example of one of my frequency tables for E1 STEMQ2 for the first question, *What is science?* I collected codes under two themes by color.

STEMQ1: What is Science? (Category: SCIENCE) Student response code table

Theme:		Specialized Activity		Way of Knowing		Other				
Code:	**Don't Know**	**Doing experiments**	**Potions/ concoctions**	**Learning more/ Discovery/ Research on the natural world**	**"Figuring out" an explanation/ cause and effect**	**The knowledge underlying techology**	**The natural world itself**	**STEM**	**Work**	**Total codes**
Student ID:	1009	2001	1001	2106	1005	2004	2103	3106	1106	
	1002	2002	2007	2110	2007	3107				
	1008	2015	3002	3005	3004					
	1104	3002		3009	3107					
	1107	3004		3101						
	3103	3008		3107						
		3010								
		3111								
Totals:	6	8	3	6	4	2	1	1	1	32
Theme total:	6	11		10		5				32

Figure 3.1. Example STEMQ code frequency table.

Once I had coded responses for each question, I examined the frequency of coded responses and looked for patterns across relevant question sets (e.g., by disciplinary category). I compiled descriptive codes and synthesized them into themes describing predominant ways that students characterized individual disciplines as well as STEM (see Figure 3.1 above). Thus, I used Stake's (1995) techniques of direct interpretation and categorical aggregation in the STEMQ as well. I repeated this process for both STEMQ1 and STEMQ2, and compared patterns to look for evidence of any changes during the fieldwork period. Analyzing data from the whole class provided me with a sense of common patterns and trends throughout the sample, and enabled me to contextualize focus student responses. The descriptive codes from the written questionnaires also served to inform and triangulate the coding I undertook with interview transcripts (Lincoln & Guba, 1985). I followed the same process for E1 and E2, generating independent codes and themes for each case. In Chapter IV, I report predominant STEMQ themes in each case as a percentage of the coded responses.

Student interviews. At this point, themes were emerging and evolving, which is why I looked to data from student interviews. After I gained a holistic picture of the whole class responses from the MM-DAST(E) and the STEMQ, I worked systematically through each interview transcript from focus students in first the E1, and then the E2 class. The interviews allowed for additional depth to be voiced around these students' characterizations, and provided more detailed evidence to support my developing assertions about each case. I analyzed each interview inductively in multiple coding cycles. First, I applied codes to pre-interviews with the E1 students, checking my codes with my thesis advisor and sharing them with participating teachers as well. I undertook first cycle coding according to elemental techniques I had used in previous analysis. In addition to descriptive and in vivo codes, I added gerund-based *process codes* to interpret students' descriptions of their classroom activities and what they believed scientists and engineers did. Saldaña, (2016, p.111) notes that these three techniques are "appropriate for virtually all qualitative studies" and are often used as a suite of coding methods, rather than on their own.

Throughout multiple coding cycles, I generated a summary interpretive commentary of each student's interview at both time points. I revised my codebook multiple times and revisited my field notes and descriptive data, shifting my analytic stance from "what did that mean?" to "what did that mean in the context of these experiences, now that time has passed?". I created a summary list of codes for each focus student at the conclusion of my coding process and linked my open codes from each interview to the themes from the STEMQ, which allowed me to visualize patterns of student responses and identify themes that emerged from interviews (see Figure 3.2 below).

	A	B	C	D	E	F	G	H
1	Student/ Interview		Category	Aspect	Subcategory	Theme	Code	Quotation
2	Ruthie 10/3/2016	Inclusive	Science	Who	becoming a scientist	necessary skills	starting out young	Um so I decided to make um someone that's is young because PAUSE… I… it just makes um…. Well, a lot of scientists they um, or engineers they start out when they are, probably like younger. [R: Mmhmm] So that's probably the reason why I made it a little bit younger.
3	UE4024.OctIn	Creative	Science	What	becoming a scientist	creativity/imagination	inventing cool things	I decided for her to make the time machine because um PAUSE I thought it would be cool if you could like travel PAUSE… and so the reason why, so I thought I would be cool if you could like go to different periods so you could like learn stuff in time and you could like meet different people [R: hmmm] and ask them questions and stuff like that
4		Connected	Science	Why	purpose of science	social ties	learning about others	and so the reason why, so I thought I would be cool if you could like go to different periods so you could like learn stuff in time and you could like meet different people [R: hmmm] and ask them questions and stuff like that
5		Inclusive	Science	Who	becoming a scientist	gender stereotypes	positive messaging/ empowerment	I also put the word be yourself on the shirt because, you can do anything, really?
6		Connected	Science	What	doing science	social ties	communication	She is um, she is….maybe she is talking or showing people about like the time machine or something, because the time machine's right there
7		Connected	Science	Who	becoming a scientist	social ties	family influence	Um well how I thought about it was….PAUSE I was thinking a lot about my sister and she looks something like that
8		Connected	Science	Why	becoming a scientist	becoming a scientist	gender stereotypes	I think it's cool that when like girls are doing… um important, like stuff that, like 'cause usually there's… a lot of… men doing these kind of things so…. that's why I made it a girl...Yeah and people used to think like that girls weren't as…Girls weren't as like smart, or so....that's… why

Figure 3.2. Sample code spreadsheet for Ruthie's pre-interview.

I repeated the same procedure with the E2 interviews. As each class was considered an independent unit of analysis, it was important to me to maintain a separate initial codebook for each group of students. Given that my focus students in each class did not necessarily attend the same lessons, I was less interested in comparisons between students than in patterns across them (Stake, 1995). Table 3.4 (below) indicates examples of codes and data to provide the reader with a sense of the different strategies I used.

Table 3.4

Coding strategies, sample codes, and data exemplars

Code type (I = first cycle, II = second cycle)	Sample codes	Data exemplar and source
I. Descriptive code**:** denotes the content or topic	Experimentation Potions Research Engineering design process Peer influence Media influence In the lab Gender Race	**Race*:** "I think that like…some people, may think that, like, **only white people can be…like scientists**…or something." (LE3002.OctIn) **Gender, in the lab:** A black **man** with spiky dark hair standing **in front of bubbling test tubes with a white outfit and pens in his pocket**. He has glasses and his mouth is open and he is smiling. (LE3111.Nov)
I. Process code: describing actions or processes participants associate with STEM	using special tools making a job easier studying the natural world reasoning in your brain solving problems	**Making a job easier:** "They use it by thinking of ways to do things when things are hard." (LE2002.Nov) **Using special tools, studying the natural world:** "I do science. I have studied the anatomy of a flower with a microscope. I also studied seeds with a microscope." (UE5004.Sep)
I. In vivo code: direct quotes from participants	"see what happens" "anyone can be…"	**"See what happens"**: "I love to mix two or three types of chemicals together and **see what happens." (**UE6025.Sep) **"Anyone can be…":** "**Anyone can be** a scientist if they want to be." (LE3002.OctIn)
II. Pattern code: Related to STEMQ categories and themes	Becoming a scientist Doing engineering Inclusive perspective	**Inclusive perspective:** "Yes, we experiment and test in our classroom. **We don't always call it science,** like biology, which is the study of plants and animals." (UE4123.Sep)

**Note.* Bold text indicates the code evidenced by the exemplar.

Second cycle coding and developing themes and assertions. Working from my literature review and interpretation of my descriptive data, I developed more encompassing analytical categories by gathering my initial codes and searching for patterns, a second cycle of coding that Saldaña (2016) calls *pattern coding*. From these categories, I identified major themes in the interviews and related them back to those generated through my STEMQ analysis. From correspondence (Stake, 1995) of evidence between the MM-DAST(E) and the category codes in the STEMQ and second-cycle coding in student interviews, I synthesized my results to develop overarching themes and assertions for each case. I looked across students and data sources to make sure that the assertions fit, repeating my assertions to myself as I read my commentary. While I used frequency as one type of evidence for the strength of my assertion, I also looked for consistency in characterizations. Finally, I searched for counter-examples that did not fit my assertions. I discussed assertions and interpretations with both participating teachers as well as the older students I interviewed. I shared selections from my codebook and manuscript drafts with participating teachers as a form of member checking (Lincoln & Guba, 1985). I report these results in Chapter IV. In Chapter V, I synthesize across the two cases in relationship to established literature and my own learning.

Trustworthiness

Both during fieldwork and analysis I took steps to build a chain of evidence and increase the trustworthiness of my interpretations. Yvonna Lincoln and Egon Guba (1985) provide guidelines on different measures researchers should employ throughout the process of naturalistic inquiry to aid in establishing different aspects of trustworthiness, namely: "credibility, transferability, dependability, and confirmability" (p.328). I took the following steps (see Lincoln & Guba, 1985, p.301):

- *Prolonged engagement and persistent observation.* I maintained regular contact with participating teachers and the field site between June 2016 and May 2017. I observed weekly between September and December 2016, and again in February 2017, to familiarize myself deeply with each classroom, the structure of lesson and student behaviors and build trust.

- *Research journal*. In addition to the field notes I generated during observations, I kept a personal research journal to document events outside of my observations. This journal also served to record my thoughts, reactions, questions and decisions about the evolving inquiry. Finally, the journal helped me externalize my feelings and maintain awareness of my biases, promoting reflexivity.
- *Audio and collegial debriefing*. I was not often able to immediately debrief in conversations with peers; however, following site visits I used an audio recorder to record my initial reactions. Biweekly meetings with my thesis advisor gave me opportunities to debrief with an outside professional.
- *Participant meetings*. I met with participating teachers informally several times over the course of the fieldwork to share my observations and preliminary interpretations and to provide Carrie and Erica with opportunities to reflect on their practice and ask questions.
- *Collection of referential archival materials*: I audiotaped my observations and teacher conversations. I also took photographs and made floor plan sketches of each classroom, as well as of student work, which I archived. Both Carrie and Erica took occasional photographs and shared notes with me to provide additional information regarding lessons I could not observe. Finally, I obtained copies of school admissions materials to provide additional information about the school context.

By collecting detailed information from a variety of sources and member checking with participants, I attempted to craft a credible multi-dimensional portrait of the classrooms under study. As Stake (1995) writes, use of different perspectives and data sources enables both researcher and readers to understand learning activities and student perceptions in context. These activities also helped triangulate my interpretations, which Lincoln and Guba (1985) state is absolutely key to trustworthiness.

Lincoln and Guba (1985) stress that naturalistic inquiry is a dynamic process, and that one thing that can help enhance all measures of trustworthiness is to keep a personal journal with notes on logistics, decisions, and reactions. This journal helps document the case as a living entity. The following extract illustrates one example of how my inquiry evolved. In October, my thoughts were focused on STEM integration practices in the classroom and teachers' thoughts about student learning, whereas by January my analysis focused primarily on student self-reports:

> …My working analytic categories for observations include STEM Content, Processes, Language, and "Culture/Community." Content refers to the subject matter that the students learn (i.e. the topics of the presentations and the interests that they follow). Processes refer to the practices that students engage in and whether they associate them with STEM. Language refers to the way that teachers and students talk about STEM, whether they use technical vocabulary or special words that are emphasized, and how they communicate with one another. The final category, *culture/community*, refers to how STEM activities are integrated in the unique life of the classroom, and how students negotiate belonging in the classroom community through participation in the MSTEM lessons. Teachers chose the MSTEM lessons and that this choice reflects what they feel "counts" as STEM. They might bring a Cosmic Education ethos into some of the lessons, but this does not mean that they include the traditional Montessori Great Stories in their idea of STEM. In that sense, I feel that the pedagogical aspects of the presentation might influence what ends up being MSTEM, and how the children follow up the lesson, more than the content itself.
>
> For our meeting tomorrow, I would like to talk about how the work shows students' learning, and what the teachers feel students are learning from the activities (both about STEM and about Montessori Cosmic Ed). I am not sure if I should share my analytic categories at this point, or wait until our next meeting to do so. One

> article I read yesterday discussed Dewey's view of curriculum as existing between two poles: the child's interests and the subject matter structure. I wonder if this would be an interesting thing to bring up, since I think it is an important idea that has bearing on how they think about student learning. (Research journal, October 18, 2016)

Lincoln and Guba (1985) note that transferability of findings is "in a strict sense, impossible" (p.316); however, suitable detailed description of the context and inclusion of ample raw data allows for readers to make their own interpretations (see also Stake, 1995). By weaving extracts from my field notes, research journal and teacher interviews into my narrative descriptions of focus students and each classroom case, I hope to give the reader a window into not only the classroom as I saw it, but also provide evidence of the path I took through the case, from data collection to summary. My extensive descriptions of the process I took throughout the inquiry helps with transferability (Lincoln & Guba, 1985). Last but not least, a reflexive attitude on the part of the researcher goes a long way to establishing trustworthiness. Thus, I provide more information on my own role below.

Role of the Researcher

Stake (1995) advocates for "interpretation as method" (p.40), noting that the researcher's personal view shapes the case study. He writes that a researcher takes many roles, including that of teacher, advocate, biographer, theorist and interpreter. For instance, the researcher teaches others about what she found, but also must persuade readers and establish evidence for her interpretations. She may end up taking a position or making suggestions based on what she learned. She integrates the "vicarious experience" related in her description with her reconstruction of the events she witnessed and which were narrated to her (Stake, 1995, p.9). From a social constructivist standpoint, a case study narrative mediates between what Stake terms the "three realities": the reality accessed through sensory experience, the reality corresponding to personal interpretation of sensory experiences, and the reality illuminated through social construction and analytic activity of interpersonal interpretations (Stake, 1995, p.101).

Throughout the duration of this study, I made choices about my role. Because my goal was naturalistic inquiry, but I also wanted to respect participants and ensure that the project benefited them, I did not position myself as an expert with an agenda for intervention or evaluation of existing practices. While I remained open to teaching participants through my experiences, I did not advocate for one position or substantially change what was going on in the classroom. Instead, I hoped to provide a second pair of eyes and ears facilitating reflection and synthesizing patterns of student characterizations. I participated in classroom activities only on explicit invitation, but throughout the fieldwork period I met periodically with teachers to share my thoughts. Ultimately, I wanted to be able to create a story that could be shared with participating students and teachers about what they think, say and do, in the hopes of providing insight onto current and future efforts in Montessori elementary STEM integration. Thus, in Stake's (1995) terms, my primary role in this research project was that of an interpreter.

What Stake (1995) does not address in detail, however, is how the roles he outlines intersect with positionality. In all of these roles, the researcher's subjectivity is not considered a design failure, but an epistemological grounding. However, this does not mean that potential bias is simply assumed but remains hidden; it must be acknowledged, and problematized if need be. My own positionality requires elucidation beyond the general role of interpreter. As the primary "instrument" through which all of my observations and interviews were mediated (Miles et al., 2014), I filtered what I saw through my experiences as a Montessori student, teacher, and educational scholar in training. As a White settler and English-speaking, educationally-privileged, cisgender woman who grew up attending nontraditional and independent schools in relatively affluent communities, my perspective has long represented the status quo of powerful narratives in progressive educational discourse. Certainly, the demographic characteristics ascribed to me are nominally similar to those ascribed to the majority of my participants, although important differences in age, geography, race and ethnicity exist between us as well.

I did not force myself to approach my experience in the classrooms as a blank slate; instead I sought to balance my previous experiences as a Montessori student and teacher with my emerging knowledge of STEM education and educational research methodologies. While I am an insider to the overall culture of independent Montessori schools in the United States, contemporary ethnographic methods demand a high degree of reflexivity (Lincoln & Guba, 1985). Many years spent in Montessori environments enabled me to build rapport with participants and readily immerse myself in the classroom due to my familiarity with the curriculum and culture; however, I also had to remind myself of potentially over-identifying with, or misinterpreting, participants. I remained willing to critically question my assumptions or preconceptions regarding the value and efficacy of Montessori methods, and I recognize that my personal and professional experiences shaped my interpretations. Discussing my observations with professors and other comparative “outsiders” to Montessori helped me think carefully about what practices and behaviors might be unusual from an etic perspective. I share this information not as a limitation of my study, but as considerations shaping my frame of reference. However, I believe it is important to note several limitations, which I detail below.

Limitations

This study was delimited by several factors. First, I was not present for the administration of the student tasks, as I did not want to unduly bias responses and make the tasks seem too out of the ordinary. However, this meant that I could not be present to determine if the protocol for administration was followed completely. For instance, all students did not have equal access to the full range of colored pencils due to supply scarcity; therefore, the skin colors of students’ drawings were not necessarily intentionally chosen. As another example, not all students answered every question on the STEMQ. Secondly, the data sources I report on in this thesis were collected for the purposes of this study, rather than being artifacts of everyday classroom instruction. As previously mentioned, whole-class tasks with specific rules to follow, such as those outlined by the instrument protocols, are relatively unusual for students in Montessori classrooms; they are used to choosing what they want to do and when on their own. I complement reports from these activities with descriptions of the learning context generated through my observations, a practice that is more in the non-intrusive spirit of naturalistic inquiry (Lincoln & Guba, 1983).

While I undertook to enhance reliability of students' responses through my own observations and discussions with the teachers, it was not possible for me to observe every lesson or follow-up that occurred in the classroom. This was further constrained by my schedule: visits were often at similar times of the week rather than being spontaneous or capturing the full range of activities. I assume that activities to which students alluded in their responses were recalled to the best of their abilities and described actual events that went on in the classroom, but it was not possible to independently verify all events that students described. I asked students to describe and elaborate on events or responses that may have occurred from one week to several months previously (in fact, some students recalled lessons from years previous); therefore, striving for accuracy of recall is not realistic. However, I feel confident that students shared information with me that they felt was memorable or personally significant. Student reports, and my own, do not represent a single truth about what they think about STEM, but dialogically and experientially informed interpretations.

Conclusion

In this chapter, I described the methodology of my study, including the justification for my choice of an instrumental case study (Stake, 1995). I provided an introduction to the school site and participants to help the reader gain familiarity with the learning context. I detailed which data sources I collected, when, and how they were administered, as well as my procedures for analyzing the data. Finally, I explained how I developed trustworthiness, and explored my role as a researcher throughout this project and the limitations I encountered. In the next chapter, I present findings from my analysis. I describe patterns of student responses in each classroom case and how they changed over the course of the fall. I also explore common themes and assertions, providing insight on the learning context and STEM activities.

Chapter 4 : Findings

This multiple instrumental case study sought to explore the research question, *How do Montessori elementary students characterize aspects of STEM?* This chapter presents the results of qualitative analysis of data from students in Carrie's[5] lower elementary classroom (E1), and Erica's upper elementary classroom (E2). I treat findings from each classroom case separately. For each case, I first reorient the reader with a description of the teacher, classroom, and STEM lessons based on my observations. This description provides the social context for students' characterizations. Next, I summarize findings from whole class tasks — the MM-DAST(E) and the STEMQ — administered at the beginning and end points of my fieldwork. I describe selected predominant patterns and discuss key changes that took place. I then detail the STEM characterizations of four individual students, synthesized from interview data and observation field notes. Throughout, I introduce a set of assertions for each classroom case supported by themes found across focus students and data sources. My assertions speak to the following analytic questions: *Who* can be/become a scientist or engineer? *What* does it mean to do S-T-E-M? Where and when do these activities take place? *Why* is "STEM" important, and what is its purpose?

Lower Elementary Case

The Learning Context

The first case I explored was Carrie's lower elementary classroom at North Star Montessori: E1. Carrie had been teaching at North Star for sixteen years. She completed a

---

[5] The names of teachers, students, and the school are pseudonyms.

graduate certificate in Montessori STEM (Ibes & Ng, 2011) through a local university three years before this study was conducted, and has since been working to integrate the lessons she learned there with her existing Montessori practice. Carrie's prepared environment embodied basic Montessori principles of intentional order, aesthetic harmony and respectful community (American Montessori Society, 2017; Lillard, 2007). Figure 4.1 on the following page shows the layout of the classroom environment.

The hub of activity in E1 was a large open space in the center of the room. This gathering and work area was surrounded on all sides by shelves organized by subject—Zoology, Botany, Chemistry, Geography, and laboratory materials. Montessori materials and natural objects were carefully arranged on these shelves. Children had easy access to art materials and other supplies, as well as basic hand tools on a pegboard in one corner of the classroom (Figure 4.2). Child-sized wooden chairs and tables provided space for individual and group activities. A vase of wildflowers stood invitingly on a table by the doorway, and each worktable had a small vase as well. The south-facing windows let in ample sunlight, and a disco ball suspended from the ceiling threw sparkles across the room. Framed student watercolors and batiks adorned the walls, along with a series of printed images showing paths for a "growth" or "fixed" mindset.

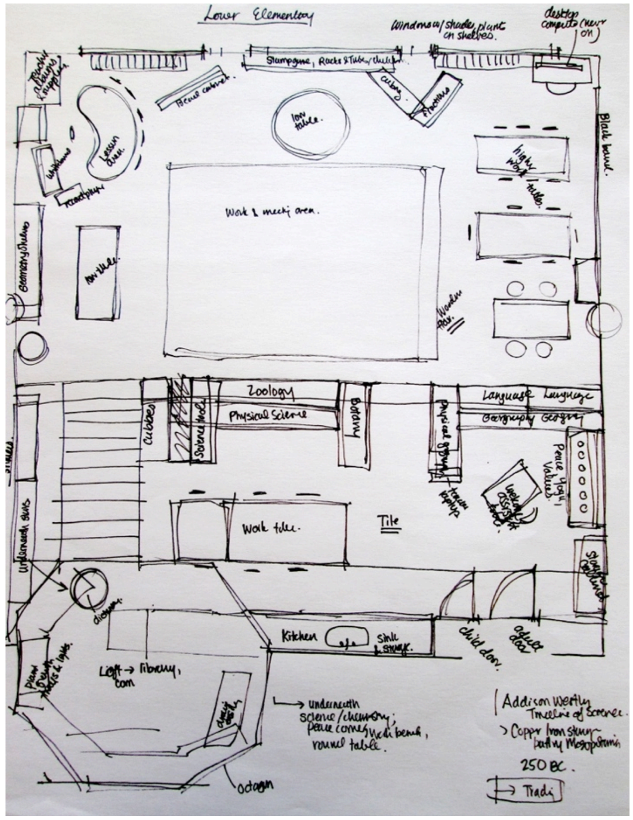

Figure 4.1. Sketch of E1 classroom floor plan, showing work tables and shelves.

Carrie's classroom stood out for its veritable menagerie of life: the students were responsible for the regular care of dozens of potted plants, as well as four hermit crabs, two guinea pigs, several fish, a snake, and a tortoise. Caring for plants and animals is an important part of cultivating respect for other beings and the environment, a common theme in Montessori education (American Montessori Society, 2017).

Figure 4.2. E1 Classroom environment and tool area, North Star Montessori.

The flow of events I observed in E1 was typical of most Montessori elementary classrooms: a brief morning meeting followed by two and a half hours for students to engage in learning activities of their choice (Polk Lillard, 1996). During this time, Carrie invited small mixed-age groups to attend short lessons. Dr. Montessori believed young children should have ample time to freely select tasks and complete them independently. Teachers are therefore encouraged to let children work without interruption, presenting new information only when they seem ready for the next element in a sequence or express an interest in a given topic (Montessori, 2000). Thus, rather than participating in daily blocks of whole-class instruction, E1 students received several different 20-30 minute presentations in multiple subjects on a given day. While Carrie presented all lessons, a full-time classroom assistant, Susanna, helped prepare materials and support individual student learning.

Each school day in E1 began with the whole class meeting at 9am to review necessary information. At the conclusion of the meeting, the students were dismissed to work. This transition involved considerable, though not chaotic, movement: children took down chairs from atop tables, unrolled rugs, gathered materials from shelves, and marked their spots with laminated nametags. Once students had settled in pairs or trios on small work rugs in the center of the floor or with their notebooks at the large group tables, lessons began. Carrie personally invited individual children to come to the lesson table with their work journals. Students wrote down the time and title of the lesson they received—a process they called “logging in”—and handed their journals to Carrie for inspection. She reinforced spelling and mechanics conventions, and offered feedback on anything from students’ handwriting to activity choices.

From 9:35am until noon, E1 students rotated through small group lessons and independent activities. On a given day, they attended presentations on a wide variety of topics across and beyond STEM disciplines, such as “the Earth’s Rotation”, “Paragraph Structure”, “Types of Lines”, “Uses of Adverbs”, and “Fraction Operations” (Field notes, February 13, 2017). Carrie’s deep familiarity with Montessori, gained through many years of teaching, enabled her to deliver almost all the lessons I observed from memory. Student groups were typically composed of three to six children from multiple grade levels; therefore, a lesson could be review for some students and new material for others. At the conclusion of a lesson, students either received suggestions for independent practice such as completing a card with premade problems, or Carrie simply asked them to “think about” what they had learned and “follow up” on a detail that interested them.

When not in lessons, E1 students engaged in a wide variety of spontaneously chosen activities using mathematics, technology, and science. For example, on February 13, 2017, Max spent over fifteen minutes using Montessori materials to solve a nine-digit by three-digit multiplication problem, while Tuna put on her headphones to use the reading-enrichment application Lexia on an iPad. At the same time, Julia and Rose, two third-year girls, consulted a science reference book for information about carrying out an experiment on conducting electricity with a lemon battery; Julia recorded their notes in a green notebook labeled “Science”. Boy-girl pair Mars and Kate discussed how to plan a trip to the science museum to learn more about space and gravity, using a form that Carrie developed to help them structure the purpose of their trip and figure out contact information for relevant personnel. Bob and his friend Ryan observed the fish (which had just given birth), taking turns using a timer. Their peers moved throughout the room and in and out of the hallway, creating a background hum of sound and movement.

During my observations, the E1 students were talkative, active, and considerate of one another, asking other children if they needed assistance, stepping deliberately around work rugs, and softly remarking “excuse me” if they knocked another’s elbow by accident. They worked with peers across genders and grade levels, a practice Carrie explicitly encouraged. As many students in E1 were still learning how to read and write, Carrie noted that an older peer reader was a great advantage to help carry out a research project or consult a reference text.

E1 STEM lessons. As part of this study, I asked Carrie to provide me with an opportunity to observe how she integrated STEM in her classroom. In response, she developed a nine-lesson series of three Montessori STEM strands (see Table 4.1 below). She arranged students in three mixed-age groups of nine to ten and met with them twice a week. Lessons typically lasted between twenty to thirty minutes. STEM lessons in E1 generally took place at the lesson table. Occasionally, Carrie brought students to the floor, where they manipulated materials. It is worth noting that Carrie had not used this type of sequence structure in previous years (she typically spread STEM lessons out rather than teaching them on a regular twice-weekly rotation), and these groups were somewhat larger than those she invited to other lessons.

The E1 STEM lesson series was based on presentations Carrie learned in her STEM certificate course; learning resources she had personally collected; and content from the professional development program we had attended the previous summer. Given Carrie's desire to make STEM more common and my schedule constraints, we agreed that she would give STEM lessons on Tuesdays and Friday mornings. While students stayed with the same group of peers over all nine lessons, they rotated through the sequence so that all students did not receive the lessons in the same order. Table 4.1 on the following page shows the individual strands Carrie created, along with the dates I observed each lesson.

Table 4.1
E1 STEM lesson series

Strand	Lesson	Observed
What is Engineering?	The Engineering Design Process	9/30/16
	Naked City	10/14/16, 11/29/16
	The King, the Mice, and the Cheese	11/15/16
Story Problems	How do we Use Numbers/Math Every Day?	9/30/16
	Word Problems	10/11/16
	Making Bar Graphs from Story Problems I	10/14/16
	Making Bar Graphs from Story Problems II	10/18/16
What is Chemistry?	Biosphere to Atoms	9/30/16
	Introduction to Chemistry	10/14/16, 10/28/16
	Parts of an Atom	11/8/16
	Research Check-In	10/18/16, 11/1/2016

Note. I observed some lessons twice, with a different group each time.

The E1 STEM lesson series I observed was composed of three strands of three related lessons. In the first, "What is Engineering?" students learned about the engineering design process and participated in a building challenge activity with spaghetti and marshmallows. In the next lesson, students traveled outdoors and heard the story of the "Naked City," then speculated on how their school and neighborhood would look in the absence of engineering and technology. In "The King, the Mice, and the Cheese," students listened to a fiction text about a series of problem-solving failures involving an unlucky cheese-loving king and his mouse problem, which Carrie connected to the idea of a "null loop" in engineering design. The students then worked on ways to communicate their learning and apply the engineering design process to a problem they were experiencing in class; for example, one group of students presented an original play dramatizing the origin of engineering thinking in early human times. Another group decided that a puppet show would help their peers be more motivated to complete jobs on time.

The second strand, “Story Problems”, focused on using math in everyday life. In the first lesson, after discussing ways humans use math without thinking about it, students chose adults around the school to interview about how they used math in their jobs. Next, students used these interviews as evidence for story problems they created. Using the classroom saw, a piece of scrap wood, and one of Carrie’s signature red clogs, one group of students made up their own measuring tool, the “clog,” which they used to measure the heights of their peers and teachers. They constructed a chart of this data and turned it into a bar graph, then collected their own data as independent follow up. This activity, which the first group in the rotation completed but which was not done by the other two groups, prompted those nine students to identify themselves “as the cloggy people” at the beginning of each subsequent lesson (Field notes, October 18, 2016).

The third strand, “What is Chemistry?” introduced students to scientific vocabulary and practices through an exploration of atoms in a cosmic education context. In “From Biosphere to Atoms”, students learned about hierarchical organization of life from the biosphere to atomic level as Carrie used illustrated vocabulary charts to “zoom in” on successive levels of organization. Next, Carrie presented an original lesson in which she used granola as an analogy to explore the concepts of mixtures and compounds, and physical and chemical changes. Students listened to a biography of Dmitri Mendeleev and explored print resources about the periodic table. As follow-up to this strand, they engaged in independent research on a detail of their interest: one group made a model cell, others researched elements, and two students learned about ocean and forest biomes.

E1 STEM lessons contained several common Montessori pedagogical strategies. Carrie was the primary speaker in all STEM lessons I observed, a pattern characteristic of teacher presentations in Montessori primary and lower elementary classrooms and in contrast to the self-directed student discourse that occurs when children are not in lessons (Lillard, 2007). Students did not give extended explanations in lessons, although their opinions were frequently elicited in a "yes" or "no" manner (this coincides with findings by Rinke et al., 2013). Angeline Lillard (2007) writes that Montessori believed in the power of observational and peer learning; therefore, children are often expected to spend more time watching the teacher's first presentations of new material, but then to learn from their own hands-on activity and peer interaction later on.

According to Montessori (2007), children must be able to visualize something before memorizing it, and new information must be presented in a way that "touch[es] the imagination" of the students and stimulates interest (p.10). Carrie's speech often took the form of storytelling; she regularly encouraged students to use their imaginations and to consider what else they might explore later on. An initial story was followed by the introduction to a new concept, term or idea in a manner that made abstract ideas concrete. For example, if the new element was a technical vocabulary term, Carrie wrote the term on a small paper label and linked it to a visual representation. Once the new information was formally presented students, practiced using the terms and connected them to real-world examples.

A short conversation from a lesson on the "Parts of an Atom" illustrates these STEM lesson elements. At first, the children revisited vocabulary from a previous lesson, "Biosphere to Atoms":

> Carrie *continues through the sequence, as the children answer chorally. There is some confusion over where cells go, and the relationships between small molecules and cells.*
> Elexor: Cells are made up of atoms?
> Tuna: Atoms are made up of cells?
> Carrie: I think we skipped one. Organs and tissues are made up of…
> Students: Cells!
> Carrie: You have to have a cell to have a subcellular structure… Okay, small molecules are made up of…
> All children answer together loudly: ATOMS!
> Carrie: And here we are today. You may remember that I told you that atoms are made up of things as well. And we're going to talk about that today. *Carrie makes sure she has all of her materials. She puts a series of paper labels on the table that say, "name", "location", and "charge."*
> Carrie: there are things in atoms, and those things exist in a certain place in the atom, a location or spot. And, they have a charge. Negative, positive, or no charge at all. Now let's step back a minute. This is a strand of lessons that's about chemistry. Does anyone remember what chemists study? What the study of chemistry is about? *The children say nothing. Carrie explains*: Chemistry is the study of matter. Matter is anything that has mass and takes up space and is made of atoms. In some ways of looking at things, you might say that an atom is the fundamental building block. When they're found by themselves they can bond with others, and can make new things. *T links arms with another student affectionately, combining their two first names as one would in a molecule.* We're [CarMaxide]! *The other students laugh. She continues:* So here's something I want you to think of. *She defines matter again*. Who can name something that is a chemical?
> Elexor: Water?
> Bob: Oil?
> Max: Vinegar?
> Tuna: Syrup?
> Max: Trees?
> Carrie: Yes! Are trees made of matter? [Students: Yes] Do they take up space? [Students: Yes] Do they have mass? [Students: Yes] Are they made of atoms? [Students: Yes]. So it's not just liquids. Really, every thing is a chemical because it's made of matter.
> *Students say, laughing*: I'm a chemical. I'm matter. I take up space.
> Carrie: Now if you're afraid of chemicals you're chemophobic which means, guess what, you're afraid of the world... (Field Notes, November 8, 2016)

This conversation recounted above subsequently became an invitation for students to explore the parts of an atom on their own, using hands-on modeling materials (see Figure 4.3 below). In most lessons, this type of follow-up activity was presented in the form of a question. Carrie asked: “What could you do? What are you interested in? Do you think that would be good to research?” At the end of the term, most students created one or two physical work products as a result of their STEM lessons.

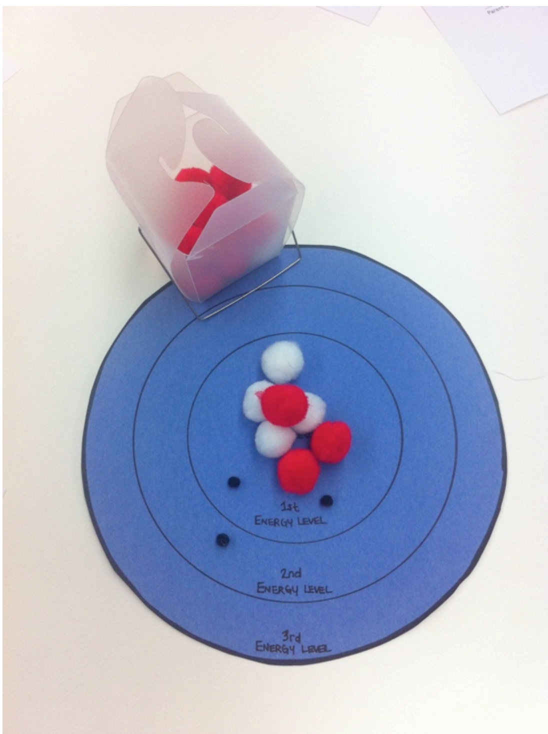

Figure 4.3. Montessori E1 STEM Lessons. At left, a teacher-made material for constructing atomic models. At right, students making a bar graph, with hermit crabs in the foreground.

As shown in Figure 4.3, E1 students had opportunities for hands-on exploration of materials to concretize abstract concepts[6], which Stohlmann, Roehrig and Moore (2012) recommend as a best practice in integrated STEM education. As I show in the following sections, students drew on these classroom experiences as well as peer and family influences from outside of school. I next present in my analysis of the instruments and interview data I collected from E1.

STEM Characterizations According to Whole Class Tasks: E1

MM-DAST(E) results. The MM-DAST(E) provided information on how E1 students viewed scientists and engineers, including their gender, skin color, and work environment. Table 4.2 (p.94) summarizes categories and frequencies of descriptive codes of interest in the drawings of engineers and scientists made by consenting students in E1 on September 20, 2016 and December 2, 2016. I report student gender, drawn character gender, skin color, and scene characteristics. Students are indicated by student code and date (e.g., LE2109.Sep). Of 27 students who answered the first MM-DAST(E), 26 students responded in December, for 53 total drawings. Some students drew multiple characters, making 65 total characters in the dataset.

Gender. I interpreted students' drawn scientist and engineer gender from positive student identifications as well as conventional markers like hair length and clothing, or

[6] While students in E1 received multiple lessons their teacher, Carrie, designated to me as "Montessori STEM lessons," it is important to note that each of Carrie's individual STEM lessons did not integrate all STEM disciplines. Secondly, many students did not express familiarity with the term "STEM" itself, or kept their characterizations separate by discipline. Therefore as I gather students' characterizations of aspects of STEM, I do so within these constraints.

names such as “Bob” (LE2109.Sep), or “Ruby” (LE3009.Dec). Out of both MM-DAST(E) groups, students depicted slightly more male characters (48%) than female characters (41%) or gender amorphous characters (11%). The latter were typically stick figures without features. As the sample was 55% female and 45% male, female figures were underrepresented in the drawings, especially among scientists. However, as is clear from Table 4.2, while the protocol called for original random assignment of scientists and engineers, females were significantly overrepresented in the engineer drawings (11 females: four males in September, and nine females: four males in December). Males were significantly overrepresented in scientist drawings (four females: eight males in September, and five females: eight males in December). While five females drew male characters in the first round (this decreased to two in December), no males ever drew females. Thus, there are more male scientists and more female engineers in both September and December, even though male engineers decreased in frequency.

Table 4.2

E1 MM-DAST(E) descriptive code frequencies, September and December, 2016

Descriptive Code	Scientist		Engineer		Frequency	
	September (n=12 students, 14 characters)	December (n=13 students, 15 characters)	September (n = 15 students, 19 characters)	December (n=13 students, 17 characters)	Total (n = 65 characters, 53 drawings)	% of characters/ drawings
Gender of student						
Female	4	5	11	9	29	55%
Male	8	8	4	4	24	45%
Gender of character						
Female	4	3	10	10	27	41%
Male	7	9	9	6	31	48%
Not specified/ amorphous	3	3	0	1	7	11%
Skin color of character						
Peach/ Light yellow	1	2	13	8	24	37%
Tan	4	5	2	5	16	25%
Dark brown	3	5	2	1	11	17%
Other (e.g. green, blue, pencil, etc.)	6	3	2	3	14	21%
Scene type						
Indoors						
Laboratory	9	11	0	0	20	38%
Machine shop/ workbench	0	0	4	0	4	7%
Factory	0	0	2	1	3	6%
Office	0	0	0	4	4	7%
Outdoors						
Construction site	0	0	1	2	3	6%
Accessorized portrait (e.g. hammer)	1	1	4	2	8	15%
Non-accessorized portrait	2	1	4	4	11	21%

The overall pattern indicates that 100% of male and 67% of female students drew characters with gender markers corresponding to their own, suggesting that they identify people like themselves as STEM professionals. However, in total, more students represented scientists and engineers as male. While this is overall consistent with findings from Leon Walls' (2012) study of African American third graders (68% male scientists) and Brenda Capobianco and colleagues' (2011) large sample of Midwestern elementary students (58% male engineers) in grades one through five, there is a greater percentage of female characters in my sample.

Skin color. Students had access to a range of colored pencils for their drawings. 42% of drawings depicted scientists with tan and dark brown skin, and 37% of drawings had peach or light yellow skin. 70% of the E1 class is identified as White, and 30% as students of color. One pattern worth highlighting is the striking difference between the skin colors depicted amongst the engineers and the scientists, particularly in September, when 68% of the engineers were drawn with light-colored skin. Drawings of scientists displayed considerably more variation in skin tone: 66% of December drawings depicted characters with tan or brown skin. Therefore, students' drawings of engineers roughly corresponded to the skin color makeup of the class, but students depicted scientists with a greater variety of skin colors than the peers they encountered every day. Furthermore, there were fewer light-skinned characters overall in December than in September. Walls (2012) notes that most studies with the DAST do not report skin color or race, or hold to the stereotype of a White male scientist. He reports that 86% of the African-American students in his study drew scientists that had skin colors like themselves, but when asked to select a “real” scientist from a series of photographs, 35% chose a White scientist (Walls, 2012, p.17). I was not present to observe how colored pencils were distributed to the students or whether all students had access to the same drawing materials; however, the diversity of skin colors in the sample suggests that this group of majority White students were representing scientists from a range of backgrounds.

Not all children were explicitly asked to name the race, ethnicity, or skin color of their scientist or engineer. This question was asked directly only to those that were interviewed; for younger children I tried multiple terms such as “skin color”, “race” and “ethnicity” because some of the students stated that they did not understand what one of the terms meant. Four students I interviewed explained that their skin color choices were intentional, either because they were drawing a person who “looked like” another student, a family member or friend (e.g., LE1008.OctIn; LE2004OctIn; LE3002.OctIn; LE2103.OctIn.) or because they “liked the color” (LE3005.OctIn). Other students stated “I don’t know” (LE1002Oct.In) or made a distinction between the color that they used in their drawing and the color they had in their minds because of which materials were available to them (LE3101Oct.In, LE2002Oct.In, LE2103Oct.In). One third year White female student, Julia, who had drawn the only Black female scientist (“Megan the archaeologist”) stated: “I think that like…some people, may think that, like, only White people can be…like scientists…or something…but I think that anyone can be a scientist if they want to be” (LE3005Oct.In). She did not specify how she established this perception, but her statement suggests that, even as a young student, she was aware of racist stereotypes connected to STEM. Julia was the only student who made an explicit statement about racial stereotypes in her interview. However, in December, a second-year male student (LE2105.Dec) drew a house with three stick figures of various skin colors surrounded by scientific equipment, with the caption “Welcome” (See Figure 4.4 below).

Figure 4.4. Drawing by second-year male student of three gender amorphous scientists of various skin colors in a lab, with a caption entitled “Welcome.”

Scenes. The E1 drawings were remarkably thematically consistent. Some students reproduced almost the exact same scene in December as they did in September (see focus student Max, LE2103, page 127). The majority of drawings (58%) depicted scientists and engineers working indoors in a laboratory, machine shop, factory, or office. Only 6% of drawings depicted engineers outdoors, at a construction site. The remaining 36% depicted a scientist or engineer as a person against a background with or without accessories like a hammer, wrench, or pens with a pocket-protector. 21% of drawings were simply portraits, either a face or a figure alone of the page.

Scientists were almost exclusively depicted alone in the lab—85% of December scientist drawings showed a figure at a table with a microscope or beakers and a single lamp, and 38% of all drawings showed laboratories. This is consistent with Walls' (2012) and Chambers' (1983) findings. Scientists in the lab had a microscope, test tubes, or a lamp next to them; these materials were also available for students to use in the classroom. Three students I interviewed identified these materials as equipment used by scientists for "experiments" (LE3002.OctIn, LE2103Oct.In, LE3101Oct.In).

Engineer drawings exhibited more variety, such as accessorized portraits with tools of the trade like a hammer or wrench, or scenes in a factory (e.g., LE1009.Sep) or at a construction site (e.g., LE2002.Sep). This suggests that Montessori children in this E1 classroom associated engineers with fixing, building, and tool use, a pattern also described by Capobianco and colleagues (2011). In the classroom, E1 students had access to a tool corner with safety goggles, hammers, wrenches, and pliers (Figure 4.2).

One interesting change over the course of the fall was a shift in students' representations of engineers. In September, 30% of engineer characters were drawn in a machine shop or workbench setting. In December, there was only one such drawing. Instead, four engineers were depicted with posters, notebooks, or pens in an office setting. Two female students (LE3004.Dec, LE2007) and one male student (LE3003.Dec) explicitly included a cartoon identifying steps of the Engineering Design Process (see Figure 4.5 below). This suggests that while the majority of students still associated engineering with building, fixing, and construction, a small number depicted it as office or design work, a shift potentially connected to their lessons on the Engineering Design Process and characterization of engineering as a problem solving process.

Figure 4.5. Third-year male student’s December Engineer drawing, showing Engineering Design Process graphic, with the caption “I will fix this problem”.

Overall, data from the E1 MM-DAST(E) demonstrated patterns of interest worth exploring in greater detail with a larger sample of Montessori students and a greater number of interviews. This task did not cue students to represent “STEM”; rather, they were encouraged to draw a scientist or an engineer. Therefore, results provide the most direct insight into how the E1 Montessori students in this study characterized what scientists and engineers look like and what they do. Drawings represent people of all genders and multiple skin colors engaged in a narrow range of activities. Scenes included materials available in the classroom. More engineers were depicted female with light-colored skin, like most of the female students in the class. E1 students also displayed a majoritarian view of scientists: as isolated male figures engaged in chemistry-related experiments in labs. However, these pictures did not all conform to the stereotypical White racial identity of the scientist as identified by Chambers (1983).

The patterns I describe above complement existing studies by Walls (2012) and Capobianco and colleagues (2011), which are treated more extensively in the discussion (Chapter V). These results lead me to my first theme and assertion regarding E1 students' characterizations of STEM: *whom* they characterize as scientists and engineers. This assertion will be further supported when I discuss individual focus students.

- *Assertion E1.1: Who? Inclusive:* E1 Montessori students' characterizations of scientists and engineers adhered to prevailing stereotypes but also represented people of all genders and multiple skin colors. The latter occurred in instances when students identified with their drawn characters, such as drawing engineers as female and positively identifying people of color engaged in STEM activities.

STEMQ results. Students' responses to the STEMQ provided information on their definitions of science, technology, engineering and mathematics, as well as information on how they characterized their own classroom activities in the STEM disciplines ("*What?*"). The STEMQ also queried students' familiarity with the term "STEM" and their evaluations of its importance ("*Why?*"). 27 E1 students answered the STEMQ in September, 2016 (STEMQ1) and 24 students answered in the last week of November, 2016 (STEMQ2). Across gender and grade levels, E1 students voiced similar characteristics of STEM disciplines at both time points (Table 4.3). I first report on themes emerging from the majority of students' characterizations of individual STEM disciplines (i.e., science, technology, engineering, and mathematics). I then discuss students' characterizations of "STEM" as a single term.

Table 4.3
Major themes in E1 students' characterizations of aspects of STEM, September and November, 2016

		Frequency of codes, as a percentage of total coded responses per category	
Category	Theme	STEMQ1 (September)	STEMQ2 (November)
Science	Specialized activity, mainly experimentation	44%	61%
	A way of knowing more about the world	31%	25%
Technology	Using personal digital/electronic devices	39%	41%
Engineering	Physically creating products or buildings	33%	38%
	A problem solving process	15%	35%
Mathematics	Arithmetic procedures	59%	62%
STEM	Applied to everyday problems	22%	27%
	Increasing understanding	38%	21%
	Helping improve human lives	34%	29%
	Defines our contemporary world	0%	17%

Science. The STEMQ asked the following questions about science: *What is science? Do you do science in your classroom? What do you do?* While they did not have a class or lessons specifically dedicated to the subject of Science itself, E1 students increasingly expressed their own ideas of what "science" was over the fieldwork period: while 22% of responses in STEMQ1 were "I don't know", in STEMQ2 this percentage decreased to 8%. At both time points, over 70% of E1 students affirmed they did science in their classroom.

E1 students defined science *and* characterized their own scientific activity in two main ways. I designated these themes as *specialized activity, mainly experimentation* and as a *way of knowing more about the world*. While both themes held across STEMQ administrations, the frequency of responses and first cycle codes shifted (Table 4.3).

Science as a specialized activity. When students defined the term science and described the science they did in their classroom, they most often characterized it as a *specialized activity*. 44% of codes in STEMQ1 were included in this theme, and the percentage increased to 61% in STEMQ2. Responses within this theme described experimentation with chemicals, potions, or concoctions, or using tools such as microscopes to make observations, in other words, actions that required specialized materials.

> *One way to describe science is experimenting with interesting objects.* (*LE2105.Sep)*

Over the course of the fieldwork period, E1 students increasingly characterized science as doing experiments. In STEMQ2, students also described experimenting with specific references to chemistry.

> *Science is combining things and coming up with solutions. (LE2007.Nov)*
>
> *Science is using chemicals to make something. (LE2015.Nov)*
>
> *Science is a way to test and perform experiments by combining chemicals. (LE3005.Nov)*

By the end of fall 2016, the majority of students in Carrie's E1 class characterized science as the specialized activity of experimenting, particularly by mixing chemicals. As these students were introduced to basic scientific practices through chemistry lessons in the STEM sequence, this shows a correlation between their classroom experiences and their STEMQ responses. It also supports the stereotype of science as restricted to laboratory experimentation identified in previous research (see Chambers 1983, Walls, 2012). Finally, this theme corresponds to the drawings students produced of scientists in lab coats using microscopes and holding beakers (see MM-DAST(E) results above) as well as students' self-reports of looking at fossils or plant stomata under a microscope (e.g. LE3002.OctIn) and testing acids and bases using pH paper (LE1008.Nov).

Science as a way of knowing more about the natural world. The second major theme included 31% of coded responses in the category Science in STEMQ1, and 25% in STEMQ2. While not as frequent, it encompassed the dimensions of studying or learning about the world in lessons. I interpreted this theme as learning scientific content or information through writing reports, listening to stories, and attending lessons, rather than active engagement in experiments to test or manipulate substances.

[Science is] Reports. (LE3101.Sep).

We learn about it in lessons and we learn what science is. (LE2007.Nov)

Science as a way of knowing was finding out or referencing an extant reality, and also included the established body of knowledge about nature. A female third grade student (LE3005) associated this way of knowing with the quality of "being curious" in both her September and November responses.

For two students, the two major themes were connected, so that scientific activity was explicitly characterized as way of understanding the natural world. Only E1 student identified questioning and explanation as scientific practices.

It's something where you do experiments to learn about stuff. (LE2017.Nov)

Science is a way to explain questions by doing an experiment. (LE3008.Sep)

These responses indicate a more complex understanding of the purpose of experimentation, although they still give primacy to the act of experimenting as the defining characteristic of science.

While the majority of E1 students did not identify individual lessons on science in their STEMQ responses, a female second-grader (LE2002.Sep) and a male third-grader (LE3107.Sep) provided "the first Great Story" (a Montessori lesson about the formation of the Earth) as an example of the science they did in E1 (see Chapter II). While I did not expect that students would consider the Great Stories to be scientific, it is possible that these students were recalling a baking soda and vinegar volcano demonstration that Carrie typically performed during the presentation, and not the content of the story itself. Further research is necessary to better understand how students might conceptualize the role of the Great Stories in their science learning.

Interestingly, although most students described science in their classroom as the specialized activity of experimentation, they did not view this as a regular practice. When I interviewed Bob (LE3101.OctIn), Tuna (LE1008Oct.In), and Julia (LE3002Dec.In) they all described a single experiment they had completed that year or the year previous. While I saw Julia and Rose look up an experiment in a book, I did not see any student perform an experiment during my observations. In December, Carrie showed me where she kept plastic boxes with pre-made experiment cards, and a form she had created for students' science notebooks where they could write a procedure, observations, and an explanation of what they found; however, she noted that no child had yet used the materials that year. This discrepancy between the frequency of actual experiments in the classroom and students' characterizations of science suggests they may be drawing on outside of school experiences, or that the hands-on experiments they performed were particularly memorable. Students' discussions of their scientific activities lend evidence to my second assertion regarding E1 characterizations of STEM, which is further supported in student interviews:

- *Assertion E1.2: What? Connected:* Montessori E1 students' classroom experiences influence their characterizations of STEM, but so do family ties and outside of school experiences; however, students were more likely to identify particularly memorable and participatory lessons in the M-STEM sequence (including "Everyday Math", "Parts of an Atom" and the "E.D.P") as related to science or engineering than they were activities from the traditional Montessori curriculum.

Technology. The STEMQ asked the following questions about technology: *What is technology? How do humans use technology? How do you use technology?* E1 students had a wider range of characterizations of technology than science, as shown by the relatively low percentage of codes in the leading theme. In part, this is due to students' self-reports of unfamiliarity with the word "technology". The in vivo code "don't know" comprised 24% of coded data in STEMQ1 and STEMQ2 responses, and included all but one of the first-year students.

Based on correspondence between descriptive codes assigned to students' answers for all three questions, I identified one overarching theme characterizing technology: *using personal digital/electronic devices*. This theme comprised 39% of total coded responses in the category Technology in STEMQ1, and 41% in STEMQ2. *Using personal digital/electronic devices* was the predominant category for children's definitions of the word, their descriptions of human technology use, and their descriptions of their own technology use. The theme *using personal digital/electronic devices* included identification of specific devices, and students' descriptions of their personal uses. Given that I posed the STEMQ Technology questions from a user or consumer perspective, this theme may have been more prominent as a result of the question format.

> *Technology is using a screen to do something. [Humans use it] to text and watch a movie. [I use it] mostly to play games and watch TV shows. (LE2105.Sep)*
>
> *Technology is using computers and iPads. (LE3106.Sep)*
>
> *[I use] computers, phones, iPads and iPods to look things up and call. (LE3101.Nov)*
>
> *[I use technology for] looking up books in the Resource Center, watching TV, researching things. (LE2007.Nov)*

When students described their use of technology in this way, they included activities at school and at home. Their responses suggested they had regular access to devices and electronic toys and were comfortable using them for learning and leisure alike; thus, this theme likely reflects objects students associated with their everyday life. It is worth noting that Carrie's E1 classroom included a single desktop computer and several iPads that students used for the Lexia reading application, but only a single student mentioned this use in STEMQ (LE3010.Nov). I did not observe E1 students using digital technologies for STEM lessons in class.

The remaining E1 responses included a broad characterization of technology as a tool, examples of transportation or other modern products, or links to other STEM fields. Only two third-years defined the word technology broadly as any useful tool developed for human purposes, the definition that Carrie herself subscribed to and the one that was developed in the Montessori STEM training (K. Ibes, personal communication, March 1, 2017).

Technology is something you can use to make your job easy. (LE3004.Sep).

Technology is a tool that lots of people use. (LE3008.Nov)

One of the most encompassing characterizations was offered by male third-grader:

It is the future. Everything you look at is technology. (*LE3101.Nov)*.

Between STEMQ1 and STEMQ2, about 22% of the E1 class identified connections between technology and other STEM fields.

[Technology is] something like engineering. (LE1104.Sep).

Electricity. It's sort of like science and engineering. (LE3107.Sep)

Overall, results from the technology section of the E1 STEMQ demonstrate that students' characterizations did not change substantially over the course of the fieldwork period. First-year students expressed the least familiarity with technology, while second and third-year students described everyday encounters with personal electronic devices whether or not they had frequent classroom access to devices. A small number of students characterized technology in a more expansive way. While technology was not explicitly addressed in any of the STEM lessons I observed, the ubiquity of personal electronic devices in contemporary life, especially in families with access to resources, likely enabled these young children to identify multiple purposes and examples of technology based on their personal experiences. However, most E1 students did not connect technology with other STEM disciplines.

Engineering. The STEMQ asked the following questions about engineering: *What is engineering? Do you do engineering in your classroom? What do you do?* While most E1 students offered a definition in STEMQ1, they became even more familiar with the word "engineering" over the course of the fieldwork period: 18.5% of students responded "I don't know" in STEMQ1, but only 8% students responded this way in STEMQ2. Two students mentioned family members who were engineers in their responses.

> *[Engineers] Fix stuff. My dad is an engineer. (LE1002.Sep)*
>
> *[Engineering is] Figuring out how to do things, planning it, and doing it. Like my aunt*. (*LE2001.Sep)*

These responses show how students' definitions of engineering as well as their characterizations of their own activities fell into two main themes: the first, *physically building or fixing products or buildings*, emphasized making concrete things. The second, *a problem solving process*, described engineering as a method or a reasoning pattern, rather than as physical labor.

Physically building or fixing products. In September, 33% of total coded data in the Engineering STEMQ section fit with this theme. Although it counted for 50% of students' coded *definitions* of engineering, the total percentage decreased because many students did not describe their own engineering activities in this way. In STEMQ2, the percentage of data in the Engineering section coded within this theme increased to 38%.

The first dimension of this theme included descriptions of various forms of physical labor involving a concrete product, which were categorized together because students often grouped them with one another.

> *[Engineering is like, working on cars and stuff, pretty much. Building? (LE1104.Sep)*
>
> *It is making new things. (LE2105.Sep)*
>
> *It's building and maybe architecture. (LE3005.Nov)*

The second dimension of this theme referred to students' descriptions of building challenges they conducted in their classroom. While students themselves did not engage in full-scale construction projects, five second and third-year students mentioned that they worked in teams to complete "building challenge" activities such as the one I observed in Carrie's STEM lesson. In the words of one male and one female third grader:

> *We make towers, we have to figure out how to build them. Building challenges. (LE3111.Sep)*
>
> *Well, sometimes our teacher has us do a building challenge for example 5 straws, 2 cups, and 10 Popsicle sticks. (LE3005.Nov)*

These building challenges were analogous to the types of physical labor that children expected professional engineers to do, as detailed in their MM-DAST(E) drawings of construction workers. Students' drawings of mechanics also corresponded to their characterizations of engineering as fixing or repairing (see Capobianco et al., 2011).

A problem solving process. This theme is notable because of its change over time: while only 15% of coded data in the Engineering section of the STEMQ fit into this theme in STEMQ1, the percentage increased to 35% in STEMQ2. One dimension of this theme was students' descriptions of engineering as planning or problem solving.

> *Engineering is taking an idea and improving it. [I use it in] the engineering design process, and most work (LE2007.Nov).*
>
> *It is something that you use to solve problems (LE2106.Nov)*

Another dimension of this theme was explicit references to lessons involving the engineering design process used to solve problems in class. Students listed this characterization of engineering as problem solving separately from building challenges or physical activities.

> *One time I had a lesson and we came up with a problem in our class and solved it. (LE3005.Sep)*
>
> *[In my classroom, I do] EDP and building stuff. (LE3101.Nov)*
>
> *[In my classroom, I do] the Engineering design process. (LE3103.Nov)*
>
> *We solve problems. (LE2103.Nov)*

One student responded that he used engineering in the class "in plays" (LE2106.Nov), a reference to the performance the students did dramatizing the origin of engineering in early human times.

While I have so far described the two themes separately it is important to note that they could also both be present in a single student's response, when they connected the act of product creation to the reasoning process behind it.

Engineering is drawing and detailing a picture and then getting all the materials to build it and then building the thing you were wanting to build. (LE2103.Sep)

Three students explicitly stated that engineering products have a purpose or are designed to be improvements. A third-year boy gave the only description of engineering that included a client.

Engineering is taking an idea and improving it. (LE2007.Nov)

Engineering is a way to test your ideas by building and testing to make it better. (LE3004.Sep)

People tell somebody something and then people make it and test it. 'We need a water bottle that can keep stuff cold,' and stuff like that. I draw stuff and try to make it better and I think of ways we can change it up a little bit to make it better. (LE3107.Sep)

These E1 students' characterizations of engineering in the STEMQ also correspond to trends identified in their MM-DAST(E) depictions. In STEMQ2, an increasing number characterized engineering as a reasoning process (but not necessarily an iterative one) used to solve problems whether or not a physical product was created, just as multiple students depicted their engineers in office settings with graphics of the EDP (see Figure 4.4). The latter characterization was more commonly associated with classroom activities; while E1 students had access to basic hand tools such as hammers, saws, and pliers, I did not observe them use these tools to build or fix any items.

There were two significant changes in students' characterizations between September and November. First, more students reported doing engineering in their classroom. While 50% of students initially stated that they did not do engineering in their classroom, that percentage was reduced to 25% in November. Interestingly, although Carrie presented multiple lessons on engineering to all of her students, only 75% of E1 students reported doing engineering in their classroom in the fall of 2016. In November, the seven students who could not describe any engineering activities were first-years, with the exception of a single third-year boy.

Second, as shown by the increased percentage of the theme *a problem solving process,* students shifted their ideas of engineering to include the characterization of a process of designing solutions to problems. This suggests that at least some students directly associated the ideas conveyed in the STEM lessons they received on engineering during the fall of 2016 with their personal characterizations of engineering in STEMQ2. During member checking, Carrie found these results surprising, especially among students who had been in E1 for multiple years. She shared that she gave an Engineering Design Process lesson at least once every year, and was not sure why older students did not recall that lesson in STEMQ1.

Mathematics. The STEMQ asked the following questions about mathematics: *What is math? How do humans use math? How do you use math?* I grouped E1 students' characterizations of math into two main themes: *arithmetic procedures* and *applied to* *everyday problems*. The theme *arithmetic procedures* described pure mathematical activities or numerical operations, whereas the theme *applied to everyday problems* included descriptions of everyday situations in which a person might use mathematical thinking, such as in baking, measurement, making change, or distributing cupcakes to friends.

Arithmetic procedures. 59% of all coded data in the Math section of STEMQ1 and 62% in STEMQ2 fit this theme. It was more common for how students defined math and described their own mathematical activities than how they characterized math done by others. One dimension of this theme included explicit naming of operations or uses of numbers within and beyond what was offered in the classroom.

> *Math is addition, subtraction, multiplication, square root, and things I don't know about. (LE2103.Sep)*
>
> *Math is adding numbers, subtracting, multiplying and factors. (LE2106.Nov)*
>
> *Counting, numbers, what equals numbers. (LE1001.Sep)*
>
> *Math is a way to count and calculate numbers and letters (including algebra). (LE3101.Sep)*

The second dimension of this theme was solving arithmetic problems, often with paper and pencil, and either independently or with assistance from a peer or adult. During my observations, I saw children ask each other and Carrie to make up math problems they could solve with materials, and also watched students think up problems on their own.

> *Math is adding and using materials. (LE1106.Nov)*
>
> *I use math with someone writing down problems for me. (LE1005.Sep)*

I write addition math problems then do it on paper. (LE2004.Sep)

The predominance of this theme in the dataset indicates that most students readily characterized mathematics as a school activity or subject that consisted of well-defined procedures, and suggests even though the majority of students used Montessori materials to solve math problems, the paper and pencil aspect was more significant to them as "math".

The second theme, *applied to everyday problems*, comprised 22% of total STEMQ1 responses and 27% of STEMQ2 responses in the category Math. This theme had three dimensions. The first was responses describing situations in which mathematical thinking was used in everyday life or work. The second was responses in which students noted multiple uses for math. The third was when students connected mathematics to other STEM fields, either in building or scientific practices. This theme appeared more often when students discussed how humans in general used math than when they defined the word or described their own activities.

[Humans use math] to help them with work. To help them survive. (LE3010.Sep)

Humans use math to solve problems in the kitchen and in school. I use it to cook and bake a lot, also at school. (LE3004.Sep)

They use it in all different ways. (LE2007.Nov)

While Carrie's STEM lessons on math focused on measurement, data collection, and word problems, only two students mentioned "word problems" in their STEMQ2 (LE3005, LE2103), and only focus student Tuna (LE1008.Nov) used the word “measuring”. Four students supplied math applications to other STEM fields (LE3107, LE2007, LE2105 and LE3008; the first two included examples in both STEMQs):

[Humans use math] for building, health, education, technology, engineering, and science. (LE2007.Nov)

One way to describe how humans use math is figuring out how much liquid you need in a science project. (LE2105.Sep)

One third-year boy’s STEMQ1 answers to all three questions applied to this theme. He stated,

[Math is] so that people can learn numbers and look at something. Engineering has a lot of math and science and building. ‘How many inches in a foot? How many millimeters in one inch? [Humans use math] as learning about numbers, telling how much stuff you need to build this and what you should have for that. [I use math by] probably working with tools and how big stuff is and how much money this is and how much feet I need. (LE3107.Sep)

This student made several connections between mathematics applied to measure length and quantity, its use in buying goods, and his characterization of engineering as building. His response suggests that he views math as a way of thinking with and through numbers, which can be a useful method of looking at something in the world. Similarly, other students’ whose responses fell within this theme recognized how math could be applied to life situations outside of the school context. This theme increased slightly over the course of the fieldwork, corresponding to the lessons Carrie gave that underscored everyday uses of mathematical thinking.

STEM. The STEMQ asked the following questions about STEM: *Can you think of an example of people using science, technology, engineering and math all together? Which one of these things do you like and why? Why might people think STEM is* *important?* Most E1 students did not characterize the term "STEM" as a single construct. In September, 70% of students could not identify examples of integrated STEM when asked to do so; in November this percentage decreased somewhat, to 54%. Of those eight who supplied examples of people using the STEM disciplines together in STEMQ1, five elaborated on what that was:

> *Electricity. (LE2001.Sep)*
>
> *Watching a TV show about math and science. (LE2004.Sep)*
>
> *Making and building stuff. (LE3107.Sep)*
>
> *Solving problems. (LE3004.Sep)*
>
> *A science and technology fair project. (LE3002.Sep).*

For the seven students who provided answers to this question in STEMQ2, two stated simply, "STEM" (LE2007.Nov, LE2103.Nov). One female second-year supplied, "building a light bulb" (LE2002). A male second-year said, "combining things and solving problems" (LE2105.Nov). A female third-year gave the name of her class, "[E1]" (LE3002.Nov). A male third-year (LE3107.Nov) stated "EDP." Another female third-year said she could think of an example but did not know how to explain it. Thus, in both STEMQ1 and STEMQ2, students' examples of integrated STEM were most similar to their characterizations of engineering and technology. When I asked the students who wrote the word "STEM" in their STEMQ what the term meant to them, all three defined it as an acronym for Science, Technology, Engineering, and Math (LE2103.DecIn, LE3005.OctIn, LE3002.OctIn). When I asked Carrie in an interview what she thought her students might say if asked to define STEM, she stated they would probably provide a definition like this (Personal communication, January 18, 2017), but not provide a further explanation.

I identified three themes characterizing STEM from the third question, *Why might people think science, technology, engineering and mathematics (STEM) are important?* Among students who responded to this question, these included: *increasing understanding, helping improve human lives*, and *defines our contemporary world*. The first two themes were present in both STEMQs, while the third appeared in the second STEMQ only.

Increasing understanding. This theme applied to 38% of STEMQ1 responses and 21% of STEMQ2 responses. There were two dimensions of this theme. The first encompassed responses in which students described the purpose of STEM as learning for its own sake, either by "getting smarter" (LE2103.Sep) or gaining intelligence in their "brain" (LE3008.Sep, LE300.Sep, LE2004.Sep, LE3010.Nov). The second dimension focused on understanding the world.

[STEM helps us learn] about the history of the world. (LE2105.Sep)

STEM help[s] us understand the world around us better. (LE3004.Sep)

Within this theme students did not specify an application for their knowledge; thus, STEM was important as a learning tool itself rather than applied or integrated into specific fields.

Helping improve human lives. This theme had two dimensions. One referenced specific useful inventions without which modern human lives would be difficult.

There would be no inventions like, houses, cars, or phones. (LE2001.Sep)

We couldn't have our houses without technology and engineering. We also couldn't get around. (LE3111.Sep)

The other dimension identified the role of STEM in meeting human socioeconomic needs, although only one student referenced jobs.

[STEM is important] because it's work. (LE1106.Sep)

STEM help[s] people with their education and health and security. (LE2007.Sep)

It helps our world. (LE2106.Nov)

[STEM is important] because it helps you in life. (LE3009.Nov)

Responses coded under this theme included applications or beneficiaries of STEM knowledge and provided STEM with a purpose: helping.

Defines our contemporary world. This theme did not appear in STEMQ1, but applied to 17% of coded responses in STEMQ2. All four of these students stated the world would be different without STEM.

I think these things are important because if we did not have these things our world would be very different. (LE2105.Nov)

Just imagine our world without it! (LE3002.Nov)

Without them our world would be very plain and different. (LE3004.Nov)

Without STEM, we would be walking on a deserted land. (LE3111.Nov)

For these students, STEM was a defining characteristic of contemporary life. Just as Carrie's story of the Naked City suggested that most of what humans see around them has been created as a result of design, these students offered a similarly encompassing characterization. They also provide evidence for my third assertion about the E1 case, which is treated in further detail through the focus student narratives:

- *Assertion E1.3: Why? Helpful:* Most Montessori E1 students did not independently identify instances of STEM integration and perceived “STEM” as a mysterious acronym; however, they linked individual STEM disciplines and viewed them as both personally relevant and helpful for improving human lives…even if this improvement had potentially negative impacts for the Earth.

E1 Focus Student Narratives

In this section, I detail individual E1 students’ evolving characterizations of STEM, synthesized from their MM-DAST(E), STEMQ responses and interviews, and supplemented with observation field notes. I provide narrative description of four students whom I interviewed twice during the fall semester. Quotations from interviews are attributed by student code and the suffix “OctIn” for October interviews and “DecIn” for December interviews. For each student, I present major themes of interest drawn from my open, pattern and thematic coding cycles. These themes address multiple aspects of STEM that I identified through my analysis (see Chapter III), reproduced below for reference.

- *Who* can be/become a scientist or engineer?
- *What* does it mean to do S-T-E-M? Where and when do these activities take place?
- *Why* is STEM important? What is its purpose?

These themes are also linked to the major assertions I have been making for each case.

Tuna[7]. Tuna was a biracial African-American female first-year student. She took part in a number of STEM lesson activities as a member of the "cloggy people" group. Tuna worked with other students to make a bar graph of E1 students' heights in clogs during one lesson. She contributed to the solution her group proposed to the classroom issue of not getting jobs done on time—a puppet show as an extrinsic motivator. She also worked with two older students to construct models of different chemical elements. Tuna was conscientious and methodical about recording her activities; for instance, she brought her work journal to our December interview and inquired what would be appropriate to "log in" (LE1008.DecIn). During my observations, Tuna moved between activities independently and with purpose, but was also comfortable consulting older students to ensure that she knew what to do or how to spell a word accurately. Themes emerging from my analysis of Tuna's interviews provided information on her views of who can be/become a scientist or engineer *(Who)* and her characterizations of her own STEM activities *(What)*.

Who can be a scientist or engineer? Family influence and developing identity. Tuna's characterization of who could be/become a scientist or engineer provided evidence for my first assertion for E1:

- *Assertion E1.1: Who? Inclusive:* E1 Montessori students' characterizations of scientists and engineers adhered to prevailing stereotypes but also represented people of all genders and multiple skin colors. The latter occurred in instances

[7] Students chose their own pseudonyms.

when students identified with their drawn characters, such as drawing engineers as female and positively identifying people of color engaged in STEM activities. Tuna was one of the few members of E1 I interviewed who reported knowing someone in a STEM career. Her father was an engineer, and she drew his portrait for the MM-DAST(E) in both September and December. This family connection influenced her characterizations of engineers and scientists alike. Tuna drew her father's face, smiling and in the center of the page for her first MM-DAST(E) Engineer drawing (See Figure 4.6 on next page). She explained that her engineer's skin color was "brown because [my father] comes from Africa" (LE1008.OctIn).

When asked to describe a short story about the engineer she drew, Tuna answered that, "he would probably be in a bunch of meetings. He just went on a work trip, and there were probably meetings" (LE1008.OctIn). Tuna was not familiar with exactly what her father did at work, as when she asked him he said that there were always meetings. Tuna stated that, like her father, other engineers "build stuff and fix problems" (LE1008.OctIn). While she did not describe engineering as *physically creating products and buildings* in her second STEMQ or interview, she maintained the characterization of engineering as *a problem-solving process* throughout both STEMQ1 and 2 and both interviews.

For the second MM-DAST(E), Tuna accidentally received a paper that asked her to draw a scientist, although she was originally assigned to draw an engineer. She again drew her father. This time, she depicted him in the laboratory with "a bunch of chemicals…he's going to mix them together and see what happens" (LE1008.DecIn).

When asked to describe what her character did at work, she responded with the same description she provided of an engineer, “he goes to meetings and he solves problems too” (LE1008.DecIn). In December, Tuna stated that a person who wanted to be a scientist needed “to be really good at math” (LE1008.DecIn), a quality she identified with herself due to the personal liking for mathematics she expressed in STEMQ2 and later in the interview.

Figure 4.6. Tuna’s first MM-DAST(E) drawing, a portrait of her engineer father, at left. Her second drawing, at right, shows him as a scientist mixing chemicals in a lab.

In her second interview, Tuna explained that she did a considerable amount of engineering at home, rather than in the classroom. While other students cited the Engineering Design Process (EDP) they learned in lessons as what they used for engineering problems, Tuna stated that she did not follow steps for a specific reasoning process: “I just think of an idea and it’s usually good” (LE1008.DecIn). At the beginning of the year, she was one of the few students to possibly envision herself as a future engineer, responding “maybe me?” when asked who could become an engineer (LE1008.OctIn). Tuna’s familiarity with engineering from her father’s career and her own interests in math and home engineering activities therefore influenced her characterization of who can be a scientist or engineer; in this case, she depicted an African male as an engineer, thus countering the racial stereotype identified by Chambers (1983).

What is S-T-E-M activity? A mysterious acronym, but helpful. While Tuna was not familiar with the term STEM itself, she provided characterizations of individual disciplines. In her December interview, Tuna stated that she had heard the word STEM “at the lessons” (LE1008.DecIn), whereas she did not mention it in her first STEMQ or interview. However, Tuna was not sure what the word itself meant; thus, it remained a mysterious acronym.

Alaina: What do you think it means?

Tuna: I don’t really know.

Alaina: Does somebody just say, we’re going to have a STEM lesson?

Tuna: Yeah. (LE1008.DecIn)

While her responses were always concise, Tuna’s tendency to say more on her own as the semester progressed was reflected in her STEMQ and interviews. In STEMQ1, Tuna dictated her responses and answered, “I don’t know” for seven questions; in STEMQ2, she wrote them herself and provided answers for four questions she had not answered in STEMQ1. It is important to note that the school year had just started and Tuna was in 1st grade when STEMQ1 was administered.

In STEMQ1, Tuna did not provide characterizations of scientific activity or her own use of technology. During her first interview, Tuna elaborated on her views of science by adding that doing science could mean "finding stuff [with] a microscope" (LE1008.OctIn) While Tuna did not define technology in STEMQ1, she stated that humans could use it to "look up stuff", a response coded as "research" under the theme *using personal electronic devices* (LE1008.Sep). In the second STEMQ, Tuna expanded her characterizations. She defined science as "experimenting" and encompassed her classroom scientific activities with a single experiment: "learning acids and bases and how to use pH paper," which fell under the theme *science as a specialized activity* (LE1008.Nov). As with many E1 students who stated that they did experiments, Tuna cited a single, memorable experience: testing various substances with pH paper to determine which were acidic and which were basic. In her December interview, Tuna added to her science characterization when she identified the lesson "Parts of an Atom" as the only other science lesson she had attended so far (LE1008.DecIn). Her responses then fell under the theme *science as a way of knowing more about the natural world.* Tuna stated that she enjoyed experiments and wanted to do more of them. In the second interview, she did not give examples of any other lessons on science beyond the "Parts of an Atom" lesson (refer to Table 4.1). This suggests that aside from her recent memorable experience she did not see science as an activity that she did regularly throughout her first semester in E1.

In STEMQ1, Tuna reported that she did not know if she used engineering in her classroom, but said that other humans "use it to build buildings and houses," a response coded within the theme *physically creating products and buildings* (LE1008.Sep). She later expanded on this response when she discussed engineering as *a problem solving process* in her first interview. In STEMQ2, Tuna did not report doing engineering in her classroom but defined it as "fixing problems," which she later elaborated on in a similar manner as in her first interview (LE1008.DecIn). Tuna reported that she used math to "figure out math problems," a response coded under *arithmetic procedures* (LE1008.Sep). In STEMQ2, Tuna defined math as "measuring and math problems," both of which she reported doing in her classroom: thus, her first characterization changed to include *applied everyday problem solving* as well as *arithmetic procedures* (LE1008.Nov).

Tuna did not supply her own definition of STEM, but when asked to characterize the STEM disciplines and describe her classroom activities Tuna offered information about STEM lessons I observed and a science lesson I did not. In both interviews and her own STEMQ writing, Tuna did not share an example of integrated STEM. However, she felt that scientific, engineering, technical and mathematical knowledge was helpful for people, particularly in terms of house construction: "You wouldn't get houses, because you need to measure the walls and stuff" (LE1008.DecIn). She was more ambivalent when I asked if STEM was helpful to the Earth, because of "cars" (LE1008.DecIn). Tuna explained that at home, she learned that gasoline from cars pollutes the air, and stated that electric cars with batteries would be better for the environment. Tuna's interviews and STEMQ responses provide additional support for my second and third assertions:

- *Assertion E1.2: What? Connected:* Montessori E1 students' classroom experiences influence their characterizations of STEM, but so do family ties and outside of school experiences; however, students were more likely to identify particularly memorable and participatory lessons in the STEM sequence (including "Everyday Math", "Parts of an Atom" and the "E.D.P") as related to science or engineering than they were activities from the Montessori curriculum.
- *Assertion E1.3: Why? Helpful:* Most Montessori E1 students did not independently identify instances of STEM integration and perceived "STEM" as a mysterious acronym; however, they linked individual STEM disciplines and viewed them as both personally relevant and helpful for improving human lives…even if this improvement had potentially negative impacts for the Earth.

For Tuna, the term STEM, as a unitary construct, was a label for a certain type of lesson. However, elsewhere in her interview she linked engineering and technology to contemporary life, such as homes, cars, and computers, and viewed these positively in terms of meeting people's needs. She did not view science and engineering as subjects that played a prominent role in her day-to-day classroom activities, unlike math, which she enjoyed. Her characterizations of engineering and technology were informed by her home experiences, particularly with her engineer father. She directly referenced "Parts of an Atom", which included a hands-on follow-up activity during which students worked in pairs or trios to build model atoms and count the number of protons, neutrons, and electrons. Thus, Tuna's characterizations included both in and out-of-school activities related to personal experiences. As seen in her interviews, she identified STEM careers with herself and her family; she stated that scientists needed to be good at math and like experiments, both qualities she associated with herself.

Max. Max is a biracial Asian-American male second-year student. He had an older brother in Erica's classroom. Like Tuna, Max was also part of the "cloggy people" lesson group. He particularly enjoyed the math interviews and data collection activities from the Story Problems strand (see Table 4.1). Max liked to challenge himself mathematically. He worked with multiple peers, but also displayed considerable concentration in independent activities. Themes emerging from my analysis of Max's interviews provided information on who could be a scientist or engineer *(Who)*, the activities he did in his classroom (*What*), and the purpose of STEM *(Why)*.

Who can be a scientist or engineer? Family influence modifying the stereotype, and the importance of a growth mindset. In September, Max was randomly assigned a scientist in the MM-DAST(E). He attempted to represent what he thought "most scientists" looked like, and used his brother and himself as models when he didn't know how to draw the picture that was in his mind. This resulted in a highly detailed laboratory scene of a male scientist he named Bob, depicted on the left on Figure 4.7 (next page). Max explained his picture took place in,

> The science lab…most scientists have white lab coats and they wear white pants and I don't know why I did the green shoes. We didn't have any like light colors so I decided to make his skin brown and then I couldn't really draw straight hair so I drew curly hair…[The skin color of my scientist] isn't supposed to be dark brown but it's supposed to be tannish, like my brother's skin is kind of tannish so it's supposed to be that kind of color. (LE2103.OctIn)

Figure 4.7 Max’s first and second MM-DAST drawings, Bob (left) and Finn (right), laboratory scientists with glasses, modeled after his brother and himself.

Bob’s skin color and hair look like that of Max and his brother, in contrast to the “light color” skin and “straight hair” Max presumably also associated with “most scientists” (see quote above). Max drew another curly-haired figure with brown skin in this second MM-DAST(E) drawing, which he named Finn. He again chose to represent a person similar to himself and his brother.

While Max’s comment suggests he felt there was a normative way most scientists may look, he reported that a science career was open to anyone who had access to higher education and put in the effort. In October, Max stated,

> Anyone can be a scientist if they go to college and they want to be. If they figure it out in college, then when they grow older they'd actually go to a science lab and then do their work (LE2103.OctIn).

Max expressed a similar characterization in his December interview, but added that scientists required a high literacy level and access to special equipment, along with effort and practice. This time, he did not specifically mention college, but did say educational training was required:

> Maybe anyone [could be a scientist] if they study and work hard a lot…and practiced what a real scientist would do…. They might need to read a lot, to know about things. They might need to have safety goggles just in case…they might need to have trained in a school and practiced working with test tubes. (LE2103.DecIn)

Rather than viewing science achievement and a career as outcomes of intrinsic intelligence or fixed abilities, or explicitly tied to gender, race, and class, Max expressed that a person's desire, motivation and hard work were keys to success. Indeed, on the wall of Carrie's classroom, posters demonstrating two paths, a "growth" and "fixed" mindset, were prominently displayed. According to Max, becoming a scientist was not an easy path. However, it was one that was open to anyone willing to develop skills with the necessary equipment and commit to specialized training in college. Max's characterization was echoed by his peers, and provides evidence for my final assertion regarding E1 students.

- *Assertion E1.4: Who? Agentive:* Montessori E1 students attributed participation in STEM careers to personal desire, effort and motivation rather than identity or intelligence; however, training in college was considered a prerequisite to becoming a scientist or engineer.

What is S-T-E-M activity? A naturalist's view of science. Max's views of STEM remained relatively consistent throughout the semester, especially with regards to science and technology; however, the small changes in how he talked about engineering and math were directly related to his participation in the STEM lessons.

In both STEMQs and interviews, Max characterized science as various ways of interacting with "nature" (LE2103.Sep), which I explore in more detail below. Max consistently characterized technology as *using personal electronic devices* for entertainment and communication, by stating that technology involved "electricity" such as the "computers and TVs" he used (LE2103.Nov). Although he initially stated he did not do engineering in his classroom Max was also one of the few students who described engineering as both planning and building in STEMQ1, explaining "Engineering is drawing and detailing a picture and then getting all the materials to build it and than building the thing you were going to build" (LE2103.Sep); in STEMQ2, however, he defined engineering as "solving problems," which was also how he described the engineering he did in his classroom (LE2103.Nov); thus, his characterization was expanded to include both themes. Like his characterization of technology, Max stated that humans use math in lots of "different ways", although his own math activities were arithmetic procedures because he was "writing down math problems and answering them" (LE2103.Sep). In his first interview, Max expanded this characterization of *arithmetic procedures* to include his conversation with one of the adults at North Star, a follow-up from Carrie's lesson on Everyday Math:

> Well, the cross country teacher [uses math in her job] because in cross country she has to divide, oh no, she has to measure the course and then check their scores and times them, and she also, well, she is teaching junior high and we went to ask her and she said she had to divide the teams, so she uses math. (LE2103.OctIn)

Max maintained a characterization of math as *arithmetic procedures* and *applied everyday problem solving* in STEMQ2, and added “word problems” to his response for how he used math, another follow-up from Carrie’s STEM sequence (LE2103.Nov).

In STEMQ1 and STEMQ2, Max was one of the few E1 students not to mention experiments as scientific activity he did in his classroom; however, he talked about science at length in both interviews as a result of our discussion about his detailed MM-DAST(E) drawing. His responses encompassed both *knowing more about the natural world* and *specialized activity*. In STEMQ1 he wrote that the science he did in his classroom was, “Nature. Plants and animals” (LE2103.Sep). When Max described his first MM-DAST(E) scientist, Bob, as well as the activity of other scientists, he also included practices not out of place for a 19th century naturalist: naming, labeling, observation, and collecting. He stated: “[Bob] makes more labels for living things and maybe he also draws…planets and more things that could erupt like volcanoes” (LE2103.OctIn). When asked if all scientists do what Bob does, Max said that scientists

> Also look at things under a microscope at things that are really small…they might plant things so that they can observe them…or put trees and pots and plant it outside when it starts to get big. (LE2103.OctIn)

Max elaborated further on this characterization of science as a naturalist’s way of knowing more about the world in his December interview. Here, he defined science through its objects of study mediated by scientific tools—in this case, animals and plants with which he himself was familiar.

> Well like, I think, like plants are science because scientists look through them with microscopes and animals might be um science because like when there are dead bugs sometimes some scientists, like, put them in a glass container and cover it and put it under a microscope and look though it...and they might have pets to

> study them, like maybe a fish. Maybe they [also] look at them kind of outside, like they look outdoors at, like, real animals. Like maybe they would look at squirrels, um, possibly mice. (LE2103.DecIn)

In December, described the science he did in his own classroom as "caring for animals."

> [I care for the animals in class] like guinea pigs, hermit crabs, a snake, a tortoise, and some fish. We care for them, like, as a science. Like, we have to get the right food for them, like sometimes we feed the hermit crabs cheerios but then we realized that they didn't like those, so we might have used science to figure that out. (LE2103.DecIn)

For Max, the scientific aspect of caring for animals was the knowledge involved in determining an appropriate food source, presumably gained through observation of the hermit crabs' behavior. Interestingly, none of the activities Max described as scientific in the interviews were directly connected to the STEM lessons I observed, other than Carrie's practice of making labels for technical nomenclatures she introduced—however, his responses regarding science incorporated more traditional Montessori references, which is why I include them at length. Aside from the STEM lessons she gave, Carrie also presented Montessori lessons in Botany, Zoology, and Geography. Many of these lessons involve identifying parts of animals and plants, or comparing landforms using technical vocabulary. It is possible that Max was drawing on these other experiences, which I did not have the opportunity to observe, in his characterizations. This suggests that for Max, non-STEM Montessori lessons a part of his STEM experience, while Carrie herself distinguished them from one another.

Why STEM? Helping improve human lives: A historical, humanistic perspective. Throughout the semester, Max maintained a clear separation between STEM disciplinary boundaries. However, he believed they all were important, necessary and could contribute to improving human lives in different ways. His interviews also lend support for my third assertion (*E1.3:Why? Helpful*). In STEMQ1, Max provided the following explanation for the importance of the STEM disciplines: "They are important because nobody would get smarter without **math** and nature and animals might not have gotten their names without **science** and there wouldn't be clocks, cars, or computers without **engineering** and **technology"** (LE2103.Sep, emphasis in original). This was almost the same answer he provided in STEMQ2, although he changed the use of engineering to solving problems: "Because math makes you smarter. We need science because there might not have been animal names without it. We need engineering to solve problems. We need technology for all phones." (LE2103.Nov).

In these STEMQ characterizations of STEM, Max distinguished between the disciplines of math and science as fields that enhanced knowledge: making people "smarter" or providing particular "names" for natural phenomena humans learn more about the world. Engineering and technology were applied fields characterized as what made it possible for modern humans to live their lives, with the purpose of technology being the tool itself. Thus, in this characterization all four disciplines were human endeavors that contributed in different ways to making the world the way it is, but served separate purposes: Max's "purpose of STEM" characterizations throughout the fieldwork period fell under the theme *helping improve human lives.*

Max added an unusual historical standpoint to this theme. In both interviews he speculated on how early humans might have survived without modern technology helping them know what to do, a connection arguably inspired by his peers' presentation imagining the origins of engineering in early human times. At first, Max felt that certain daily tasks would be difficult or absent without technology and engineering: "If we didn't have clocks we wouldn't know what time it is…[if] we didn't have alarm clocks we wouldn't be able to know when to wake up" (LE2103.OctIn). When I asked what people might have done before clocks, Max explained, "Well, there really wasn't school at the first times so maybe they just wake up how long they wanted to and how long they didn't want to" (LE2103.OctIn). At the end of the interview, when I asked if there was anything he wanted to add, he said,

> Also without engineering and technology we wouldn't be able to build houses without engineering, because people drew things on paper and then they built it and back then I don't know if they lived in houses…they probably didn't, they probably lived in caves. (LE2103.OctIn)

For Max, the time before clocks was long ago, when people lived in caves and did what they wanted. He referenced an example from his own life, waking up for school with an alarm clock, to suggest it is technology that keeps humans accountable to the schedule they need to follow. He also extrapolated from his previous characterization of engineering as planning on paper before building, and suggested that people therefore did not build houses in those times.

In December, Max and I had a similar interchange, in which he attributed scientists' activity to bestowing names on animals. This time however, Max stated that even without language, cavemen were engaged in engineering, in the form of making clothing and using fire as a tool. Therefore, Max equivocated engineering with the manufacture of any technology requiring human design intervention, and science with the language identifying what exists in the natural world.

> Max: Like it's helpful to the Earth. Like science is helpful to the Earth, like science named animals and plants, scientists named those… that's what I think.
> Alaina: Do you think that before scientists named them do you think that other people had other names for the plants, and the animals?
> Max: Maybe, maybe not, they didn't really have language, cavemen didn't really have language. But they had engineering.
> Alaina: They had engineering…
> Max: They made, like clothing out of animal skin, and fire?
> Alaina: Hmm. When do you think scientists named the plants and the animals?
> Max: Well it was probably like a really long time ago. When they named the first animal or the first plant. (LE2103.DecIn)

While Max stated that early humans had engineering capabilities, he was not clear about what happened between the pre- and post-scientific and technological ages. He felt that scientists must have been active a long time ago but did not provide a sense of when or how these changes occurred, nor whether they were localized in a certain geographic area. In Max' characterization, science and engineering were part of humanity in a storied, almost mythological way. It is not clear whether Max believed that the science that named animals was a specific group of people or if he were referring to how all humans name plants and animals. When I suggested he search for the origin of scientific names, and whether other names for plants and animals predated them, he agreed that it would be "a good research" (LE2103.DecIn).

While Max initially provided separate purposes for the four STEM disciplines in his two STEMQ responses and speculated on the role of STEM in long ago times, in December Max also expressed that STEM thinking was a potential way to solve problems in his own life. In STEMQ2, Max was one of two E1 students who wrote the word "s.t.e.m." in answer to the question, *Can you think of an example of people using science, technology, engineering and math together?* In December, Max offered the following explanation for his definition of STEM, which was using "science, technology, engineering, math…to solve problems":

> STEM…It's science, technology, engineering, math, and like, those are all important to us, and if we were using them together we would maybe be like solving a problem.... For example like my car, like one door can't open because the cord is broken, that's a little bit of technology. We haven't fixed it yet so maybe we could solve it using… science and maybe a little math and we would use engineering because like engineering is like solving problems. (LE2103.DecIn)

While Max did not articulate further what type of science would be useful or how engineering might help with the problem solving process, this explanation suggests he felt different disciplinary fields could be operationalized in the course of solving an everyday problem with a piece of common technology. In this case, the technology product was broken, science supplied the knowledge to fix it (along with math), and engineering was the process by which the problem was solved and the broken door made better. This imaginary scenario did not take place in a formal or professional setting, but one applied to Max's own life and useful to his family. Although he was not able to outline precisely how STEM would be relevant in providing a solution, he thought it could be helpful for him and for other humans. Thus, Max contextualized STEM as helpful in his own life as well as human history, and characterized each field as making a contribution to solving problems in the modern world.

Julia. Julia was a White female third-year student who had been in Carrie's E1 class for three years. In lessons, she shared her opinions at length. She also liked to take the lead in projects. Julia helped direct her friends in a play presenting an imaginary explanation for the origin of engineering in early human times. Whenever I visited, she came over to say hello and tell me about her latest science-related work. Once, she asked me if I would provide her with information she could use to make up a word problem. Julia brought in a book on female engineers to share with the class on her birthday. While confident with her peers and in the classroom, she often spoke in a questioning tone with me during her interviews, as if she were unsure of her responses. Julia's interviews provided information regarding her views on who can be a scientist (*Who*), and memorable STEM activities (*What*).

***Who can be a scientist? "Anyone.*"** Julia, like Max, reported that "anyone" could be a scientist. For her first MM-DAST(E) drawing, Julia drew a scientist in a lab with a lamp and a microscope. She noted that she thought of "what a scientist might look like" and based the picture on similar ones that her sister made (LE3005.OctIn). She was the only student to depict a Black female scientist character, and did so in both her MM-DAST(E) drawings. "Megan," Julia's first scientist, was named after one of her family members. In December, Julia drew a similar scientist she named "Alea". Julia explained that Megan and Alea were both African-American archaeologists whose "favorite thing to do is look at fossils" of animals (LE3005.OctIn). Julia depicted both scientists as solitary figure in a lab coat (Figure 4.8, next page). Megan's was purple to match the rest of her outfit because "she likes purple" (LE3005.OctIn).

Julia understood her depiction of Megan went against a stereotype. She stated her scientist was

> African-American. I think that like…some people, like may think that, like, only white people can be…like scientists…or like something… but I think that anyone can be a scientist if they want to be. (LE3005.OctIn)

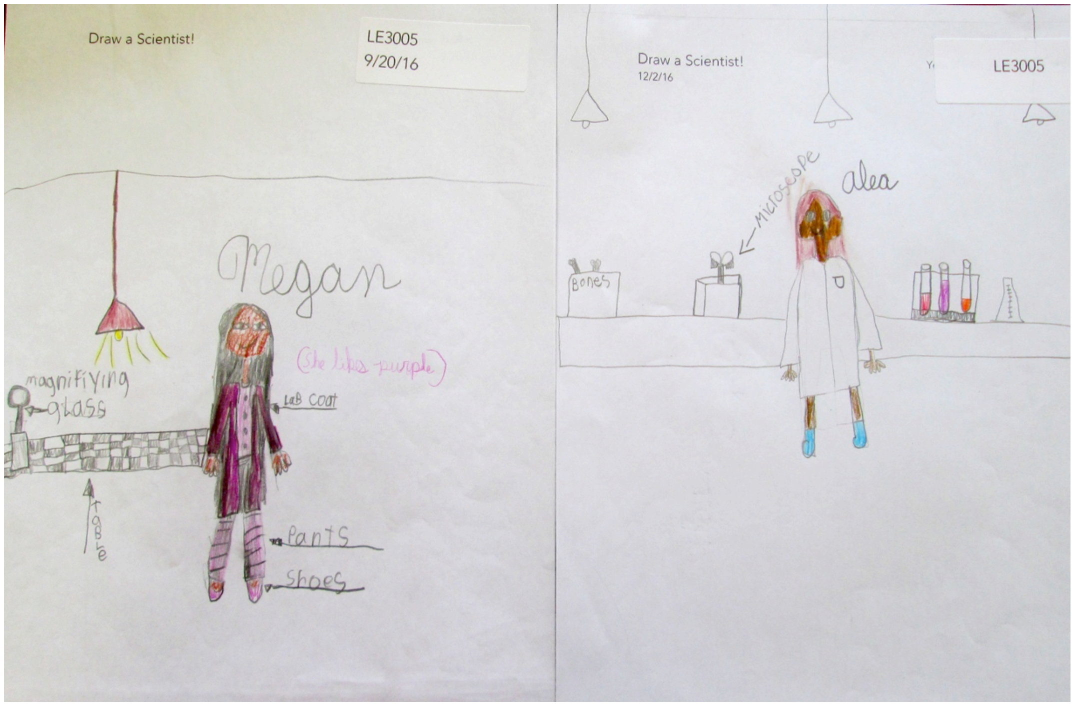

Figure 4.8. Julia's MM-DAST(E) drawings of Megan (left) and Alea (right) in the lab.

Julia repeated this last phrase two more times in her October interview, once when asked who could be a scientist, and again when asked how a person could become a scientist, although she qualified that college coursework was also helpful:

> Alaina: So who do you think could be a scientist?
> Julia: Anyone if they want to be.
> Alaina: What does it take to become a scientist?
> Julia: Um…you might want to take some classes in college so you're not just like so you don't know what to do…and so…but really anyone can become a scientist if they want to be. (LE3005.OctIn)

Julia's repetition of this *agentive* characterization suggests that it is a phrase that she is familiar with and believes in (see *Assertion E1.4: Who? Agentive*). While she still depicted some aspects of Chambers' (1983) stereotypical scientist in terms of the professional setting, the race and gender markers she chose went against his Standard Image. Julia depicted a female character like herself, and intentionally chose to refute what she identified as an exclusive and mistaken representation of science as White people's work.

What does it mean to do S-T-E-M activity? What I do, but more so. Julia's STEMQ responses exemplified the predominant whole class themes for science, technology, engineering, and math, and the codes and themes remained consistent across STEMQ1 and 2; therefore, I do not report them here. However, Julia elaborated extensively in both on individual STEM lessons from Carrie's sequence in her interviews, and her explanations provide a more in-depth picture than the short responses in the STEMQ.

One notable pattern was the small distinctions Julia made in her interviews between her own scientific activities and those of other scientists. While I asked about multiple aspects of STEM, Julia offered lengthy descriptions of her scientific activities; in December, she spent a quarter of our interview detailing what she had learned in the "Parts of Atom" lesson (LE3005.DecIn). Julia's characterization of scientific activity—as using a microscope, working with models, and planning experiments was based on connecting specific memorable events in her classroom to what she believed, or had been told by her teacher and her sister, that professional scientists do. In her first interview, Julia described Megan as satisfied in her job in the lab, and noted that "she doesn't really find the fossils, she just looks at them" (LE3005.OctIn). When asked what else scientists do, Julia listed other natural objects that scientists could look at, related to her STEMQ1 view of science as "about being curious [and] find[ing] out more" (LE3005.Sep). In both STEMQ responses and her interviews, Julia returned to the activity of looking at fossils under a microscope. According to her science notebook, she herself had done this activity in class the week prior to the first interview, and enjoyed it immensely. Julia stated that while she believed other scientists also used microscopes, theirs were probably “more powerful” (LE3005.OctIn) or “would cost a lot of money” (LE3005.DecIn) compared to what was available for use in E1.

In her December interview, Julia connected the hands-on modeling activity she did as follow-up for the “Parts of an Atom” lesson with the work of other scientists. This was one of the few lessons after which students had the option for immediate hands-on follow-up activities in Carrie’s STEM sequence. Julia explained how she and a partner picked an element, then used the atomic number to determine how many protons were in the nucleus and how many electrons in each energy level to balance the charge. She also recalled that the atomic weight helped her figure out how many neutrons were in the nucleus.

While Julia claimed that she did science experiments in her classroom, and I observed her looking up how to perform one in a book, she identified a single instance of experimentation in her December interview. In this case, she described an idea for an experiment she developed with a friend using dry ice. She said that the experiment was never carried out because it was “kind of dangerous…we were thinking of putting it in a bottle and then, just screwing it on…and then we would have to run away and see if the bottle would explode.” (LE3005.DecIn). Julia explained that she and her friend could not find a suitable location that was far enough away from other people in case the glass was broken. This concern for others led them to not carry out the experiment.

Julia was one of the few students who expressed familiarity with the term "STEM" in STEMQ1. She associated it with "problem solving" (LE3005.Sep). When I asked in the first interview how she used STEM in problem solving, Julia described of a lesson Carrie had given the previous year on the Engineering Design Process (EDP).

> Well like 'cause in problem solving you could use math…technology…like so we do some engineering. There's something called the engineering design process and so… I had a lesson on that and we used some of these things like… we used technology to FaceTime my friend's dad because our problem was that we weren't taking care of our animals and …so like Luke, Luke is the person and so his dad …we FaceTimed him and he said that we could make uh… an alarm on iPad so we used technology for that… and we used math to like…. well we used some math… this was a year ago, so it's a little hard to remember but… it was really… yeah but I know we used math somehow 'cause I remember like doing something … so you …you might use STEM… it has engineering right ? So engineering. Hm, what else? Um… um… S-T-E-M…oh, it has science. So you might use some science in problem solving because like… you might want to learn more about something and you could put those… facts together that you learned… from looking at something or discovering something. (LE3005.Sep)

In this description, Julia worked to remember what the letters in STEM stand for and how they applied to a real-life classroom problem: forgetting to feed the pets on time. She associated science with the content or facts of the problem, engineering with the reasoning or solution process, and technology with the tool needed to get to the solution. The role of math was harder for her to recall, but she attempted to find some example of how all the disciplines in the acronym were incorporated. Later in this interview, she elaborated on the role of technology as a tool for making communication easier and more convenient. Julia's STEMQ responses also fall within the theme of STEM as *helping improve human lives*: in her STEMQ1, she stated that all STEM disciplines were useful, although she did not know how to explain their importance in STEMQ2. Thus, for Julia, the acronym STEM remained mysterious as she sought to generalize it beyond a memorable lesson she could recount.

In her December interview, Julia similarly characterized STEM as an acronym that applied to particular kinds of lessons, but she was not sure exactly how this combination occurred: "Science, Technology… S… T… Engineering, Math. And you can also combine them all together to make, STEM, like, we have STEM lessons?" (LE3005.DecIn). This time, she recalled two more engineering lessons from previous years. Even though she hadn't had it yet, Julia felt enough ownership over a lesson called Mable Marble (which I did not observe in E1 but did see in E2) to explain it in great detail. Both Carrie and Erica told me that Mable Marble was a perennial favorite from the lessons they learned during their certificate program, and its creator Katie Ibes noted it was one of the lessons she felt captured integrated stem and design thinking in an authentic, Montessori way (C. Ibes, personal communication, March 1, 2017). Indeed, students in Erica's class remembered Mabel from E1, and immediately recognized it when Erica continued using the same context in her own lessons on speed and velocity.

Montessori lessons are notable for their use of storytelling as an engaging context for student learning (Polk Lillard, 1996). "Mable Marble" involves a character, Mable, who lives at the top of a hill. Her goal is to gently kiss her grandmother, who lives at the bottom. Mabel's elderly grandmother is in a wheelchair, and the students are told that their challenge is to make a course for Mable so that she can kiss her grandmother without hurting her and causing her to roll away (C. Ibes, personal communication, March 1, 2017). Julia similarly recalled,

> Julia: Like there was one engineering thing called Mable Marble, I haven't had the lesson but you have these bricks that you like stack up and then you put a, um, board, and then you…Mable is a marble, and she wants to give her grandmother a hug, and so you have to roll her down through this, through obstacles so she won't fall off, and then you see if she can give her grandmother a hug, that means she bonks, like, they touch each other, and if they don't touch each other, you find out how, um, how you can make them touch?
> Alaina: So…what is STEM about that? Where does STEM come in?
> Julia: Um…engineering I think? Because you have to figure out, like, how you can get her down to the place, and there's also one thing with engineering that we do, um Carrie sometimes has us do building challenges, where we'd have like, um, like, say, five straws, ten popsicle sticks and ten cups, and then you'd have to build something, and then she's like, maybe whoever gets …the tallest tower or the sturdiest tower, like maybe wins…but we don't really do prizes or anything… (LE3005.DecIn)

Again, Julia conflated engineering design, building challenges, and integrated STEM into one idea of problem solving or challenge. The STEM lessons Julia recalled in her interview involved collaborative hands-on investigations using materials, even when she did not herself partake in these investigations. STEM and engineering converged in the process of "figuring out" or reasoning how to solve the problem at hand in the course of an activity, which she also associated with building challenges. In this second example, Julia also noted the non-competitive culture of the E1 class.

Julia thus characterized aspects of STEM through cultural touchstone experiences, memorable lessons she had in the classroom. She associated the experiences combining physical science and engineering most closely with STEM. She continued to believe that the STEM disciplines were "useful" and "helpful" in human lives generally (LE3005.DecIn), but struggled to come up with a specific example. Following three years in E1 and multiple STEM lessons, Julia was continuing to work on contextualizing these individual experiences within a larger framework of understanding. Her experience supports my second assertion:

- *Assertion E1.2: What? Connected:* Montessori E1 students' classroom experiences influence their characterizations of STEM, but so do family ties and outside of school experiences; however, students were more likely to identify particularly memorable and participatory lessons in the STEM sequence (including "Everyday Math", "Parts of an Atom" and the "EDP") as related to science or engineering than they were activities from the Montessori curriculum.

Elexor. Elexor was a highly animated White female third-year student. Self-confident and energetic, she was somewhat reluctant to do assignments she felt were repetitive or not immediately relevant, such as copying down the graph that her group created during one of the Story Problem lessons. When Elexor attended STEM lessons she participated vocally, although Carrie occasionally reminded her to redirect her comments to the content at hand. She sought out multiple partners for follow-up projects, but did not complete any group work during my observations.

Elexor's characterizations of individual STEM disciplines were consistent across data sources over the course of the fieldwork period and fit into all of the predominant whole class themes, although she elaborated on them more in her December interview. However, Elexor's responses were written in an original style. For example, while she characterized math as *arithmetic procedures* in STEMQ2, she wrote a short rhyme to communicate this: "Adding two things together, splitting it into even groups (or more), taking some away and x-ing it so no! It's not a boring bore, filling our brains until they pop!” (UE3002.Nov). Elexor’s self-professed creativity shone through in many other areas throughout her interviews. Both interviews provided information on who Elexor thought can be an engineer (*Who*) her characterizations of STEM (*What, where/when)*, as well as its purpose (*Why?*).

Who can be an engineer? Creative STE(A)M pursuits outside the E1 classroom. Elexor identified positively with a definition of engineering she constructed which included “making stuff,” imaginary play with friends, design and art (LE3002.OctIn). Elexor prided herself on her imagination and creativity, and talked extensively in both interviews about her outside of school STEM pursuits, including her activities at home, in the art room, or on the recess field. In fact, for both M-MDAST(E) tasks, when asked to draw an engineer, she created practically identical pictures of herself and her two neighbors (Figure 4.9 below).

Figure 4.9. Elexor’s MM-DAST(E) drawings of herself and her two neighbors.

Elexor identified all three characters as females with skin colors like herself, although she felt that "anyone" could be an engineer (LE3002.OctIn). In order to become one, she explained, "You have to practice I guess and you have to be really creative and you have to be okay getting a bit messy" (LE3002.OctIn). When I asked her in October to elaborate on why she chose to draw her neighbors, she explained gave examples of their interests in building, using technology, and being creative with toys and games.

> We are kind of engineers…we all like to build LEGOS, we like to play Minecraft, and we like to do art stuff…everyone's kind of an engineer, but I guess I'm the most engineering-ist of the group… [because] I like making toys, I really like making stuff. It's just fun…I'm also really good at it. (LE3002.OctIn)

Elexor provided the same rationale for her second drawing, including a description of how she designed and made toys from socks and rice, in her December interview. Throughout the fall semester, Elexor expressed that being "really creative" was an important quality for engineers, and if an engineer weren't creative "it would be kind of difficult" (LE3002.OctIn): the activities she mentioned involved building or creating objects, whether or not they had the purpose to improve human lives or met a stated need. While she stated that her creative process involved a certain amount of tinkering, Elexor confidently noted that engineers, "don't just make it. They draw it out and plan it. I do that sometimes but not all the time…[sometimes] it's a surprise what it turns out like." (LE3002.OctIn).

In her December interview, Elexor elaborated that her activities in Minecraft involved "building houses" and "creating things," which she felt were similar to the activities of professional engineers because, "Well, engineers, they…they can make stuff, I guess sometimes they do…but sometimes they solve problems" (LE3002.DecIn).

Elexor connected this to the process she used to make her toys, referencing the EDP graphic Carrie presented in her lesson. She sought to connect her own reasoning process with what she learned in school.

> Um, I'm planning it out, and like I usually draw before. And…then I design it, and then I create it, then I test it, and if something feels, like, wrong about it, then I could like, make it better? Like the engineering design process circle, I guess I'm kind of using that. (LE3002.DecIn)

In both interviews, Elexor's emphasis on creativity in engineering extended to her characterization of science as creative experimentation (In STEMQ2, "mixing ingredients and looking closely", LE3002.Nov). Elexor conducted science activities at home, often using her a science kit with her friends. Her characterization of science involved following her own inspiration, rather than testing hypotheses.

> I basically do it at home, like, I'm in the bath sometimes and then I take some shampoo and put it in there and shake it and shake it and pour it on the closest doll's hair and see what happens…I usually don't use science in the classroom very much. (LE3002.DecIn)

Thus, for Elexor, STE(A)M activities were embedded in her everyday acts of creation and socialization, and not confined to the classroom. In fact, in December, she remained unsure about the word STEM itself even though she felt it applied to her classroom identity.

Why STEM? A mysterious acronym, embedded in everyday human activity. In Elexor's case, the question "Why STEM?" had a different meaning: if humans were already doing engineering, math, and science without really even thinking about it, what was the purpose? Elexor felt that the word STEM was "some cool name they made up…I'm not actually sure if it's like…precise about anything or like, if it's short for something" (LE3002.DecIn). However, she had a highly personal characterization of engineering and technology, as well as characterizations of science and math that were relevant to her everyday life. In December, she described her EI class as an example of integrated STEM because "we are people using math, science, engineering and technology all together" (LE3002.DecIn).

As previously mentioned, Elexor did not think that she did much science or engineering in class. While she attended all the same lessons that Max and Tuna did as part of the "cloggy group", Elexor connected science to an art project when asked about her scientific activity,

> Once I was painting and I didn't really finish and then I came back, like two days later, and all the paint had just evaporated, and it was just like, I mean all the water part of the watercolor paint had just evaporated and it was just stuck in the thing, but if you put water in it, it would still be the same watercolor paint…they separated and the water evaporated. (LE3002.DecIn)

In this case, Elexor recognized that watercolor paint was a mixture: the colorful pigment had to be suspended in an aqueous solution because of the change she observed in its appearance. Elexor applied the concept of evaporation to explain why the paint dried out; she did not discuss any formal instructional experiences but described a type of scientific thinking.

Elexor also connected her everyday life experiences to mathematical thinking, explaining in her December interview that humans and other animals subconsciously used math to move around. In her characterization, mathematics underlies a reality shared by humans and other animals.

> Plain old thinking uses math. Your brain, like automatically has to use math, like I'm using math to know how much my foot needs to move, to put it right there…I'm using math right now to just like, move my hand. Like I know how to

> move my hand, like what angle, and what direction…and also animals have to do it too, I mean, like, that fish knows, he has to know how much to flap to get away from that little fish that's chasing him. (LE3002.DecIn)

In other words, for Elexor, STEM was everywhere, and scientific and mathematical thinking can happen automatically. She wrote in STEMQ2, "we wouldn't be here" without the STEM disciplines (LE3002.Nov). While the above examples point to a more metaphorical interpretation, when I asked what she meant by that comment in her December interview, Elexor offered a more concrete explanation:

> It needs engineering and technology to make the school. Like, you need technology, to make the crane, to lift the bricks, to super high places that you can't climb up to without falling down and getting hurt. And you'd use engineering to be like, how wide do we need this building so that we don't run into the road, how much…how much should we divide equally every room so that there are no rooms bigger than others, stuff like that. I mean it would take engineering and stuff to even make this (she points to the cloth on the table), we need to know how many threads, like you would need to know how long a piece of thread, like to go all the way across…And you would need to know to dye the wool.
> Alaina: To dye the wool?
> Elexor: And to cut off the wool from the sheep without hurting the sheep!
> Alaina: So, do you think these things are helpful?
> Elexor: Yeah.
> Alaina: Do you think they're helpful…to…people, to the Earth? Who are they helpful for?
> Elexor: Especially people, cause it would be strange without it, like, we wouldn't have clothes, we wouldn't have this building, I wouldn't be talking to you because we wouldn't have cars to drive here, and we wouldn't even have houses or streets so we wouldn't know HOW to get here! (LE3002.DecIn)

For Elexor, technology provided the machines, and engineering the process, of solving design challenges using math. She did not give science an explicit role, but viewed keeping the sheep from being hurt as part of engineering problem solving. In her characterization of STEM within the theme *helping improve human lives*, Elexor let her imagination take off. She associated STEM thinking with the infrastructure of contemporary life as well as everyday activity. A realization that the evidence of engineering and technology as human endeavors are all around influenced Elexor's STEM characterizations and contributed to her identification with an example of STEM integration. This same big idea was communicated in Carrie's story of the "Naked City". Rather than disciplinary curricular connections, Elexor thus interpreted STEM in an embodied manner: as a member of E1 engaged in all of these activities, even if not simultaneously.

E1 Case Assertions

Thus far I have presented findings from the lower elementary case, including students depictions of scientists and engineers in the MM-DAST(E), and their descriptions of their own and other humans S-T-E-M activities in the STEMQ. I also highlighted four individual students I interviewed. Throughout, I was guided by the following analytic questions:

- *Who* can be/become a scientist or engineer?
- *What* does it mean to do S-T-E-M? Where and when do these activities take place?
- *Why* is "STEM" important? What is its purpose?

Four main assertions emerged from my analysis of the E1 data over the course of the fall semester regarding who can be a scientist or engineer, what students characterized as STEM activities (including activities within individual disciplines) and students' characterizations of the purpose of STEM. These assertions are supported from evidence found across focus students and data sources, and are discussed in relationship to the literature in the next chapter. I restate them below:

- *Assertion E1.1: Who? Inclusive:* E1 Montessori students' characterizations of scientists and engineers adhered to prevailing stereotypes but also represented people of all genders and multiple skin colors. The latter occurred in instances when students identified with their drawn characters, such as drawing engineers as female and positively identifying people of color engaged in STEM activities.

I interpreted E1 students' characterization of who can be/become a scientist or engineer as an "inclusive" one, exemplifying the "science for all" mandate to which both RBS and STEM education respond (Carlone et al., 2011; Honey et al., 2014). Previous research has indicated that "celebrated subject positions" associated with science (Carlone et al., 2011) are typically White and male, and that children develop gendered assumptions regarding scientific and engineering work early on (Archer et al., 2010; Capobianco et al., 2011). However, all E1 students interviewed believed that "anyone" could be a scientist or engineer (see also Assertion E1.4) regardless of gender or race. Aside from Julia, the students did not specify certain groups or persons that have experienced structural discrimination and limitations that restricted their opportunities for becoming STEM professionals. Educational attainment and effort, which the students viewed as internally mediated characteristics, were seen as governing who could become a STEM professional (see Assertion E1.4). This assertion was shown in focal student interviews even if other aspects of their representations reflected a stereotypical view. It was also supported by descriptive code frequencies in students' MM-DAST(E) drawings, which depicted a variety of genders and skin colors even when light-skinned males were still the predominant group. In cases in which students intentionally represented themselves or family members, such as Max and Tuna, they ended up refuting more aspects of stereotypical representations.

- *Assertion E1.2: What? Connected:* Montessori E1 students' classroom experiences influence their characterizations of STEM, but so do family ties and outside of school experiences; however, students were more likely to identify particularly memorable and participatory lessons in the STEM sequence (including "Everyday Math", "Parts of an Atom" and the "E.D.P") as related to science or engineering than they were activities from the Montessori curriculum.

I interpreted Montessori E1 students' characterization of what it means to do S-T-E-M activity as "connected" to their in and out of school lives, bridging lessons and everyday problems. Even though students deemed their classroom STEM experiences infrequent occurrences, they could all identify and describe at least one or two STEM lessons, sometimes months afterward. Evidence for this assertion comes from students' STEMQ responses as well as, in particular, Julia and Tuna's interviews. It also indicates that both the Montessori classroom and larger social context were significant for students' characterizations even if their definition of the term itself was as a mysterious acronym associated with lessons (see below).

- *Assertion E1.3: Why? Helpful:* Most Montessori E1 students did not independently identify instances of STEM integration and perceived "STEM" as a mysterious acronym; however, they linked individual STEM disciplines and viewed them as both personally relevant and helpful for improving human lives…even if this improvement had potentially negative impacts for the Earth.

I interpreted Montessori E1 students' characterizations of the purpose of STEM as "helpful," even if they could not articulate exactly how STEM fields might work together, or recognize the unitary construct "STEM." Nevertheless, Montessori E1 students saw the utility of STEM fields in their daily lives, namely through technological applications or the products of engineering. They expressed a view that engineering and technology, in particular, made the modern world around them possible. Evidence for this assertion, which follows from the previous assertion E1.2, comes from students' STEMQ responses as well as all four interviews; however, only Julia, Tuna, and Max mentioned negative associations with STEM—pollution and global warming.

- *Assertion E1.4: Who? Agentive:* Montessori E1 students attributed participation in STEM careers to a person's desire, effort and motivation rather than inherent abilities or intelligence; however, training in college was considered a prerequisite to becoming a scientist or engineer.

This assertion is linked to the first regarding students' inclusive perspective, and extends it with the notion that while anyone can become a scientist, it takes effort and practice, such as in college. I interpreted this characterization as signifying the importance of individual agency in STEM achievement, although the qualifier that a college education determined professional prospects suggests that these middle-class students existed in a social context where higher education was a prerequisite to adult life success, at least in

STEM. Evidence for this assertion was drawn primarily from Max, Tuna, and Julia's interviews.

Next, I examine results from the second case, E2. It is worth noting that while I conducted analysis separately and sequentially, I noticed areas of overlap, particularly with regards to overarching themes and assertions. These areas are synthesized in Chapter Five.

Upper Elementary Case

The Learning Context

The second case I report on in this thesis was that of Erica's upper elementary classroom at North Star Montessori (hereafter, E2). Erica was an experienced Montessori guide who had been teaching at North Star for eight years. She had also completed a STEM certificate three years prior to this study. The door to her second-floor classroom was perpetually open, enabling 28 students corresponding to grades four through six (plus two trusty guinea pig companions) to eat snack in the "commons," or work in the music studio and art rooms across the hall. Students regularly took advantage of this freedom of movement; I often observed fewer than 20 children in the room despite the larger size of the class. Montessori (2007) noted that children of this age group are intensely social and sensitive to their peers. E2 students shifted workspaces several times in a single hour as they moved from activity to activity checking in what their friends were doing. The entire E2 class was approximately 50% self-identified male and 50% female; 14% of the students in E2 were students of color, and none were considered English Language Learners.

As shown in Figure 4.10 (next page), Erica's room had a large open space for students to gather for meetings and lessons, group worktables arranged around the perimeter, and materials grouped by subject area on shelves. Students had a variety of seating options, including floor cushions, yoga balls, and wooden chairs. A lofted area served as a quiet individual workspace and a support structure to hang decorations for classroom celebrations. Potted plants sat on each sill of the three large windows on the far wall. Art objects from around the world, along with a wasp's nest, a starfish endoskeleton, and several large seashells, were displayed on decorative shelves above the blackboards. The most visible decorations were student-made models—including a life-size papier-mâché bald eagle that hung from the overhead lights, an equally large and detailed three-mast sailing ship, and a replica Civil War rifle constructed to scale of cardstock and hot glue (Figure 4.11).

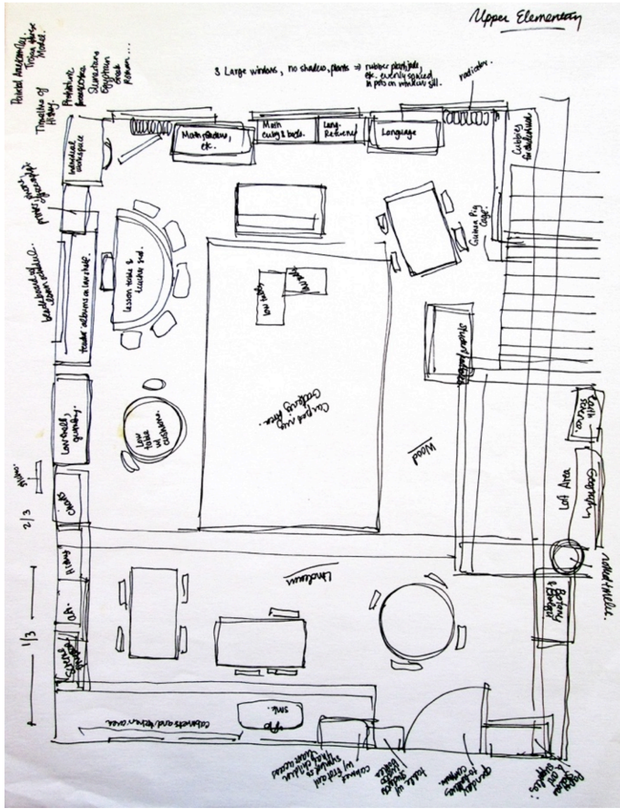

Figure 4.10. Sketch of floor plan of the E2 classroom at North Star Montessori

E2 Students began the day with a brief whole class meeting and an independent two and a half hour work period from 9:00am until 11:25, during which they attended small group lessons. The following list illustrates the considerable variety of STEM and non-STEM topics E2 students encountered during their morning work cycle: “Land/sea breeze; eagle population; poetry sort; types of motion; root variety; multiples chart C; active/passive voice; squaring (dot paper) and multiplication and division by powers of ten” (Field notes, February 2, 2017). Each of Erica’s lessons included mixed-age groups of three to six students, and took place at the lesson table in the back corner of the room. While students were expected to “log in” the time and title of the presentation and listen without writing, at the end they were encouraged to record basic notes on the concepts discussed before they could be dismissed back to work. Students did not use pre-made workbooks or textbooks for individual subjects; however, I frequently observed individuals or pairs engaged in daily math problems on sheets of paper.

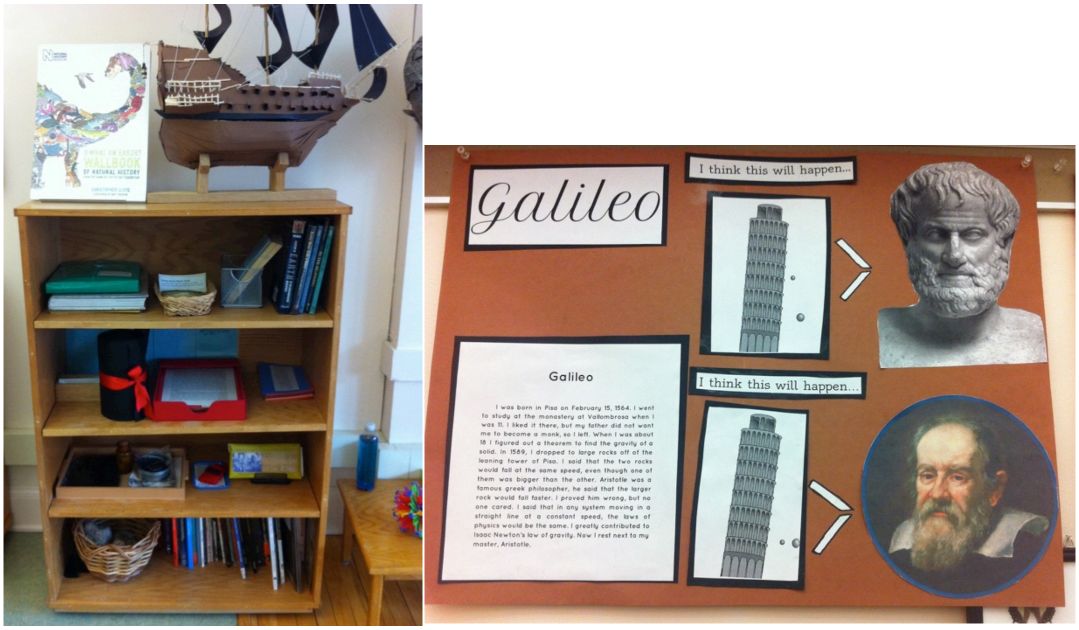

Figure 4.11. E2 science shelf with ship model (left) and student poster on Galileo (right).

Montessori upper elementary students are expected to undertake extended independent research based on their personal interests (AMI, 2016b). Erica encouraged students to use STEM lesson follow-up as an opportunity for what she described as "project-based learning" (Personal communication, January 18, 2017). E2 students were avid readers, writers and artists. They created several detailed poster projects over the course of my fieldwork. Anecdotally, these were related to STEM topics, ranging from Aristotle's theory of gravity (Figure 4.11), electric cars, and the fundamental forces, to the history of the pesticide dichlorodiphenyltrichloroethane (DDT). While E2 students regularly consulted encyclopedias and dictionaries for posters and accompanying reports, they also used digital technology for this purpose. Laptops and iPads served as references for information and photographs alike. Students required Erica's permission before conducting web searches or publishing digitally; however, multiple devices were available as needed.

The following extract from my personal research journal on October 24, 2017, illustrates the wide variety of STEM investigations students pursued, both for and beyond poster projects:

> On Tuesday, I talked with Erica about her classroom. She mentioned to me that students were doing a lot of different things. One group of boys had been working with molecular models; Erica gave them a worksheet that had them build and draw different molecules and learn about numbers of atoms. Another two groups had built tracks for Mabel Marble and collected data on their inclines and speed calculations. One girl had finished her bar graph of resting and elevated heart rates for students in the class. Another student had made a diagrammatic poster of Work, and two boys had created a little poster on fundamental forces. There was still some energy around the interdependencies charts and an EDP solution to the problem of the afternoon productivity slump, which was providing tea for all E2. Two girls were creating a permission slip to ask parents whether caffeinated tea was okay for their children. (Research journal, October 24, 2016)

The students were absorbed in these investigations, and always interested to share their results with peers or visitors like myself. Erica supported them by providing materials, asking for records of their activities, and setting up a time to share their results with the class. Such student projects are characteristic of Maria Montessori's belief that children in the second plane of development (ages six through 12) should have ample opportunity to work together and follow their own interests (Polk Lillard, 1996).

E2 STEM lessons. The STEM lessons I observed in E2 focused on engineering design practices and physical science content. I detail the lessons below in order to provide background information regarding students' activities, before proceeding to students' self reports. Mathematics, technology, and engineering design activities were integrated in students' explorations of speed, energy, work, and power (see Table 4.4 below). Erica originally created a three-strand series based on Carrie's structure, and wanted to arrange two new lessons and one check-in session a week for Monday, Wednesday and Friday. However, by the end of October she deemed this type of rotation structure to be too artificial and switched to smaller groups of three to six students. The group composition for individual lessons shifted over the course of the fieldwork period. I did not always observe the same group of students working together, nor did all students receive the same lessons. In addition, given the organic way in which Erin's STEM instruction evolved, I had the opportunity to observe other Montessori science lessons and presentations not in the series she planned at the beginning of the school year.

Table 4.4 below outlines the E2 lessons I observed in the fall of 2016. All lesson plans were drawn from Erica's Montessori STEM training; thus, two Engineering lessons were also given in E1 that fall (Ibes & Ng, 2011).

Table 4.4
E2 STEM lesson series

Strand	Lesson	Observed
Engineering	Yvonne's Story/ Engineering Design Process	9/20/16
	The Engineering Design Process, pt. 2 (The King, the Mice and the Cheese)	10/19/16
	Naked City	N/A
	Engineering Tools	11/8/16
Matter, Energy, Work, Power	Four Forces	9/30/16
	Potential and Kinetic Energy	10/5/16 11/1/16
	Work (Mechanical energy)	10/17/16
	Human Power	N/A
Speed/Velocity	Mabel Marble	10/24/16
	Measuring Mabel's Speed	10/5/16
	Understanding Velocity	11/8/16
Other observations	Interdependencies	10/11/16

Solutions	10/24/16
Student Presentations	10/28/16 10/31/16
Roman Arch	11/11/16
Types of Fruits	11/15/16

Note. Some lessons I observed twice; those marked N/A I was unable to observe

Erica's first STEM strand began with a whole class lesson on engineering design, "Yvonne's Story," during which students watched a short video about a real-life engineer and her work. They then used a building challenge activity to inductively identify actions in the Engineering Design Process (EDP). This was the only whole-class lesson I observed. Erica then facilitated further study on engineering design for a smaller group with a discussion of null loops and a reading of "The King, the Mice, and the Cheese" (see E1 lessons, Table 4.1). She then told students about the "Naked City," and they speculated what a city would look like if it were unwrapped of all engineering and technology (Table 4.1). The final lesson in this strand involved a presentation of a Montessori timeline of human evolution, in which Erica highlighted the different tools humans made throughout time as examples of simple machines requiring engineering design to develop and refine. This lesson led one student to learn more about making hand axes, and others to present a play on how early humans used stone tools and fire.

The second strand included lessons on "Matter, Energy, Work and Power". First, Erica introduced the four fundamental forces, and students researched interactions in which the forces were involved. Students next explored kinetic and potential energy by testing the effect of incline height on the velocity of a marble. Continuing this exploration, they used spring scales and pulleys to investigate the concept of work.

Finally, they looked at the ways in which human bodies did work and could power machines.

The third strand, “Speed/Velocity” explored speed and velocity through lessons involving the character Mabel Marble. Students heard the story of Mable and her quest to travel from her house at the top of a hill to her grandmother’s at the bottom, and give her grandma kiss without her rolling away. The students were tasked with creating a course that would slow Mabel down from a set incline height. In the next lesson, students set up different course designs and calculated Mabel’s speed. Finally, they applied their understanding of speed and distinguished it from the concept of velocity. This lesson included students choosing a direction and racing each other across the recess field, then making a bar graph from the resultant data.

I also observed traditional Montessori lessons in which students used a chart to examine interdependent relationships between humans and the environment; learned about different types of roots and fruits; compared solutions composed of common household ingredients like lemon juice and milk; and discussed the history of the Roman arch. Erica considered these lessons to be a part of her Montessori science and cultural curriculum, rather than in the “STEM” sequence she created.

Lessons I observed in E2 had a similar structure to those in E1. First, students gathered at the lesson table and logged in, then put their materials away. Erica began the presentation with a short story, offered as a provocation just as often as an explanation for everyday phenomena. She used visual analogies to introduce technical vocabulary or science concepts, as Montessori (2007) recommended. For every STEM lesson students were given a "key question" to investigate, often right away; Erica explained to me that this was a technique she learned in M-STEM training that she had incorporated into her personal teaching practice (Personal communication, January 18, 2017). The following extract from my field notes for a lesson on kinetic and potential energy illustrates how one STEM lesson developed:

> *Erica began with a story about a person riding a bike up and down a hill; she made a drawing on the whiteboard, and used gesture to help illustrate what might happen with the speed of the bike. Students were asked to imagine the outcome. She then introduced the terms "potential energy" and "kinetic energy" and labeled the diagram. Once terms were introduced, she asked a question:*
>
> Erica: What if you had a ramp, an inclined plane, and started your marble from the same position, but you changed the height of your inclined plane. What would happen?
>
> Student: like Mable Marble?
>
> *Erica led a conversation about what units of measurement to use, encouraging the students to* "be more accurate and consistent" *by choosing centimeters. Two male students experimented with the marble and an inclined plane at the lesson table; the boys had their hands on the materials while the girls sat back and watched with their hands off the table. Erica helped the students gather the necessary materials: timer, stopwatch, boards for incline planes, ruler. She continued to ask students questions about their process:* How many trials do you think would work? Who wants to be the first group?
>
> *She told them to conduct at least five trials and set two different heights so that they can see the connection between height and time, and helped them form groups (three girls and two boy-girl pairs.* (Field Notes, October 5, 2016)

For this reason, individual STEM lessons sometimes lasted up to an hour, with students traveling into the hallway or even outside to conduct a test and collect data. When their investigation was complete, the students returned to the lesson table to share their results. Students were never pressed to write extensive explanations at that time, but encouraged to go further. Erica presented follow-on work as an independent choice to be decided by the students.

This open-ended invitation to follow personal interests often resulted in creative responses. The first lesson I saw, for example, introduced the engineering design process. Erica began by showing the whole class a YouTube video made by a teacher from her Montessori STEM training, a female, Asian-American engineer who worked with her husband to develop a prosthetic foot that would help improve her own life and others with similar disabilities. "Yvonne's Story" served as the jumping-off point for two iterations of a building challenge using index cards and Popsicle sticks. Rather than set out the "Steps of the Engineering Design Process" beforehand, Erica asked students to describe how they decided on their design solution; she then guided them to identify the E.D.P. actions based on their experiences. As in E1, the follow-up to this lesson was for students to identify a problem in the classroom community and come up with a creative solution. As Erica reflected,

> After discussing realistic problems in the classroom the students settled on "low(er) energy" afternoons. Why, I asked? They suggested a protein snack. I told them it had to be quick and easy to prepare and low cost. They chose cheese, cracker and salami sandwiches. They polled students to get their preferences and served the snack during read-aloud. They worked together in the kitchen and walked to the co-op to get food. Then they debriefed and talked over what went well and not so well. They admitted that the preparation was so exciting that the serving was inefficient and they lacked communication. Then, they came up with ways to do it better! Again? Maybe in a few months. It was fun to watch them problem solve and show leadership and execute a plan by the following day. (Personal communication, September 26, 2016)

Students also integrated multiple disciplines in the form of an artistic presentation. For example, one group responded to a discussion on null loops in the engineering design process by researching a real-world problem in China: a lack of bees able to pollinate fruit trees. These students created a prototype of an artificial pollinating wand and collaborated on a poster showing the location of the bee problem, hand-drawn diagrams of the affected fruit, and multiple paragraphs about how farmers were responding. Another lesson, on velocity, prompted three girls to use the classroom iPad to make a slow-motion video of balls of different masses being dropped from the classroom loft. They connected this experiment to Galileo and Aristotle's explanations for the effect of gravity on falling objects. Finally, a lesson on early human tool use inspired a mixed-age group of five students to write, rehearse and perform a skit dramatizing how humans developed facility with hand axes, spears, and fire. The students consulted the music teacher for help, and the final performance included costumes, props and musical accompaniment, to the delight of the audience.

My field observations enabled me to glimpse the complexity of STEM teaching and learning in the E2 class. This context is important for the reader to bear in mind, as students drew on these experiences in their self-reported characterizations of STEM.

STEM Characterizations According to Whole Class Tasks: E2

MM-DAST(E) results. Table 4.5 (following page) summarizes descriptive codes for E2 students' engineer and scientist drawings on September 16, 2016 and November 29, 2016. 18 students, ten females and eight males, completed both MM-DAST(E) tasks. Each student drew a single figure, for 36 drawings in total. Students did not provide all additional information the protocol requested, and four did not indicate whether they drew a scientist or engineer. Given the small sample size, I report codes that applied to at least 25% of the drawings.

Table 4.5

E2 MM-DAST(E) descriptive code frequencies, September and December, 2016

Descriptive Code of Interest	Scientist		Engineer		Not Specified		Total	
	September (n = 6)	November (n = 7)	September (n = 8)	December (n = 7)	September (n = 4)	November (n = 4)	Total Frequency	% of Total (n = 36)
Gender of student								
Female	5	4	3	5	2	1	20	56%
Male	1	3	5	2	2	3	16	44%
Gender of character								
Female	4	3	4	2	1	0	14	39%
Male	2	4	4	5	2	3	20	56%
Not specified/ amorphous	0	0	0	0	1	1	2	6%
Skin color of character								
Peach/ Light yellow	4	3	2	5	2	1	17	47%
Other (e.g. green, purple, pencil, etc.)	1	2	2	1	2	3	11	31%
Tan/Olive	0	2	3	0	0	0	5	14%
Dark brown	1	0	1	1	0	1	4	11%
Characteristic of drawing								
Everyday attire	2	4	8	6	3	2	25	69%
Portrait	3	0	3	2	3	4	15	42%
Glasses/goggles	3	4	2	2	2	1	14	39%
Accessorized figure (wrench, test tube, etc.)	2	3	1	3	1	0	10	28%
Lab coat/work clothes	3	3	0	1	1	0	8	22%
Indoor laboratory	1	4	0	0	0	1	6	17%
Machine workshop	0	0	3	1	0	0	4	11%
Outdoor construction site	0	0	1	1	0	0	2	6%

Gender. I identified gender using markers such as name, hairstyle, facial hair, and dress. While the overall E2 sample was 56% female and 44% male, 56% of the total drawings produced were of male characters. Furthermore, between September and December, female characters decreased from 25% to 14% of drawings. Five female students depicted males, but only one male, focus student Jake, (UE4123.Sep) drew a female character. Thus, the decrease in female scientists was due to more females and one male representing male scientists. This suggests that E2 students increasingly characterized scientists and engineers as male over the course of the fieldwork period.

Overall E2 students' drawings suggest they were increasingly conforming to the stereotype, yet four female students made small challenges to gender representational norms. One sixth-year, Maggie, drew a character that was "not male or female", (see UE6016.Sep and UE6016.Nov), explaining that, "everyone can be anyone" (UE6016Oct.In). Another female sixth year, Grace, explained in December that she drew a "boy named Debra" with short hair: "I drew an engineer and built an imaginary city because she…or he, is very good at making it. I decided to make a boy named Debra" (UE6025.DecIn). Another sixth year depicted a drawing of a female engineer with the caption "Defy the Standards" (UE6026.Nov). Finally, focus student Ruthie, a fourth year, stated in her October interview about her drawing of scientist Josie Fisher,

> I think it's cool when girls are doing important stuff like that because there's usually a lot of men doing these kinds of things, so that's why I made a girl…people used to think girls weren't as smart. (UE4024.OctIn).

Even if she felt the generalization about girls' inferior intelligence was historical, Ruthie decided it was important to depict a girl scientist. These four girls' comments suggest they were all aware of gender-based stereotyping in STEM professions, even if they did not all seek to counter it the same way.

Skin color. E2 students are identified as 78% White and 14% students of color. There are no African-American students, one Latino student, and three Asian-American students in the E2 class. 47% of E2 drawings depicted scientists and engineers with peach or light yellow skin tones. Six additional students, or another 17% of drawings, were in pencil and did not shade the white paper, so that 64% of total drawings had white or light skin. I asked students I interviewed about the skin color of their scientist using the terms "race" and "skin color," as Walls (2012) does in his M-DAST protocol. Two White students I interviewed described their scientists with light colored skin variously as, "probably from Minnesota…I don't know what race she'd be in" (UE4024.OctIn) or "Caucasian…[or] Romanian-American" (UE6101Oct.In). Two other White students I interviewed did not positively identify this feature of their scientist, both stating that they "didn't know" the race or skin color, even when one student had depicted a character with dark brown skin (UE4019.OctIn). Out of both MM-DAST(E) sessions, a single fifth year male student positively identified his drawing as "African-American" (UE5128.SepIn).

Two students of color I interviewed who drew characters with light skin were also vague about the skin color or race of their drawings, in contrast to the positive identifications Walls (2012) received from the African-American students he interviewed. Courtney, who is Asian American, explained, "I didn't really choose one; there are so many to choose from" (UE5004.OctIn). Jake, who is Latino, bluntly asked, "Does it matter? I don't think so." (UE4123.DecIn). Erica, the E2 teacher, mentioned explicitly that she hopes students will be exposed to STEM professional role models from a variety of backgrounds. She shared a video detailing the story of an Asian-American engineer, Yvonne, as the first lesson in her STEM sequence (Field Notes, 9/20/2016). One way to read these responses is as expressing color-blindness; as E2 is a relatively racially homogeneous environment, it is difficult to say whether or not students are simply drawing what they see around them. This pattern would be worth exploring in greater depth in a future study.

Scene. The majority of E2 students made portraits of their scientists and engineers in everyday attire. 69% of total drawings showed the character wearing jeans and a t-shirt, a sweater and slacks or hoodie, or other similar clothing to what the students themselves wore. As portraits, 42% of the figures stood empty-handed against a blank background. As Courtney explained in her first interview that in the portrait she drew, her character was, "Posing. He's just standing there…it's like picture day or something" (UE5004.OctIn). 39% of characters were depicted wearing glasses, a pattern that Walls (2012) and Chambers (1983) both comment on as an aspect of a stereotype. 28% were accompanied by accessories such as tool, a machine, a hard hat, a test-tube or a backpack, that indicated their status as a professional or student. As Jordi explained about the engineering student, Per, he drew for his September M-MDAST(E): "I guess he's just standing? Maybe he's just like walking to class. He has his backpack on his back so I would imagine he's just walking to class" (UE6101.OctIn).

This characterization of scientists and engineers suggests that E2 students represented them as everyday people, rather than professionals engaged in specific kinds of tasks at their places of work; this was particularly the case with engineers. A fifth year boy I interviewed explained about his portrait, “An engineer is a normal person. They don’t look any different” (UE5128.OctIn). This interpretation is supported by all the students I interviewed who stated that “anyone” could be a scientist or engineer (e.g. UE4024.OctIn, UE4123.OctIn, UE5128.OctIn, UE5004.OctIn, UE6101.OctIn, UE6025.OctIn). However, as noted above, this seemingly inclusive statement contrasted with certain aspects of students’ actual drawings, which showed fewer women and people of color.

Students in E2 depicted scientists and engineers with light skin, increasingly as male, in everyday clothing, having access to some specialized tools like wrenches or test tubes (also available in the E2 classroom), but without too many distinguishing characteristics. In other words, their MM-DAST(E) drawings looked nominally like the majority of people that they saw around them in the classroom. While all students I interviewed claimed that “anyone” could become a scientist or engineer, the overrepresentation of males and the prevalence of light-skinned drawings suggest either that students’ verbal statements may be in tension with stereotypical images in their minds, or that they nevertheless chose to represent characters that looked like themselves. The codes I analyzed included gender, skin color, scene, and common attributes (such as glasses or clothing type) previously identified in the literature (e.g. Chambers, 1983).

These patterns would be better examined with a larger sample of students in a future study.

E2 STEMQ results. Table 4.6 on the following page shows major themes from my analysis of both E2 STEMQs (STEMQ1 in September and STEMQ2 in November). This table represents a condensation of the coding process and frequency counts described in Chapter Three, summarized to show significant themes in each of the following categories of questions: science, technology, engineering, mathematics, and STEM. Erica posted the STEMQ questions in a public space and students were responsible for writing their responses and turning in their papers independently, practices corresponding to normal classroom expectations. 17 students submitted answers to STEMQ1 and 16 submitted STEMQ2. Not all students responded to all questions. When students did not answer a question (as indicated by N/A) this response was not coded. I report predominant themes, including dimensions and exemplary quotations, as a percentage of total data coded in each section. In cases where this information helps provide the reader with a better understanding of change over time, I include the number of students whose responses applied to the theme(s) under consideration.

Table 4.6
Major themes comprising E2 Students' characterizations of aspects of STEM, September and November, 2016

		Frequency of theme, as a percentage of total coded data per category	
Category	Theme	STEMQ1 (September)	STEMQ2 (November)
Science	Multidisciplinary perspective	51%	51%
	Investigating with peers	0%	17%
Technology	Devices using electricity	45%	61%
	Ubiquitous perspective	38%	28%
Engineering	Designing creative products	71%	57%
	STEM lessons	0%	30%
Mathematics	School basics	59%	42%
	Daily life	34%	58%
STEM	Educational initiative	50%	40%

Science. Two themes emerged from my analysis of E2 student responses to the STEMQ questions about science: *What is science? Do you do science in your classroom? What do you do?* The first theme was an *multidisciplinary perspective* on science, which characterized E2 students' definitions of the term and their own activities. The second, *investigating with peers,* emerged in STEMQ2 only and characterized students' reports of their classroom activities.

Multidisciplinary perspective. In both STEMQs, E2 students' predominant characterization of science fell under the theme *multidisciplinary perspective*. This theme included 51% of coded data in the Science category in STEMQ1 and STEMQ2. It characterized how students defined science as well as described the science they did in their classroom. Within this theme, E2 students viewed science as a multidisciplinary way to learn about the world. They connected the lessons they received in individual disciplines such as botany and zoology together under one idea of science, even if this label was not explicitly mentioned.

> *Science is discovering and learning new things and doing stuff like biology, chemistry, zoology, and botany. We do science, but we don't usually call it science (UE4118.Sep).*

Dimensions of *multidisciplinary perspective* included responses in which students named specific natural science disciplines; distinguished between the overarching idea of science as a school subject and the types of lessons they received in the classroom; acknowledged that others might have multiple perspectives on science, and included additional disciplines such as math, art or history in the definition of science. Thus, the idea of multidisciplinarity referred to multiple natural science disciplines as well as including related fields, such as biology and geography or math, in the term "science".

> *Science is studying many things. There are many types of science, such as trying to find cures for sicknesses or diseases. Some people think the study of science is the body. (UE5004.Nov)*

A fifth-year male student made a distinction between doing a school science project and the multidisciplinary definition of science when he said

> *[Science] can be so many things. It can be the science of life, plants, geometry, and it can be math…by the way I explained it, nearly everything is science. No, I rarely ever log in 'science project' [in my work journal]. Science is learning so researching anything would be science. Reading some books, being in a lesson, and working on follow-up work. (UE5117.Sep)*

This student described several generic activities that often took place in E2 under the umbrella of science: reading, being in a lesson, follow-up work, and research. His characterization reflects the most extreme end of the inclusive perspective theme; only two other students in September included math and geometry. The dimension that I saw more regularly included explicit mention of natural science disciplines. As a female sixth year stated,

> *Science can be so many different things. It can be chemistry, geology, and biology. It is such a broad category. I think everyone thinks about science differently. I do a lot of science in class [and] I think everyone does…. My favorite thing to do in science is either chemistry or botany. I am fascinated by the periodic table. I also like studying plants. (UE6026.Sep)*

In this response, the student connected individual experiences, such as learning about the periodic table and plant study, to their respective natural science disciplines, and then to a larger overarching concept of science. However, she also acknowledged that other people have different ideas than she does.

A multidisciplinary perspective did not change in frequency between September and November; in fact, three students became even more inclusive in their attitudes about what counted as science.

> *Science is everything around you. Books are science, labels are science, and even humans (UE4008.Nov).*

> *I mean everything is science: animals, chemistry, biology, botany, ecosystems, geology, weights and measurements, history, etc. (UE5015.Nov)*

> *Science is everything. It is experimenting. It is chemistry. (UE5128.Nov).*

The predominance of the theme *multidisciplinary perspective* suggests that E2 students were constructing an encompassing scientific worldview by making connections between specific activities, individual disciplines, and the word science. In this theme science is an approach to learning that includes a wide range of branches of study of the world; specific scientific disciplines are included within the broad category. This characterization relates most closely to Maria Montessori's idea of cosmic education, in which a scientific worldview provides an overarching sense-making framework for multidisciplinary study (Montessori, 2007).

Investigating with peers. The second theme I highlight is *investigating with peers*. This theme was not present in STEMQ1; however, in STEMQ2 it comprised 17% of all coded data in the Science category. This theme characterized how students discussed their classroom science activity, when they mentioned a recent science experiment, lesson or project they were working on with friends.

> *In class we can choose our work, and sometimes we do. I am doing a project with my friend and we are growing radishes. (UE6025.Nov)*
>
> *When we get a science lesson in class the follow-on is normally an experiment. I am growing and tracking a bean plant with a group of two other people. (UE6016.Nov)*
>
> *I had a lesson on EDP with three friends. I had a chemistry lesson but I do not know who[m] I had it with. (UE5015.Nov)*
>
> *I am doing some science in the classroom. I am working on a glacier [model]. I am working with four friends. (UE4127.Nov)*
>
> *In my classroom I am doing a science experiment. I am making sugar crystals with my friends. I think it's a great thing to learn about through science. (UE4008.Nov)*

Focus student Jake explained the last activity in greater detail by connecting it to the study of solutions and observing and recording practices,

> *I am doing science in my classroom. I am exploring solutions a little bit with my friends. We made rock candy as our follow-on, and we've just been writing own what we see and it took about two weeks for the crystals to finish forming. That's my most recent science. (UE4123.Nov)*

While some students identified themselves as members of the same group, the variety in these responses also demonstrates that students in E2 undertook multiple group science projects throughout the fall semester. Within this theme students' responses referenced hands-on exploration, small group lessons, and choice in follow-on; thus, when E2 students talked about working with their friends it was in investigations of their choosing following a small group lesson. The presence of this theme in STEMQ2 suggests that as the year progressed and they continued to build relationships with their peers, E2 students increasingly considered the social component of their science activities to be significant.

My observations also supported the significance of this theme outside of explicit "science" activities, as an extract from my field notes demonstrates. In this case, Courtney, Grace, and Maggie were testing how far different paper airplane designs traveled. Their interaction gives an example of what happened when students undertook investigations with peers in a more general STEM sense.

> *I check in with the girls in the hallway, who have set up a box fan at the table to help their planes go farther.*
>
> Maggie: We're going to test it.
> Courtney: Let's add some cargo.
> Grace: [we are going to measure it] Wherever it touches the ground first.
>
> *As the girls experiment with the placement of paper clip "cargo" they talk to each other and to me.*

Maggie: I wonder if having two cargos will weigh it down, I only had one that went over there. You have to balance the cargo or else the passengers might die.

They've created a scatterplot of tape on the table. Each piece of tape is labeled to show where the airplane landed. As the students keep testing the different cargo weights, they are surprised by the results.

Courtney: That doesn't seem right.

Grace: Do you think that the cargo affects it?

Maggie: We need to write down what we are doing so that we remember.

She collects all the tape pieces and sorts them into columns.

Maggie: They all passed.

Courtney: Is this one yours?

Grace: Which got the farthest?

Courtney: We can measure.

Maggie: We have to do the exact same thing. Two trials for each one. Let's re-do it. *She looks at the set-up with the fan and reorganize their materials. The girls discuss what to test and how. They want to look at the effect of cargo, and decide to test planes that have one, two, three and four pieces of paper clip cargo.* (Field Notes, October 11, 2016)

In this investigation, the students gave themselves different roles. Courtney was in charge of making the paper planes and putting different amounts of "cargo" (paper clip weights) on the wings. Maggie recorded where each plane lands using a piece of tape. Grace wrote up the results of their investigation. They named and decorated each plane, and gave the reasoning behind balancing the cargo that "the passengers might die". All three girls were highly excited and engaged throughout; they shared with me that the didn't come up with a plan beforehand but wanted to work together to find out which airplanes would travel farther. They also qualified that the tape scatterplot was a dummy test before the real investigation. Decisions made in the course of this activity were often spontaneous, and continued to evolve as the students collaborated with one another and renegotiated their roles. On the surface, what appeared as play was actually an opportunity for students to independently apply some of the practices they had previously done in Erica's STEM lessons, including multiple trials, identification of variables, and measurement.

Technology. Two themes emerged from my analysis of E2 student responses to the STEMQ technology questions: *What is technology? How do humans use technology? How do you use technology?* The frequency of these themes changed between STEMQ1 and 2. The first theme, *devices using electricity*, applied to all three questions and encompassed 45% of STEMQ1 codes in the technology section and 61% in STEMQ2. The second, *ubiquitous perspective*, applied to students' definitions of technology and their descriptions of humans' uses. It included 38% of STEMQ1 codes in the Technology section, and 28% of STEMQ2 codes. Overall trends in these two themes suggest that, over the course of the semester, students increasingly characterized technology as *devices using electricity*, either for personal entertainment or learning.

Devices using electricity. This theme described primarily how students reported their own technology use. One dimension was explicit references to personal electronic devices such as "tablets" (UE6026.Nov), "computers" (UE6101.Sep), and "iPhones" (UE5015.Nov). Another dimension included references to electricity as what powers technology.

> *Technology is using something that needs electrical power like a computer or phone or a light. (UE5004.Nov)*
>
> *We also use technology in creating stuff like lights, and electrical instruments, stoves, outlets, microwaves, stuff like that. (UE4123.Nov)*

The final dimension of this theme related to how students discussed their use of such devices, which was for entertainment and communication, finding information or social purposes. In this case, there was an implicit understanding that the device was a computer, phone, tablet, or television.

> *I think people use technology to find out about things they're wondering about and to be connected to people they know. I use technology for looking up things and emailing my friends from my old school. (UE4006.Sep)*
>
> *I mainly use technology for leisure by playing video games, and watching movies. I also write and do homework on them, as well as edit videos. (UE6101.Sep)*
>
> *I use technology for reports, T.V., texting, calling, homework, and watching YouTube (UE5004.Nov)*

While students described multiple uses of technology, this theme indicated that their personal characterizations of technology revolved around modern consumer electronics or other artifacts that helped them fulfill personal needs and desires for entertainment, communication, and learning. This characterization became more predominant over time, whereas the second theme, which described a broader view of technology, decreased in frequency.

Ubiquitous perspective. This theme decreased in frequency from 38% of coded data for the category Technology in STEMQ1 to 28% in STEMQ2. It described technology as a variety of tools humans developed over time to make tasks easier, and *more than* just contemporary digital or electronic devices. It applied to how students defined technology more than how they described their own use. One dimension of this theme included multiple ways to think about or use technology. Students whose responses addressed this dimension distinguished categories of individual products they listed.

> *Technology can be many different things. To me I feel like technology can be a lot of things but mainly for me it's like laptops, computers, iPhone, iPads, tablets, and smart phones. Other people use technology in different ways. (UE5015.Sep)*
>
> *Technology is something that people use to help them with things they need to do. Some technology is iPhones, phones, iPads, tablets, and other stuff like that, but there is also technology like machines, military technology, and catapults can be considered technology. (UE4118.Sep)*

Thus while students identified individual personal electronic devices as familiar examples of technology, they acknowledged that the term included more than those products. Another dimension included general statements about the utility of technology used in many different ways for everyday life.

> *Anything humans made up, like drones, cell phones, even some food.*
>
> *(UE5117.Sep)*
>
> *Humans use technology in many different ways. (UE6026.Nov)*
>
> *Technology is a big part of many people's lives. (UE4109.Nov)*
>
> *Humans use technology every day. It is very hard to go without it. (UE5117.Nov)*

This theme also had an historical dimension, which implied a progressive or evolutionary view of technology, but still linked it to artifacts of human production.

> *Technology is any advancement in animals using tools to make ways of making tasks easier. Humans have used technology since our earliest ancestors up to the 21st century. Most people think of technology as digital, but the first stone tool was also technology. Our modern lives revolve around technology. (UE6113.Sep)*

> *Technology is anything that has advanced through time, like the wheel, the computer, the car, and many other things. Humans are constantly using technology because technology is everything that has been advanced. (UE5128.Sep)*

The E2 students whose responses addressed this historical dimension thus viewed technology as the products of engineering design made increasingly ubiquitous. Overall, characterizations in this theme correspond to the manner in which Erica presented human tool use on a timeline of human evolution, although her lesson was intended to showcase engineering thinking rather than technology development. Students in E2 therefore held two simultaneous and distinct characterizations of technology: an encompassing definition or ubiquitous perspective of technology as a tool that has changed over time to meet fundamental human needs, and one drawn from their own everyday experiences using digital electronic devices.

Engineering. The STEMQ asked the following questions about engineering: *What is engineering? Do you do engineering in your classroom? What do you do?* While it was the STEM field with which E2 students initially expressed the least familiarity, over the course of the semester, students reported greater familiarity with the term engineering and their own participation in engineering activities. First, 23% of students initially gave the answer "I don't know" when asked *What is engineering?* in STEMQ1. In STEMQ2, however, all students who answered this question provided a definition of engineering, as well as examples of engineering they did in E2. I report on two themes that emerged from the students' responses: *designing creative products* and *STEM lessons*.

Designing creative products. This theme applied to 71% of coded responses in the STEMQ1 engineering section and 57% in STEMQ2, and included responses in which students described engineering work as the process of designing and creating products. Students used multiple distinct verbs to refer to the actions that they associated with engineering, and distinguished between actually creating something, using the terms "make" (UE5007, UE6113, UE6025, UE4008, UE5117, UE6101) or "build" (UE4127, UE5012, UE6025, UE6016, UE6101), and planning it out, using the term "design" (UE4123, UE5004, UE5012) or "plan" (UE6025, UE5117). Within this theme, students struggled to disarticulate the word building from a construction context, as a sixth year female student attempted to explain,

> *I don't really know how to describe engineering. I think it is sort of like building. Not building structures, but almost everything. Building things and figuring out how they fit together. (UE6016.Sep)*

One dimension of this theme was the creativity of the products that students mentioned designing and building, demonstrating a connection between the artistic and engineering forms of design. Responses from two female students exemplify this dimension of engineering as craft:

> *Engineering is the art of making something…We do engineering in our classroom. Today I made a triangular paper booklet and I absolutely love it. (UE6026.Sep)*

Engineering can be from making a scarf to making a car. I have a matter of fact been engineering this year. I am working on a scarf and making telescopes out of paper rolls. (UE4008.Nov)

In keeping with this creative or artistic view, none of the E2 students specified a purpose for the products they or other engineers presumably designed. Nor did they specify these products' role in meeting a need. Jake explicitly said, in STEMQ2,

Engineering is building and creating something that may or may not have any use. (UE4123.Nov)

This theme of *designing creative products* was more prominent in STEMQ1 than STEMQ2; in STEMQ2, as shown below, students began to reference the STEM lessons they had received when they described the engineering they did in their classroom.

STEM lessons. This theme included explicit references to Erica's STEM lessons. While not present in STEMQ1, it applied to 30% of coded responses in STEMQ2. In STEMQ2, five students mentioned receiving lessons in the Engineering Design Process, and one stated that she had done a lesson on Mable Marble. One male fourth-year student applied what he had learned in the EDP lesson to his definition of engineering: while he had not defined engineering in STEMQ1, he stated in STEMQ2 that,

Engineering is where you find a problem, find a solution for the problem, and then fix the problem. In my class I had to do it for a lesson that I got. I thought it was fun. (UE4109.Nov)

Other students viewed the lessons as a rare example of engineering.

Yes, I had a lesson on E.D.P but that it is it. (UE5015.Nov)

I have done a little engineering, I did the Mable Marble. (UE6026.Nov)

I have done E.D.P. or the Engineering Design Process. I studied the pear and apple tree pollination problem in China. I enjoyed learning about E.D.P. (UE5004.Nov)

The presence of this theme, while not expressed by all students, suggests that Erica's STEM lessons influenced, but did not wholly define, how students in E2 characterized engineering. Overall, students in E2 brought together an eclectic set of experiences when they characterized engineering, including crafts, building challenges, research, and lessons on the engineering design process. Thus, in their views engineering thinking could be applied in a wide variety of situations, even though they were not sure exactly what it was or how often they did it. As a fourth-year girl stated,

I think engineering is work (teamwork) and helping the world. I think I have done engineering in this class and at the Land School, harvesting. (UE4006.Nov)

The creativity of the E2 students' characterizations enabled them to express an abstract general idea of engineering, but not how building, design, or problem solving might be operationalized in real-world engineering work.

Mathematics. Two main themes emerged from my analysis of the STEMQ questions about math: *What is math? How do humans use math? How do you use math?* These two themes were *school basics* and *daily life*. When E2 students characterized mathematics, they distinguished between the activities, homework and math problems that were part of *school basics*, and uses of math in *daily life* outside of school such as cooking, measurement, and monetary transactions.

School basics. This theme applied to 59% of STEMQ1 responses in the Math category and 42% of STEMQ2 responses. It described how students defined math and discussed their own and others' use of math. Dimensions of this theme included arithmetic operations, descriptions of classroom activities, references to homework, and knowledge involving numbers.

> *Math is when you add, subtract, divide, and multiply. (UE5007.Sep)*
>
> *I use math to solve the math problems that are on my math skills and green card. (UE4127.Nov)*
>
> *I use math mostly when I am at school and when I am doing homework. I enjoy doing math because then I can keep my skills up and try to get higher scores on my math skills. (UE6026.Nov)*
>
> *Math is pretty much everything to do with numbers, a.k.a. adding, subtracting, multiplying and so much more. (UE5012.Sep)*
>
> *Math is the study of numbers (UE5128.Sep)*

Within this theme, students described math in the form of procedures they encountered in an academic setting, which was their most common daily experience with mathematics. Students gave examples of actions that they took with math or skills they developed, and also considered math as a field of study. The percentage of coded responses included in this theme decreased over the course of the fieldwork period, as E2 students increasingly characterized math as a way of knowing useful for a variety of daily life situations.

Daily life. This theme applied to 34% of STEMQ1 responses and 58% of STEMQ2 responses. It described how students discussed their own and others' use of math. Dimensions within this theme included mathematical thinking in everyday life by making change, measuring ingredients, and shopping at the grocery store, as well as general statements about the utility of math. Students stressed that math is more common that might be thought as first glance, and that it can be useful later on in life.

> *You use math on a day-to-day basis. You use math even when you don't know that you are…when you get older it helps a lot when you are going up in all different kinds of things. (UE5007.Sep)*
>
> *Math is something that we use for a lot of things. One idea is money. You buy something and they give you change. That is math. (UE4109.Sep)*
>
> *Humans use math to teach kinds one plus one and stuff like that, so if they are in the grocery store and need to read a scale, they can. I use math when I am doing my math skills, counting how many LEGOs I have so I can calculate what I build. I also use it when I am at the grocery store, for example, if my mom tells me to get three pounds of lemons. (UE4123.Nov)*

More students characterized math in this way in STEMQ2, but considered these activities to take place outside of school rather than in the classroom. This suggests that they were beginning see connections between the skill building they did in the classroom and applications that would be useful throughout their lives. While many students gave examples of mathematical thinking in daily life, only three made explicit connections to other STEM disciplines in their responses.

> *A scientist can use math…to see how much air goes into a balloon in three breaths. (UE6025.Sep)*
>
> *[Math is used to] build buildings. (UE4127.Nov)*

UE5117.Sep: Math to me is almost the same as engineering but instead of having a unique plan it is similar to another plan. (UE5117.Sep)

This final response suggests that the student, like his peers, thinks of engineering as a creative endeavor, with a "unique" plan, whereas mathematics is more standardized and involves using formulas that are "similar" to one another (UE5117.Sep). Overall, E2 students recognized uses of math both inside and outside of school. Over the course of the semester, a greater percentage of students provided examples of math in their daily lives, but most did not make connections between math and other areas of the curriculum.

STEM. The STEMQ asked the following questions about STEM: *Can you think of an example of people using science, technology, engineering, and mathematics all together? Of these things, which do you like? Why or Why not? Why might people think STEM is important?* In November, the final question was altered to: *Do you think STEM is helpful to people? Do you think STEM is helpful to the Earth?* This change was based on the large number of student responses in E1 that characterized STEM as "helpful". *Educational initiative*, the predominant theme that emerged from my analysis, described students' examples of STEM integration and the importance of STEM.

Educational initiative. This theme encompassed responses regarding classroom lessons and statements about learning as the purpose of STEM. It applied to 50% of responses in STEMQ1 and 40% in STEMQ2, in part because students answered additional questions. In both STEMQ1 and STEMQ2, students in E2 explicitly identified the term "STEM" with the lessons they received and the fact that they learned all of the disciplines in their classroom. They also viewed it as a way to learn more about the world that would help them later on in school and the workplace. Their own E2 Montessori class was the most common example that students had of science, technology, engineering and math being used all together, suggesting that the classroom context influenced student's characterizations of what STEM is. A male sixth-year's response in November exemplifies this theme:

> *I mean [STEM] is educating in a new way. It is showing us the next level in Montessori. The more people that have STEM training the better. STEM is helpful to each and every one of us…I know STEM is helpful to people, but I don't know exactly how it's helpful to the Earth. It's educating people about the Earth so they will be kinder towards it. STEM is educating many people. (UE6113.Nov)*

Education was not the only purpose that students ascribed to STEM, but it was the most common. The first dimension of this theme was explicit references to classroom lessons:

> *I think an example [of STEM] would be one of the lessons that Erica gives us could use all of the things…I think it is a way to learn. (UE5015.Sep)*
> *[We use STEM] in a Montessori classroom. We use all of them in the STEM lessons, other times as well, but STEM lessons are the main thing. (UE5128.Sep)*

Another dimension of this theme was students' recognition that they used all of the disciplines in their Montessori elementary classroom. This was interesting because students did not identify whether or not they thought of STEM as unique to Montessori.

> *We use all of them in our classroom!...I think that [they are important] because they help us learn, they help us think, but they also help us solve problems. (UE4127.Sep)*
>
> *People that use STEM all at once is us. Think about it...we learn all types of stuff that involves STEM. (UE4008.Nov)*
>
> *I can think of one example: in our classroom. (UE5007.Nov)*
>
> *A Montessori classroom where they are all seen together.(UE5128.Nov)*

Within this theme, however, students recognized the common rationales for STEM education as a policy initiative: improved STEM literacy and career prospects.

> *I think it is really important to have STEM in the world, because if we don't have STEM then there probably wouldn't be that many jobs. (UE4006.Nov)*

In both September and November, Ruthie and Courtney, two focus students who felt STEM was helpful for learning, connected the utility of STEM to jobs and life skills, including teaching.

> *Well…they're all stuff you do in school, and you really use them in jobs. Lessons, and more. You use these things a lot in your life!...If you don't know them you won't be good in school and a lot of things will be hard for you so that's why. Plus you kind of use them a lot too. (UE4024.Sep)*

> *I think school, because you use them in lessons and follow on. You also use these things in some jobs, like a doctor, a scientist, or an engineer. (UE4024.Nov)*

> *People might think that it's important because they are good life skills to have. Anybody could also just want to learn more. (UE5004.Sep)*

> *When people go to college to be a teacher they have to study STEM. Then they can use STEM when teaching. STEM can be for designing. I think STEM is helpful to people because STEM can be used for getting a job, or getting into college. (UE5004.Nov)*

Aside from their own classroom learning, students gave other examples of STEM integration as well. Two students in STEMQ1 responded "programming" (UE6026.Sep,UE6106.Sep); two responded "scientists" (UE4006.Sep, UE5007.Sep), and four students discussed "architecture" or "building" (UE4118.Sep, UE5004.Sep, UE6113.Sep, UE6101.Sep).

In the second STEMQ, I asked students whether or not they thought STEM was helpful for humans and the Earth. Students identified both positive and negative environmental outcomes of engineering and technological development associated with pollution, and some linked these to the increased knowledge made possible by STEM.

> *I [think] some parts of STEM are good for the Earth, like science and math. You can help find good things for the Earth with math to help find scientific discoveries. Technology and engineering can be bad for the Earth. Engineering will make less homes for wildlife. Technology makes too much unnecessary energy (UE5004.Nov)*

> *Yes it is helpful [to humans]. No [for the Earth] because of pollution; yes because of stopping pollution. (UE517.Nov)*

> *STEM helps people with helps the Earth. Math, engineering, science and technology are what helps us learn and makes us smarter and each of these things are important to people and the world. (UE5007.Nov)*

However, two students also became more critical in their appraisal of the utility of STEM in their personal lives. This introduced a new dimension to the theme *educational initiative*, which was a critical one. A sixth year girl, Grace, included my thesis as an example of STEM, and expressed that she did not understand the purpose of "STEM" lessons as opposed to the type of thinking that she did in her daily life. In STEMQ2 she wrote,

> *At school when teachers give lessons and kids do follow-up work. Also when some people get jobs, they start to work on this project. STEM can be useful to some people, and other people don't use it at all. I don't think it is useful to me, because I don't know the purpose. If I did know the purpose, it would be very helpful. I don't think STEM is helpful to the Earth. I think it is something that teachers and job people use to help them improve. (UE6025.Nov)*

I asked this student to explain what she meant by her remark, and she stated that she did not understand the purpose of distinguishing STEM from the other science or technology or math she was already doing in school. She felt as if she was "already" integrating disciplines just by the work that she did, and another term seemed superfluous (UE6025.DecIn). A similar sentiment was echoed by one of the sixth grade students I focused on, as I detail in the following section.

E2 Focus Student Narratives

In this section, I detail individual E2 students' evolving characterizations of STEM, synthesized from their MM-DAST(E), STEMQ responses and interviews, and supplemented with observation field notes. I provide narrative description of four students whom I interviewed twice during the fall semester. I attempt to detail the multiple and complex ways in which these students characterized STEM over the course of the study. Thus, I interweave interview data at both time points to best articulate their characterizations. Quotations from interviews are attributed by student code and the suffix "OctIn" for October interviews and "DecIn" for December interviews. For each student, I present major themes of interest drawn from my open, pattern and thematic coding cycles. These themes address multiple aspects of STEM that I identified through my analysis.

- *Who* can be/become a scientist or engineer?
- *What* does it mean to do S-T-E-M? Where and when do these activities take place?
- *Why* is STEM important? What is its purpose?

These themes are also linked to the major assertions I will make for this case at the end of the chapter.

Jake. Jake was an active and conscientious fourth-year Latino male student. During lessons, he never hesitated to explore with hands-on materials Erica brought to the presentation. He liked to conduct independent tests on equipment as well; one day while he and his friends worked on creating tracks for Mable Marble, he repeatedly compared the time readings of his wristwatch and the classroom stopwatch to determine which tool was more accurate. In the classroom and our interviews, Jake brought up current events and environmental justice issues such as resistance to the Dakota Access Pipeline, a topic he reported discussing at length with his family. Jake stated that he wanted to become a marine biologist, and was the only E2 student I interviewed that expressed personal interest in a specific STEM career. His father was a master electrician, which he distinguished from an actual engineer.

Jake was also the only male student in E2 to draw a female engineer in the MM-DAST(E) (he kept the drawing to keep working on it). In September, he drew Emily, an original character he based one of the protagonists in a recent reboot of the Ghostbusters movie (in which four women team up to combat ghosts with inventive machines). In our first interview, Jake explained that he originally wanted to depict his father, "because my dad's a master electrician, kind of like an engineer," but then decided to draw Emily because "she engineers, like actually engineers, puts stuff together and does things" (UE4123.OctIn). Consistent with the characterization of engineering Jake expressed in his STEMQ, he felt that engineering involved designing and creating any sort of invention, “that may or may not have any use” (UE4123.Nov); thus, “actual” engineering required an end product, whether or not its aims were to solve real-world or supernatural problems.

Jake’s second drawing (Figure 4.12 below) depicted a man with brown skin and red hair and glasses standing in a dark doorway next to a measuring stick. Jake explained that his character did not have a name and that he was called, “Scientist because that’s what I got on my little slip, as you can see, he’s 6 feet tall…[a] dude standing in the shadow of a doorway” (UE4123.DecIn). Despite the almost offhand nature of his initial answer, Jake immediate produced an explanation connecting his characterizations of STEM to the drawing he made. When I asked what a scientist might be doing in the doorway of an alley, Jake explained how that he would try and make light through a collaborative process of working with an engineer and applying his knowledge of the land.

> He’ll um, he’ll work with an engineer to build something and then he’ll test the land and then see where a pipe could go, um see where the best place for a wire to go through would be, by seeing if there is any sinkholes, by making things, by using scientific research that he did and looking if the land is good for building and to put a wire through. (UE4024.DecIn)

Figure 4.12 Jake's MM-DAST(E) of a scientist standing in the shadows.

As in the first MM-DAST(E) when he talked about becoming an engineer, Jake explained that "anyone" could be a scientist. When asked what qualities a future scientist might need in his second interview, Jake placed effort before intelligence: "Determination… um…they need to be focused and stay focused. Um. Be smart, study, and go to college" (UE4123.DecIn). He did not mention being "smart" in his first interview, and was the only E2 student to talk about being "smart' as an important quality for a scientist.

Jake wrote answers to five questions in STEMQ1. His responses in STEMQ1 were coded within the Science category theme *inclusive perspective*; the Technology category theme *devices using electricity* on technology; the Engineering category theme *designing creative products*; and the STEM theme *educational initiative*. In STEMQ2, Jake dictated his answers to a computer program, and answered all questions at that time. This additional data added complexity to the themes his responses exemplified. Jake's responses were coded in the Science category theme *working with peers*, in the

Technology category themes *inclusive perspective* and *devices using electricity* on technology, in the Engineering category theme *designing creative products*, in the Math category themes *school basics* and *daily life*, and the STEM category themes *educational tool* and *cosmic task*. Thus, Jake demonstrated both consistency and expansion of his characterizations of aspects of STEM over the course of the fall. In part, this is because he answered more questions. In the case of technology, his characterizations became more complex. In STEMQ1, Jake wrote,

> *Technology is electronics, like iPods, iPhone, and so on. It's also phones and other stuff that helps you and me communicate. (UE4123.Sep)*

In STEMQ2, Jake did not provide a definition of technology, but instead explained its uses in greater depth.

> *Humans use technology for good or bad. When they are using it for good, they are either entertaining themselves in a good way or making apps to help the community. We also use technology in creating stuff like lights, and electrical instruments, stoves, outlets, microwaves, stuff like that. When they use it for bad, it is basically when they are programming missiles to launch and destroy stuff, and when you're being a cyberbully and just hurting people. I use technology whenever I am entertaining myself, warming something up, or just turning on the lights. (UE4123.Nov)*

Jake's previous statements his father's role as an electrician and his own use of technology for communication purposes keeping with these statements about the pros and cons of technology use, Jake's interviews provided additional information on his views on two aspects of the purpose of STEM: its positive and negative impacts for humans and the earth, and the importance of a Montessori context for STEM lessons.

Why STEM? Pros and cons of science, technology, engineering, and math. Jake associated STEM with progress and development, which he viewed ambivalently. In his characterization, scientists and engineers had the power to help or hurt people and the Earth. In both interviews, Jake provided multiple examples of how STEM could have positive and negative impacts based on the actions of the people involved and the technologies they created. This applied to his characterizations of technology, engineering, and science alike. In his first interview, Jake expressed concern about the proliferation of a popular application because of its potential to reduce humans' awareness of their environment, even though he associated applications and entertainment with "good" examples of technology in STEMQ1. He explained,

> Technology is keeping us away from the real world, like Pokémon Go right now…people are DYING actually because people have fallen off cliffs, people have found two corpses...and um, and like it's stopping us from gardening and it's like, and technology um Moore's law, technology grows every 14, 16 months… so it can surpass human intelligence. (UE4123.SepIn)

He also expressed concern about the trade-offs between resource intensive STEM activities and the lives of other beings. Jake did not consider engineering as a monolithic field, noting that there were many types of engineers.

> Um, engineers build to help the world not always sometimes they can build weapons …um they can build medicine…. stuff like that, depends what type of engineer, like if you're asking a bioengineer, they'd say, well an engineer, my type of engineer makes medicines and… diseases and stuff that will help you…and stuff, and if you ask an engineer, like just plain engineer, they'd like… a tractor or a car or a light bulb or a building or….or an electronic, or something like that.…engineering can't always be helpful because we're using up a lot of space and we're using up a lot of fossil fuels. Because like you're taking up like some animals… like the dodo bird, um, hunted out of extinction and most of its habitat…destroyed! Jaguar is, going into um is endangered because its habitat is getting destroyed. (UE4123.OctIn)

Jake also discussed the pros and cons of scientists' work in his second interview. Similarly, he connected the work of scientists to negative outcomes of the technologies produced with scientific knowledge. From Jake's point of view, this was part of learning to be a scientist.

> Scientists learn how to help people, and sometimes how not to help people. Something that I kind of wish wouldn't have been invented is a nuke, because it really destroyed lots of people in Japan and in other places too. (UE4123.DecIn)

Despite this negative view of technological applications of STEM, Jake felt that engineering could be a tool to solve complex problems, within his characterization of engineering as building products and machines by following a plan or idea. He reported in his second interview that he did a lot of engineering at home by making robots and toy machines. He similarly felt he could design a technological solution to issues that troubled him, like global warming.

> Jake: Like, if I had to choose anything around me to help the Earth, I'd look around and see what would help nature and stuff, think of something in my mind, write it down, make blueprints, find the things that I need in the classroom, and then build it.
>
> Alaina: Is there a problem you see that you would want to solve with engineering?
>
> Jake: Yeah like global warming. Like I could build a machine that would have the same use as fossil fuels but that wouldn't get trapped in the atmosphere and rip holes and make, and let gasses in that will, that will harm our Earth. (UE4123.DecIn)

For Jake, being part of a Montessori environment meant learning to value the Earth. This technological solution came from a place of cosmic responsibility to help.

Why STEM? The importance of Montessori context. In both STEMQs, Jake referenced his classroom when he talked about STEM. He explained that an example of people using math, science, engineering and technology all together is

> *When we are at school at a Montessori STEM lesson. We do engineering by sketching it out when we are building stuff, and math when we do our math skills and our green cards. (UE4123.Sep)*

When I asked him to explain further in his first interview, he shifted this characterization to include engineering (in the form of designing creative products), math for the purpose of measuring and calculating, and technology with programing. He treated the term STEM as an acronym, and sought to explain how all the parts fit together by explaining what STEM stood for, although he didn't provide an example of science and also included the word STEAM.

> Montessori STEM is, um… science… oh no… STEAM… Technology… um… engineering … no science, technology, engineering, um I forgot, uh huh, I can't remember. Oh, math! [In STEM lessons] we like sketch out stuff and maybe end up building it and creating it, and we have to do calculations, like how big it's gonna be and how long and the perimeter, and we use engineering by building it and then…uh we use technology by then uh maybe if it's a robot by programming it. (UE4123.OctIn)

While in STEMQ2 Jake stated that he had not done any engineering yet that year, he had taken part in lessons in both the EDP and Mable Marble strands. It is possible that because these lessons did not involve building products, Jake did not count them as engineering.

In his second STEMQ, Jake connected the Montessori context to a positive purpose of STEM. In this case, scientific knowledge of biology and zoology gained in Montessori lessons would enable kids to develop greater environmental sensitivity, thus providing a good, more peaceful use for STEM:

> [STEM] can be helpful because people can use it for good or bad. Some people use it to build weapons and oil drills. It can also be used for good in a Montessori way by teaching kids about how to take care of the Earth through biology and zoology. (UE4123.Nov)

In our second interview, I asked Jake to clarify what he meant by Montessori STEM. At that time, the community was carefully following the story of water protectors at Standing Rock, ND, resisting the completion of a new oil pipeline. Jake connected the environmental justice consciousness he was developing through conversations at home with his family and in his classroom, with these current events.

> Jake: Like, STEM Montessori, like here they're teaching us like take care of the Earth because… if we don't take care of it, where are we going to live? …And right now, what's going on in South Dakota isn't going to help take care of our earth because it's going to affect millions of people.
>
> Alaina: Have you been talking about this in school?
>
> Jake: My house mostly. I've had three conversations about it in school. In my house, we talk about it all the time…It's pretty sad, because, what really makes me mad is, if it was going through the white neighborhood and they were like no we don't want this contaminating our water, [but] the Native Americans said that, and they just didn't care, they're still going to build it. (UE4123.DecIn)

Jake's characterizations of aspects of STEM had a moral dimension. Far from being neutral actors dedicated simply to the pursuit of knowledge, in his view scientist and engineers had the potential to help or hurt others through their actions and creations. This moral dimension was primarily realized in the technological realm, where Jake saw the outcome of science and engineering activity as the technological products that impacted humans and the Earth. For Jake, Montessori pedagogy was a promising way to apply STEM in more peaceful ways.

Ruthie. Ruthie was a shy, soft-spoken White female first-year student. While she was new to E2 that fall, she had attended North Star in lower elementary. Ruthie loved to read and write, and several times I observed her conferencing with a peer about her writing. In STEM lessons, she sat quietly and listened, rarely offering comments during the presentation. She was aware that she did not participate vocally, and stated that she learned science through observation:

> Well it's kind of cool to watch it because you're like, um, sort of like watching people do these things and then you watch people like explain about it, and you can, you can learn something from that. (UE4024.OctIn)

Ruthie actively consulted Erica and peers for help on topics of personal interest, however, such as a research project tracking the temperature and weather of a South American country where she had relatives. Ruthie did not answer most questions about individual disciplines in STEMQ1 or STEMQ2; however, she did provide information on the purpose and importance of STEM. Ruthie's interview provided information on who could become a scientist and how, as well as her characterizations of STEM activities and the purpose of STEM.

Who can become a scientist? The importance of early empowerment and social ties. For both MM-DAST(E) drawings, Ruthie drew a young girl scientist with light peach skin and a colorful outfit, a teenage inventor named Josie Fisher whose imaginative creations bridged the literary and technological. Both times, Ruthie reported that she intentionally made a young female character similar to herself in order to depict an empowered girl who developed an interest in STEM early on (see Figure 4.13).

Figure 4.13. Ruthie’s first (left) and second (right) MM-DAST(E) drawings of Josie Fisher

Other people she knew, including her sister, also inspired this character. In her first interview, Ruthie explained,

> Um so I decided to make um someone that’s is young because…well, a lot of scientists they, um, or engineers they start out when they are, probably, like younger. So that’s probably the reason why I made it a little bit younger… I also put the word be yourself on the shirt because, you can do anything, really?.... I was thinking a lot about my sister and she looks something like that… I think it’s cool that when like girls are doing… um important, like stuff that, like ‘cause usually there’s… a lot of… men doing these kind of things so…. that’s why I made it a girl...Yeah and people used to think like that girls weren’t as…girls weren’t as like smart, so...that’s…why. (UE4024.OctIn)

While Ruthie did not report the influence for her claim that scientists or engineers start out early on, this quotation indicates that she felt that positive messages, such as that found on Josie’s shirt, or her own representation of a girl doing “important stuff,” were key for young girl scientists. While she was hesitant to share (indicated by her frequent pauses) she felt her representation countered the stereotypical image of “men doing these kind of things” (UE4024.OctIn) and what she viewed as a historical stereotype of girls’ intellectual inferiority. Within that counter-representation, Ruthie self-identified with the image she drew. In her second interview, Ruthie stated,

> She is… I made her 12 because I wanted her to be a little bit younger…and it would be way cool if the person was like kind of my age, kind of…. She has light skin. I also have light skin, and I also wanted to make it like that kind of. (UE4024.DecIn)

This character was even closer in age to Ruthie, although she had the same name. In her initial interview, Ruthie was not as specific in her characterization of skin color. She explained,

> She kind of looks like someone that would be in like maybe she’d live um in like [my home state] and um I think she’d like, I don’t know what race she would be. (UE4024.OctIn)

For Ruthie, becoming a scientist meant taking steps in and out of school to sustain that early interest, and drawing on the support of family and friends. In her first interview, she explained in the story she offered about Josie, “I think she would go to a good school and…maybe she’d learn from her parents um how to do these type of things?” (UE4024.OctIn). Ruthie’s mother was a doctor. She also had a friend who attended an engineering club after school. She explained in her first interview that her mother uses STEM thinking in her job, and that she learned about engineering through her friend’s creations from the afterschool program. These connections informed her story about Josie as well, in which interest, inventiveness, and helpfulness are all qualities she associates with becoming and being a scientist.

> Well she's probably like when she's in school she probably, um goes to… classes where there's like a lot about science? And then maybe after school she goes to a place like an…place like an engineering group or something…I have a friend… that… goes there [to an after-school engineering club] and she shows me some stuff that she's made, like she's made these cool little like robot things… [When Josie grows up] she's probably gonna make and learn about more stuff, like maybe she'll make like things to help, to help um… like maybe she'll have like a cure for like things and a cure for stuff. I think…. a scientist is someone who…um has something that they want to do or they're interested in it and they make an experiment or they make something that can help other people. (UE4024.OctIn)

Ruthie's discussion of Josie helping to find cures resonates with the information she shared about her mother being a doctor, which underscores the significance of a family influence. In her second interview, Ruthie stated that if she wanted to become a scientist herself, she would show a similar effort and commitment in and out of school: "I think I'd probably try to, I'd probably want to try to do my best in the scientist things, maybe when I am not at school I could make stuff for my family" (UE4024.DecIn). This comment also supported her initial characterization of STEM as helping others.

Why STEM? Strengthening friendships through group projects. When Ruthie talked about her own STEM experiences in and out of the classroom, she again highlighted the importance of friendship: for her, the purpose of STEM was learning about herself and her friends' abilities and work style. By participating in projects with peers, she was able to strengthen her friendships, which made her view STEM as "helpful".

> I think it's helpful for many reasons and I can't list them all. I think one of the reasons it's helpful to a lot of people, to me the thing I like about STEM is that you're learning more about other people and stuff, to learn about other people's abilities and stuff you can learn about them. Um well, when I first came to the school I was super shy and I'm a little shy now, but once I get to know the people I might become friends with them, and I learn more about my friends from the

> first day and I learn more about them each day when I come hang out. It was helping me learn more about my abilities [too]. (UE4024.DecIn)

When Erica gave lessons, she often asked students to reflect on how they worked together, and to consider working styles when they chose partners for research projects; for her, a primary goal of STEM instruction was facilitating opportunities for collaboration between students (Personal communication, January 18, 2017).

Friendship also informed Ruthie's depictions of scientists. Her character Josie's second invention, for instance, was a machine that enabled time travel into novels. Ruthie explained that in her picture, Josie was testing out her invention: "I think it would be really cool if we could travel into books that we like, and we could just go, I like this book, I want to meet the characters, and you could go in it, and maybe you would be best friends with the characters and stuff" (UE4024.DecIn). While Ruthie infused her characterizations of STEM with the same creativity she poured into her writing, viewing STEM as a vehicle for her imagination, her interviews ultimately demonstrated the importance of social ties in fostering and sustaining interest in STEM in and out of the classroom.

Courtney. Courtney was a curious, inventive, and social fifth-year Asian-American female student. She asked many questions during our interviews and in lessons, and offered humorous responses to my own queries. During my observations, Courtney was often involved in projects with her friends, and readily informed me about what they were doing. These projects included an investigation of the effect of different paper clip weights on paper airplane performance; writing the script for a student presentation on the history of engineering in early human cultures; and creating a map of areas in China affected by declining bee populations and in need of artificial pollinators—a follow-up from Erica's lesson on the Engineering Design Process. When I visited E2 for member checking in March, 2017, Courtney was involved in the production of a cardboard model of the school for a student-made adaptation of the game of Life. She explained in a whisper that it was a gift for Erica, and that I should keep it a secret until May.

Courtney's characterizations of STEM disciplines in her STEMQ responses consistently fit into all of the major themes identified in the E2 STEMQ, which she also identified in her interviews. Therefore, I do not report them in detail here in order to discuss her interview responses more in depth. She expressed a positive view of STEM in both interviews and STEMQs, reporting in STEMQ2, "I like all math, engineering, and technology. I like to do math and I don't know why! I love to build things. I once made a working Rubik's Cube" (UE5004.Nov). In both interviews, she discussed her views of who could be a scientist or engineer, and how she characterized STEM in relationship to her classroom and outside of school experiences with engineering.

Who can be a scientist or engineer? Anyone, even a baby. Courtney believed "anybody" could be a scientist "as long as you try" (UE5004.OctIn). Courtney initially did not specify whether she drew a scientist or engineer for her first MM-DAST(E); in the interview, she decided the pencil portrait of a male with glasses she made represented a scientist. For the second MM-DAST(E), Courtney stated she drew an engineer. Both of her drawings were portraits of men named Bob against a blank background, without any particular identifying accessories. She provided what she felt was a generic image of an everyman, with a name inspired by her neighbor and facial hair (at least in her second drawing) like her father (Figure 4.14). When asked what skin color or race her drawing depicted, in her first interview she said, “I don’t know. I would say I didn’t really choose one...I have no idea. There’s so many to choose from” (UE5004.OctIn); in her second, a shorter response: “Don’t know. Doesn’t really matter.” (UE5004.DecIn).

Figure 4.14. Courtney’s first scientist (left) and second engineer (right) MM-DAST(E) drawings.

In her second interview, Courtney went even further in her characterization of anyone being able to have a career in STEM when she stated,

> Anybody [could be an engineer] if you wanted to be. Even a baby. Well, if you want to get *paid* to be an engineer you couldn’t be a baby. A baby could, like design a house, like a fake house... [but if you wanted to get paid] you’d have to study and go to school and actually get the job. (UE5004.DecIn)

Courtney's responses suggest that she characterizes engineering thinking as a basic shared human trait we all have from birth, but becoming a professional engineer involves effort, training and career preparation.

What is STEM? An engineering design-based view. Courtney characterized STEM through the lens of the engineering design process: as a way to solve complex problems and design products. Courtney's statements in interviews showed how this view was initially constructed from her experiences outside of school and later supplemented by her experiences in the classroom; in STEMQ1 she reported designing Rubik's Cubes at engineering camp at a local museum, and in STEMQ2 she stated that she had enjoyed the lessons she received on the E.D.P.

Courtney's descriptions of engineering and STEM paralleled one another throughout the fall. In her first interview, Courtney explained that STEM provided engineering "life skills" potentially useful in challenging situations:

> Courtney: Well they [the STEM disciplines] can just be used like any time, like let's say you're in like a situation and you need to use um, something, an engineer because let's say like somebody fell down a cliff? That's just probably not going to happen, but you could like, find things around you, and engineering could help them climb out.
>
> Alaina: So if someone fell, you could engineer a solution to help them climb back up?
>
> Courtney: And then again you might need math for that too, so…
>
> Alaina: So how would you use math for that, what would you need math for?
>
> Courtney: Uh, to find out how heavy you would want the rope…to be how light, or how heavy the person is. You might want to find out that…. And you would probably test it before you use it, you don't know what could happen.
>
> Alaina: That makes sense.

Courtney: Otherwise the person could fall deeper. (UE5004.OctIn)

In this interchange, Courtney characterized engineering as a way to improve a dangerous situation by applying measurement knowledge and engineering thinking to help a person get to safety. In this creative application of design thinking, engineering drove Courtney's description of integrated STEM. She elaborated on this characterization in her second interview, in this case applying it to structural design rather than problem solving:

> Yes, you could [use S, T, E, M all together]. You could. You could use it for designing, like engineering an idea, make sure like scientifically so it wouldn't like collapse or something…or…math to figure out the height and stuff and all that. Then you'd have to pay people to make it. (UE5004.DecIn)

For Courtney, science and math provided the knowledge to ensure the structure would be successful and meet design constraints, and engineering was the process from idea to production; therefore, her characterizations of engineering consistently informed how she characterized STEM as a whole. Courtney's views of STEM were driven by the problem solving approach she associated with engineering design, which she also enjoyed pursuing on her own outside of school. As mentioned in the vignette I shared discussing the STEMQ results, Courtney was used to applying STEM thinking in the investigations she pursued with her friends, even though the activity wasn't driven by science or mathematics content. Thus, she maintained a characterization of STEM as a form of thinking that "anybody…even a baby" could engage in, but which was realized by paid professionals.

Jordi. Jordi, a sixth-year White male student, was a precocious, big picture thinker with strong opinions about the world. When I asked him during member checking in March, 2017 if there was anything he wanted readers to know about him, he replied solemnly that, “you should never trust a religion that makes you pay to believe” (Personal communication, March 22, 2017). In our interviews, he peppered his speech with multisyllabic words and indicated a desire to learn further on his own, detailing how he looked up “calculus” in the dictionary and tried to understand what it meant, then explaining how he learned to use an online application to graph linear equations with his personal math tutor. For Jordi, self-directed learning experiences outside school seemed just as important as his classroom experiences when it came to his characterizations of STEM, if not more so.

In both of Jordi’s interviews, we discussed the big picture perspective he communicated in his written STEMQ responses, as well as his claims about not being involved in classroom STEM activities. Unlike the other E2 students I interviewed, who expressed positive associations with STEM and readily described several specific classroom experiences, Jordi—in his third year in E2—maintained an ambivalent attitude. In STEMQ2, when asked to discuss whether he liked any STEM disciplines and describe their importance for humans and the earth, he explained:

> I don't necessarily "like" them. They are not tangible as a thing. I do appreciate them. Guns don't kill people, people kill people. A machine is never innately evil. Evil is a construct created by lazy people. They are neither good nor bad for the Earth, they simply are. (UE6101.Nov)

Jordi’s interviews provided information regarding the relationship between how he defined STEM disciplines and his own classroom activities, as well as his understanding of STEM as a unitary construct.

***What is STEM? Strong beliefs, limited opportunities for enactment*.** Even though statements made in his STEMQ consistently indicated strong beliefs about the STEM disciplines, Jordi indicated in STEMQ responses and interviews that did not feel personally involved in E2 STEM activities, nor did he characterize his experiences positively. In STEMQ1, he expressed a limited version of an *inclusive perspective* on science when he reported, “Science is the modern study of things, like geography or physics. Some may argue that math is a science, but I disagree. In UE, our science is mainly biology and geography, occasionally zoology.” (UE6101.Sep). In STEMQ2, Jordi defined science as “the observation, identification, documentation, and experimental investigation of phenomena”, but was one of three out of 14 STEMQ2 respondents who stated that he had not done any science in that classroom that fall (UE6101.Nov). When I inquired about this statement in our second interview, Jordi said, “Science? Um, science in…the traditional sense, I haven’t really, but…it’s been math and stuff, a lot more math, it’s been a lot of math” (UE6101.DecIn).

Jordi expressed a similar claim regarding limited classroom opportunities for engineering. In STEMQ1, he reported: “To be honest, I know nothing of engineering lessons, so I am going to move on, sorry” (UE6101.Sep). For both MM-DAST(E) drawings, in which he was asked to depict an engineer, Jordi dashed off portraits of male engineers in between lessons; the first time, he explained that he hadn’t yet had “any lessons on engineering” so he didn’t know what an engineer was (UE6101.OctIn); for the second drawing, he stated that he didn’t have enough time to develop a real “backstory” for his character (UE6101.DecIn). In STEMQ2, he explained that while he had “been planning to make a hand axe," he had not done any engineering "yet" that year either (UE6101.Nov) (Figure 4.15). Both Erica and I found this claim interesting from a sixth year student; furthermore, had Erica presented Yvonne's Story and the Engineering Design Process to the entire class in September. I observed Jordi in a lesson on potential and kinetic energy, a lesson on early human tools, a lesson on solutions, and a lesson on types of fruit. However, he was not present at the other engineering or physical science lessons I attended, and Erica agreed that it was possible he had not had engineering lessons in previous years.

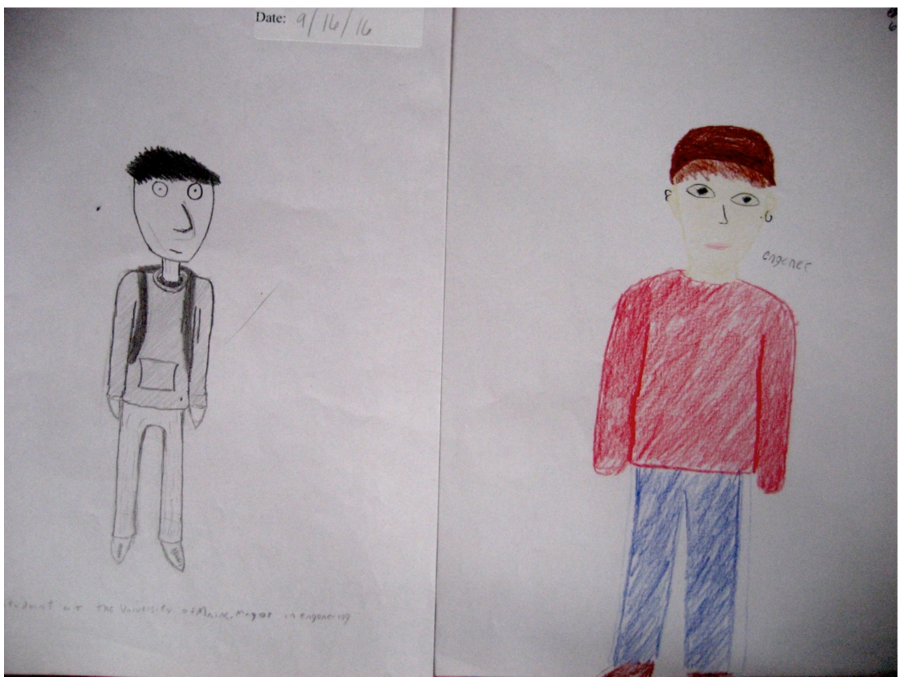

Figure 4.15. Jordi's first (left) and second (right) MM-DAST(E) engineer drawings

In STEMQ1, Jordi enhanced the *inclusive perspective* on technology he expressed with a statement about humans using technology for power: "Humans use technology as they would use anything: to acquire power. History has proven that no matter the skill of the warrior, the victor is decided through the quality of the technology. Even the computer is a weapon, capable of limitless knowledge available at the press of a button" (UE6101.Sep). Jordi viewed technology in a historical, evolutionary light, a way for societies to outcompete each other. Personally, he explained that he used technology in a far less grand manner: for completing homework assignments and editing videos. In STEMQ2, Jordi condensed this statement and related science, technology and engineering, with technology as "the application of science for commercial method" and "engineering is the act of making technology" (UE6101.Nov). His own technology use, however, was for the purposes of "leisure" or learning (UE6101.Nov).

Jordi expressed a similar systemic perspective on math's role in *daily life*, stating in STEMQ1: "It is the most prominent thing taught in schools because it is so integral to modern life. Most jobs need math and even when at home math is integral to life because of capitalism. I mostly do math because it is required in school" (UE6101.Sep). He explained further in his first interview that he referenced "capitalism because [of] money. You need to buy stuff with money" (UE6101.OctIn). Thus, for Jordi, mathematics impacted multiple facets of his existence, although his activities were constrained by the requirements of schooling.

Jordi's characterizations of individual STEM disciplines demonstrate a pattern of strong generalizations in contrast to what he viewed as limited experiences in his personal life. Jordi's statements regarding his lack of exposure to STEM experiences must therefore be taken with a grain of salt, even if they suggest that at least in Jordi's view, the impacts that science, technology, engineering, and mathematics have on humanity far exceed their articulation in the acronym STEM.

What is "STEM"? Distinguishing between S-T-E-M and STEM. In both interviews, Jordi made a distinction between "STEM" and "science, technology, engineering, and math" all together (UE6101.OctIn). He viewed STEM as a term specific to school, and not the manner in which different STEM disciplines or ways of knowing were actually integrated in real life. As Jordi explained in his second interview, he felt that humans integrated these disciplines in activities such as creating video games, in which

> Jordi: You need science to apply your math, and you need the math to create an engine for the game, and you need engineering to create the engine and to make all the variables work. You need technology to play the game. So yeah…I don't mean STEM specifically I mean science, technology, engineering and math. But not STEM.
>
> Alaina: What do you think the difference is between what you've described, science and technology and engineering and math together, and the idea of STEM, as one word?
>
> Jordi: STEM is more for educational purposes whereas science, technology, engineering and math are like…kind of just basic, like, things to do stuff… (UE6101.DecIn)

Here, Jordi described software engineering as an example of STEM integration. The game "engine" represented what is engineered, and mathematics the underlying reality that allows a person to engineer something new. He was less clear about the role of scientific knowledge, beyond the statement that it creates an explanatory framework in which to apply math. However, in all of this, he distinguished combining ways of thinking from the term "STEM." This explanation fits with a response Jordi provided in STEMQ1, in which he described the importance of science, technology, engineering and mathematics in daily life, no matter what society a person is in: "it is what we use as a community in our day-to-day lives. Also someone may argue that they are only needed in the first world, but I think that no matter where you are, they are valuable things to know" (UE6101.Sep). In STEMQ2, Jordi used the word as STEM as shorthand, but, as noted above, distinguished it from the type of STEM he encountered in lessons. This characterization encompassed the universal, evolutionary perspective he expressed when he discussed technology as well: "Humans have benefitted a great amount from STEM. It's definitely one of the things that helped us evolve" (UE6101.Nov).

E2 Case Assertions

I have presented findings from the upper elementary case, including students' depictions of scientists and engineers in the MM-DAST(E), and their descriptions of their own and other humans S-T-E-M activities in the STEMQ. I also highlighted four individual students I interviewed. Throughout, I was guided by the following analytic questions:

- *Who* can be/become a scientist or engineer?
- *What* does it mean to do S-T-E-M? Where and when do these activities take place?
- *Why* is "STEM" important? What is its purpose?

Four main assertions emerged from my analysis of the upper elementary (E2) data over the course of the fall semester regarding who can be a scientist or engineer, what students characterized as STEM activities (including activities within individual disciplines) and students' characterizations of the purpose of STEM. These assertions are supported from evidence found across focus students and data sources, and are discussed in relationship to the literature in the next chapter. In this case, I will state my assertions at the end, and provide a brief commentary.

- *Assertion E2.1:* Who, What? Universalizable. E2 students characterized the STEM disciplines, and scientists and engineers, in a universal way.

E2 students were developing a holistic/cosmic STEM worldview in which science, technology, engineering and mathematics were "everywhere" and could potentially be used by "anyone." The STEM fields all contributed to building the contemporary world and meeting fundamental human needs, and anyone could potentially be a scientist or engineer if they had effort, motivation, and support. Thus, STEM fields were not seen as strictly school subjects whose meaning was fixed, or professions accessible only to those with certain pre-set characteristics; rather, many things could belong under the categories of science and technology, and math could be valid both in and out of school. This was shown by the themes *multidisciplinary perspective* in the STEMQ science and *ubiquitous perspective* in the technology sections as well as Jake, Ruthie, Courtney and Jordi's statements that "anyone" could be a scientist or engineer if they put effort into it. However, there were limits to this inclusivity: the focus students all qualified their statements about "anyone" with comments that a person needed a college education or specialized educational training. Furthermore, more students represented scientists and engineers as light-skinned and male than any other type of person.

- *Assertion 2. What? Connected:* E2 students connected to STEM activities through their daily lives and social ties with family and friends.

E2 students characterized STEM activities through their experiences building relationships with their peers, and drew on influences from friends and family members in constructing images of scientists and engineers. Jake and Ruthie both had family members in STEM careers, and Ruthie talked extensively about the importance of social ties in developing and sustaining STEM interest. They connected STEM to their personal lives, providing quotidian examples of the type of problem solving they could use with their families. Jake, in his interview, explained:

> [STEM is] helpful by um like it's just like you sometimes use those, use those things in your daily life…Like sometimes, like yesterday we did a little bit of engineering at my house. My dog accidentally…. We have a screen door and my dog just ran into it when I got home...And it popped off...We fixed it and we bent it and we hammered it so. (UE4123.OctIn)

This theme was shown in Jake and Ruthie's interviews, as well as the STEMQ theme *investigating with friends*. My observations of students' group activities supported this self-report.

- *Assertion E2.3. What? Creative*: E2 students approached STEM creatively, using their imagination to come up with situations to apply STEM thinking.

This assertion was supported in detail by Courtney and Ruthie's interviews, and the dimension of the theme *designing creative products* in the STEMQ. Students' chosen responses to STEM activities also indicated creative connections between the concepts Erica presented and their collaborative follow-up projects, documented in my observation field note descriptions.

- *Assertion E2.4. Why? Critical:* E2 students thought critically to the relationship between STEM, society, and the environment, identifying positive and negative outcomes they associated with STEM.

This assertion is supported in detail by Jordi and Jake’s interviews, as well as some of students’ STEMQ responses under the theme *educational initiative*. E2 students connected the term “STEM” to lessons they received in the classroom, which they distinguished from the integrated STEM thinking they did in everyday life: they saw STEM as a shorthand concept developed by teachers to improve learning and job prospects, whereas they thought about integrated science, technology, engineering and math as ways of thinking and solving problems common to all humans.

Chapter 5 : Discussion and Implications

In this chapter, I first restate the research question I sought to address and review the purpose and activities of my study. Next, I summarize my findings and contextualize them within the literature. Finally, I reflect on lessons learned from the case and conclude with implications for future teaching and research.

Review of the Study

The purpose of this thesis was to explore Montessori elementary students' characterizations of integrated science, technology, engineering, and mathematics (STEM) education. My research question was, *How do Montessori elementary students characterize aspects of STEM?* Instrumental case study methodology (Stake, 1995) guided the study design. One lower elementary (E1) and one upper elementary (E2) classroom served as two separate cases within a single school site. This research took place in the context of three months of integrated STEM instruction by teachers with graduate certificates in Montessori STEM education (Ibes & Ng, 2011), during the 2016-2017 school year.

At the beginning and end of the fall semester of 2016 (September, 2016-December, 2016) participating students completed two paper and pencil tasks: a modified Draw-a-Scientist Test, the MM-DAST(E) (Walls, 2012) (Appendix A); and a researcher-created written questionnaire called the STEMQ (Appendix B). Following completion of the tasks, I purposefully sampled individual students for semi-structured interviews to learn more about their responses and classroom experiences. I conducted interviews at two time points, before and after a series of teacher-chosen STEM lessons. Previous studies (e.g. Capobianco et al., 2011; Walls, 2012) have not administered drawing tasks following science or engineering instruction. My data sources therefore provided multiple entry points to gather information on students' depictions of scientists and engineers, as well as their evolving characterizations of the STEM disciplines, self-reports of their own STEM activities, and thoughts on the purpose of STEM.

I inductively analyzed students' MM-DAST(E) drawings, STEMQ questionnaires, and interview transcripts to identify predominant themes. In the course of my data analysis, I highlighted different aspects of STEM by which I organized my findings, corresponding to three analytic questions. To investigate *Who can be/become a scientist or engineer* according to students in my sample, I examined student drawings and interview responses. To learn *What it means to do S-T-E-M* in two Montessori classrooms I analyzed students' STEMQ and interview responses. This analysis also provided insight on *Why "STEM" is important* in students' lives. These questions were addressed for each case in the previous chapter. In this chapter, I make claims across classroom cases, explaining my interpretations in the context of the literature base.

According to Maria Montessori, children ages six through twelve all belong to the same "plane of development," with similar tendencies, behaviors, and learning needs (Montessori, 1965). Montessori advocated for students to attend her schools from early childhood through adolescence, and therefore envisioned her curriculum as a spiraling experience (Montessori, 2007). It is possible that the cross-case aspects of my findings are due in part to the similarities in Montessori school context, teacher training, and

STEM lessons that students received. However, more evidence is needed to determine this, as it was beyond the scope of this study.

Common Themes

Who can be/become a scientist or engineer? Potentially "anyone"; in actuality, a dominant view prevails. Across E1 and E2, I noticed a pattern when I asked students who could be a scientist or engineer: the immediate answer that it was a career open to "anyone." However, students regularly followed this initial claim that "anyone" could do it by qualifiers about what was necessary to get there. While students in this study *verbally* reported anyone could be a potential scientist or engineer, this characterization was in tension with both how they described the process of becoming one, and whom the majority of students *visually* represented as scientists or engineers. This was shown by discussions about the skills and attributes necessary to become a professional, and by the coexistences of inclusive reports with elements of Chambers' (1983) standard image of the White male scientist in students' MM-DAST(E) representations.

As focus students reported, study and hard work were key characteristics of future scientists or engineers. I interpret this pattern as reflecting shared values of agency or meritocracy; students expressed that all people had potential to become what they wanted given the right opportunities to build skills. The skills students mentioned—focus, creativity, or determination—were character-based, corresponding to the holistic educational environment of their Montessori classroom (Lillard, 2007, Polk-Lillard, 1996). The students that I interviewed saw science, engineering (and math) as intellectually demanding, but felt that effort, motivation, and education could overcome that.

Like the British private and Catholic school children Archer et al. (2010) interviewed, Montessori elementary students in this private-school setting felt that learning more through STEM was a positive thing that anyone could do, but it required further study. They acknowledged that becoming a scientist or engineer later on in life required college and workforce preparation, suggesting these Montessori students' characterizations were linked to what Archer and colleagues (2010) termed "middle-class aspirations" in an independent school culture that valued education and personal striving as part of success. Jean Anyon's (1980) study of different schools' relationship to cultural capital also shows how affluent students in constructivist learning environments similarly valued agency, motivation and higher education as necessary for success. Perhaps school and family values influenced student views in this case as well. Future research incorporating a more explicit class-based analysis would add depth and clarity to this pattern, as it was beyond the scope of this study to explicitly address students' class backgrounds.

Students' inclusive verbal representations of potential scientists and engineers also contrasted to their predominant depiction of scientists and engineers in their M-MDAST(E) drawings as light-skinned males. Given the values of inclusivity expressed by both teachers and made visible in the classroom and school environments—through texts showing STEM professionals from diverse backgrounds and posters expressing values of respect and equality—the classroom context arguably mediated students' representations. However, this did not lead to many students actively acknowledging, or refuting, common race and gender stereotypes in STEM. Julia's statement that "some people" think that only "White people" could be scientists (UE3005.OctIn), or Ruthie's statement that people "used to think" that girls were not as smart (UE4008.OctIn) were notable exceptions. A closer examination of how these students affiliated with the characteristics they identified with scientists and engineers might lend greater complexity to students' general inclusive statements. As Heidi Carlone and other critical scholars (2011) have shown, examining students' (dis)identification with the normative image of a "smart science person" can reveal how dominant cultural messages may continue to be reproduced in reform-based classrooms.

Drawings made by students in this study demonstrated multiple aspects of dominant representations of scientists and engineers discussed in previous research (e.g. Capobianco et al., 2011; Chambers, 1983; Walls, 2012). Most E1 students represented scientists as solitary males in a laboratory with chemicals, though engineers showed more gender and scene variation. E2 students drew more portraits of their figures without putting them in a particular work environment; however, these were over 50% male and light-skinned. Students' scientist representations corresponded to a common stereotype, "the Standard Image" found in advertising and media (Chambers, 1983, p.259). This image was elicited in the classic Draw-a-Scientist Test by David Wade Chambers (1983) as contributing to student perceptions that science is a field belonging to White men and practiced indoors. Chambers (1983) argued this representation becomes more common as students grow older, although it was less common among my E2 sample than E1 sample.

Capobianco and colleagues (2011) also noted a dominant representation of engineers in their sample: “mechanics,” who were male (58%) and worked indoors (p.318). Only 18% of students in their study depicted identifiably female engineers; moreover, female students mostly drew female characters, a pattern I also observed with this student sample. Walls (2012) found that while African-American third-graders in his study depicted themselves or other people of color in their drawings, 68% drew male scientists. Furthermore, when selecting photographic images of people whom they thought most likely to be real scientists, 73% chose men and 35% of students chose White people. Walls (2012) suggests that students in his sample held “dichotomous” views of scientists in their minds: stereotypical conceptions that reflected mostly White males and less stereotypical conceptions that might symbolize their aspirations about who “can be” a scientist (Walls, 2012, p. 27).

In this majority White female sample, students had a more inclusive linguistic representation of who “can be” a scientist than their drawings showed, although it is true that they represented a higher percentage of scientists and engineers of color than existed in their classrooms. White students intentionally represented people of color, and students of color represented scientists and engineers with skin colors dissimilar to their own. However, few students I talked to readily ascribed an ethnic or racial identifier to their drawings, expressing hesitation around this topic. As Banks and Maixner (2016) point out, color-blind racism in Montessori school communities can help perpetuate inequality even in classroom environments where teachers intentionally espouse a whole-child approach. Thus, I believe further research on Montessori students' views on race and bias is warranted, both with regards to STEM and in general.

Overall, while their drawings suggested a deeply embedded stereotype of STEM professions as more masculine and indoors—or, alternatively, that students believe this is what "real" scientists and engineers are like—students' verbal interviews demonstrated the belief that "anyone" could be a scientist or engineer. E1 students expressed inclusive and agentive characterizations of scientists and engineers. E2 students viewed S-T-E-M as part of universal human ways of thinking, and drew scientists and engineers as people in everyday attire. The students I interviewed did not talk about STEM activities as related to "girls," "boys," "rich" or "White people" work unless to mention what they knew "some people" thought these things, and they themselves disagreed. Conversely, Archer and colleagues (2010) explained that upper elementary students in their study distinguished between "doing" science, which almost everyone enjoyed, and "being" a scientist, which children were beginning to see as a career accessible only to a few and tied to aspects of identity such as gender, ethnicity, and social class (p.621). While I did not explicitly question students about personal interest in STEM professions, two students of color, Tuna and Jake, volunteered that they were. Elexor also identified herself as "the most engineering-ist" of her friends, but asserted that most people were "kind of" engineers (UE3002.OctIn). Thus, while I observed echoes of Chambers' (1983) Standard Image in this sample of elementary students, the finding that Montessori students in this study appeared to hold the view that all people have potential to be STEM professionals—a stated goal of STEM education and science education reform (Honey et al., 2014)—invites further investigation.

What does it mean to do S-T-E-M? A contextually mediated view that STEM can happen everywhere. The Montessori elementary children in this study expressed universal, connected, and creative characterizations of S-T-E-M activities in their STEMQ and interview responses. Across cases, I claim these Montessori elementary students were developing STEM sense making frameworks creatively linking classroom experiences with everyday life activities. Even if they saw the term "STEM" as a mysterious acronym, their understandings echoed researchers' ideal characterizations of STEM. This suggests two things: first, the Montessori classroom context influenced students' characterizations in ways that implicitly aligned with mainstream best practices. Second, even if they were not sure what professional STEM work was like, students in a Montessori environment sought to bridge their school experiences with real-world situations in which they might apply the forms of "problem-solving" they identified as STEM activity (e.g. UE2103.OctIn, UE3005.DecIn; UE5004.DecIn).

As the students who characterized their own classroom as an example of integrated STEM pointed out, Montessori classrooms in general, not just in STEM lessons, are places for S-T-E-M activity. Thus, what it meant to "do S-T-E-M" was connected to what students did in school all the time. Indeed, several elements in the E1 and E2 classroom environments have been shown in previous research to support STEM teaching and learning. E2 students discussed investigating with peers in science and engineering activities, and I observed a high degree of collaboration in E1 Montessori math activities

(Field notes, February 13, 2017). Elkin and colleagues (2014), Ibes and Ng (2011) and Rinke and colleagues (2013) all note that the collaborative learning environment in Montessori elementary classrooms can be leveraged for successful STEM integration and inquiry science. These same elements were present in students' reports in my case as well.

When students talked about doing science or engineering, or using technology and math, they recalled memorable lessons both in and outside of the STEM series I observed, as well as everyday classroom activities or use of devices, toys, and kits at home. Similar to findings by Murphy and colleagues (2010), who also asked elementary students, "What is science? What do scientists do?" students in my sample enjoyed hands-on investigations and experimentation and were more detailed in their responses about these activities than other types. Hands-on investigations also ideally characterize integrated STEM incorporating scientific inquiry and engineering design (Stohlmann et al., 2012), although in this case students' projects were driven less by content standards and more by personal interest.

The claim that S-T-E-M integration took place in the context of students' activity outside of STEM lessons is also supported by Montessori practitioner reflections. John McNamara (2016), a Montessori teacher for 44 years, provided examples of integration in his classroom in *The NAMTA Journal*, a Montessori teacher publication. Rather than the curriculum and lessons, he talked about the role of the Montessori prepared environment itself in facilitating disciplinary integration. He stated,

> When I asked students to give practical examples of how math, science, technology, and the environment are integrated in the prepared environment they

> gave a number of examples. They also pointed out that they don't stop and ask themselves whether they are doing math or science. The students said that most of the projects and activities they get involved in on their own revolve around themselves and their environment [such as the garden, the weather, their own bodies, and work with Montessori materials]. When the day is not scheduled and allows uninterrupted periods of time for thought, observation, and daydreaming, students end up asking many questions. (Mcnamara, 2016, pp. 90–94)

McNamara (2016) reported that integration is happening, but in his students' views it occurred less through intentional connections made by teachers and more as a result of their own activity. The E2 students in my study who explained, "We don't call it science" spoke to McNamara's reflections. McNamara's class did not have additional STEM lessons, which supports students' views that being part of a Montessori classroom involves integrating aspects of STEM. As Jordi wrote of integrated science, technology, engineering and math in his STEMQ1: "It is what we use as a community in our day-to-day lives" (UE6101.Sep). Integrated Montessori STEM lessons thus enhance what is already there.

Even though I did not assess students' STEM characterizations against a priori definitions of STEM in my analysis, it is worth mentioning parallels to the literature. As Bybee (2013) points out, as yet there is no common understanding of "STEM". No single model exists for STEM integration (Kelley & Knowles, 2016), and STEM education reform has been largely top-down (Johnson, 2013). Research on student views of STEM is currently limited, but one study suggests that elementary children both acknowledge consensus definitions and construct their own understandings of the definition and purpose of STEM in the context of intentional integration experiences (Amherst H. Wilder Foundation, 2016). This author found that fifth-grade students' definitions of

STEM were drawn from their experiences in informal integrated STEM programs and corresponded to how students in my study defined this term: an acronym for Science, Technology, Engineering and Math (Amherst H. Wilder Foundation, 2016). Thus, previous research suggests that young children would not necessarily be familiar with STEM outside of an educational context—a claim supported by the E2 theme *educational initiative*.

Within the literature in elementary and secondary education, models for integrated STEM are often driven by engineering design (Bybee, 2013; Kelley & Knowles, 2016; Stohlmann et al., 2012) Students in my study, like their teachers, distinguished STEM lessons from the Montessori science and math they did in the classroom. They often conflated "STEM" with the engineering-based lessons they had, as opposed to the integration they did on their own. Arguably, as Carrie suggested during member checking, this distinction may have been heightened by the presence of a more regular schedule of STEM lessons than in past years, and the introduction of additional tasks such as the STEMQ and MM-DAST(E). Nevertheless, students in E1 and E2 demonstrated characterizations of S-T-E-M that reformers consider desirable.

Rodger Bybee (2013) argued that the three goals of STEM education are "STEM literacy" for all; a twenty-first century workforce; and the identification and development of future STEM professionals and innovators (p. x). He defined STEM literacy as follows:

- knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues;
- understanding of the characteristic features of STEM disciplines as forms of

human knowledge, inquiry, and design;

- awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen. (Bybee, 2013, pp. x-xi)

Students in this study demonstrated several indicators of an emergent STEM literacy (Bybee, 2013). First, they provided examples of everyday problems in which STEM-related knowledge would be useful, although they were less specific about the role of evidence in explanations. Second, they commented on the utility of STEM to humans and humanity's role in adding to STEM knowledge over time. Third, they demonstrated awareness of the contributions made by engineering and technology to the contemporary material environment; Jake and Jordi also offered commentary on how STEM disciplines intersect with power relations. Finally, students' comments about global warming and written responses regarding pollution suggest that they are concerned about the environmental impacts of STEM-related issues. While I did not intend to directly assess these Montessori students' STEM literacy in this study, this indicates that integrated STEM instruction in a Montessori classroom can be a potential context its development. This is another avenue for future research.

Students' characterizations of individual disciplines also aligned with consensus definitions in existing reports. For instance, in their agenda for research in K-12 STEM integration, Margaret Honey and colleagues (2014) offered consensus definitions of the four STEM disciplines, adapted from previous standards documents and recommendations from the National Research Council (2012). They defined science as "the study of the natural world," including the disciplines of "physics, chemistry and biology" and the "process—scientific inquiry—that generates new knowledge. Knowledge from science informs the engineering design process" (Honey et al., 2014, p.14). This definition corresponds to how students in my sample saw science as knowledge of the natural world and specialized activities like observation and experimentation, although they had a rather narrow view of what practices were considered scientific beyond those two. This is similar to what Rinke and colleagues (2013) found in their study of scientific inquiry in Montessori classrooms, where teachers asked more questions and provided explanations, while students had more opportunities for observation, collaboration, and hands-on work.

Honey and colleagues (2014) provided a broader definition of technology than the predominant electronic device-centered view students in this study expressed, but students who identified technology as used throughout history to meet human needs corresponded to the former definition. These students identified technology as "a product of science and engineering" and a few gave examples of microscopes as technical tools used by scientists (Honey et al., 2014, p.14). Students who pointed out the negative impacts of technology, like Jake and Jordi, displayed the type of perspective Kelly and Knowles (2016) termed the "humanities view": one which takes into account the ways that technology has impacted human social and environmental relations over time. While students' responses indicated they had regular access to digital technology at home, younger students in particular reported that they did not often use electronic devices in school, thus leading to their perception that they did not often use technology.

Honey and colleagues (2014) defined engineering as both a body of knowledge and a process for solving problems. However, students in this study often represented engineering as the physical process of building or creation, therefore including the act of fabrication itself within their characterizations of engineering. Capobianco and colleagues (2011) noted that most young children in their study viewed engineering as building, fixing or manufacturing, rather than a design process. While students in both classes had the opportunity to learn about the engineering design process and apply it in creative ways—thus leading to an increased number of students who characterized it as problem solving, their responses suggest their knowledge of the EDP and what it could be used for did not necessarily represent a definition of engineering as "design under constraint [using] concepts in science and mathematics as well as technological tools" (Honey et al., 2014, p.14). Instead, students in this study conflated engineering and integrated STEM simply as ways to solve problems. Thus, future efforts in integrated STEM instruction in Montessori classrooms could be directed at broadening students' understanding of engineering.

Students in this study understood mathematics as the study of numbers and arithmetic procedures, and a few identified its potential applications in other STEM fields (both attributes cited by Honey et al., 2014). On the whole, however, they had more difficulty identifying precisely how mathematics fit in to their characterizations of STEM. By contrast, Stohlmann et al. (2012) indicated that students in integrated STEM environments should have ample opportunities to apply mathematical practices and thinking in the context of meaningful data collection activities. While students increasingly described everyday uses of math beyond their typical school arithmetic activities, only a few offered examples for how different forms of measurement might be helpful for scientific or engineering purposes. Thus, their view of math was narrower than that expressed by Honey and colleagues (2014), possibly correlated to their limited exposure to the full range of conceptual categories in K-12 mathematics.

Students' views of engineering as a problem solving process, and indeed their view of STEM as a way to solve problems using math, science, and technology all together with the goal of enhancing understanding, were similar to what Kelley and Knowles (2016) discussed as integrated STEM in a secondary context: "an approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purposes of connecting these subjects to enhance student learning" (p.2). For these students, specific content mastery was not a stated goal, but many viewed STEM as a way to understand the world. Thus, Montessori students in E1 and E2 in this study expressed characterizations, particularly of science and engineering, that correspond substantially to those advanced by educational researchers and in policy documents. However, this brief comparison between them also suggests that Montessori STEM could be further enhanced by more opportunities for inquiry and iterative design under constraint. I explore these ideas in my implications for practice.

It is worth mentioning students' perceptions regarding the frequency of classroom STEM activities. While they recognized that STEM was potentially everywhere, students' responses indicated that, except for math, they did not view engaging in science, engineering, and technology activities as being a regular practice in their classroom. However, because E2 children especially included geography, geometry, and other disciplines within an overarching broad view of science, they could sometimes make the claim that "everything" they were doing was STEM-related.

Like the students in Walls' (2012) study, Montessori E1 and E2 children in this study discussed doing science and engineering at home and at school; in some cases, they felt it was an activity they did more often at home. Others, like Ruthie, noted they had friends who participated in after-school engineering clubs, which previous research suggests is important in developing positive associations with STEM fields (Calabrese Barton et al., 2012). Both male and female, and three out of four students of color I interviewed, described science experiments or engineering activities they did with toys and kits, a stance that Archer and colleagues (2010) identified as characteristic of their middle-class subjects. While Archer et al. (2010) described this form of engagement as "proper" experimentation linked to "good" and "safe" school science (p.627), Tuna, Elexor, Jake, and Courtney talked about their home explorations in a more open-ended fashion. They linked the toys and kits to what they learned in school, like the engineering design process, but described their home STEM explorations as less structured and more creative than what took place in the classroom.

Archer and colleagues (2010) also found a perception amongst the students they interviewed that science in school as made "safe" by teachers and therefore less attractive, whereas real science was "dangerous" (p.627). Students in this study also expressed concerns about danger, but did so differently. Julia talked about but decided not to perform an experiment with dry ice due to her perception that it could be dangerous for others. Yet she explained that she and her friend made the decision not to carry out the experiment, rather than being told by a teacher. While Max claimed his scientist needed safety glasses in case he was handling a poisonous potion, his was the only mention of concerns about personal safety in regards to science. More students, like Jake and other E2 respondents in the STEMQ, expressed concern about the potentially inhumane applications of engineering and technology and their deleterious effects on the Earth and other species. Thus, danger in STEM was oriented around students' concern for others, a principle advanced in Montessori's cosmic education curriculum (Montessori, 2007). Future research could examine in greater depth how cosmic education and Montessori values, such as respect and concern for community and environment, interface with children's ideas about "what counts" as STEM and what it means to "be scientific" or involved in STEM (Carlone et al., 2011).

Students' comments about STEM activities outside of school suggest that they saw the STEM disciplines as relevant or connected to their daily lives; the connections they made were often imaginative (e.g. Elexor, Ruthie) and involved play (e.g. Ruthie, Julia, Jake, Courtney) or speculation on how STEM might aid in problem solving (e.g. Max, Tuna, Courtney). Certainly, small everyday engagements with play could contribute to fostering increased engagement in a private school population where students already enjoy increased cultural capital, as Archer and colleagues (2010) suggested. However, Montessori communities emphasize the values of respect for people and the environment (Polk Lillard, 1996), and it is possible that this aspect of the learning culture also influenced students' characterizations. This came out more strongly in students' responses about the purpose of STEM, which also offered another perspective on their view that S-T-E-M integration in their daily lives was distinct from STEM lessons.

Why STEM? A helpful educational initiative for humans, but potentially negative consequences for Earth. As I have hoped to suggest thus far, the Montessori environment itself offers a foundation for integrated STEM instruction that can be further enhanced. Honey and colleagues (2014) identified two major purposes of STEM education: workforce development and scientific and technological literacy. While E1 students did not often discuss jobs in their responses regarding integrated STEM, more E2 students commented that STEM was important for success in future work and careers. Both E1 and E2 students viewed STEM as a way to learn more about the world that is useful for daily life, an attitude that suggests they saw the purpose of STEM as scientific and technological literacy. However, older E2 students also were critical in their distinction between STEM being a type of lesson that was important for school and work, as opposed to the forms of everyday integration that they might use in daily life.

Students in E2 also made multiple statements about the positive and negative aspects of STEM. Jake and Jordi, in particular, commented extensively on the misuse of STEM knowledge by greedy or power-hungry people, and Elexor, Courtney, Max and Tuna all discussed negative outcomes of STEM through their examples of increased pollution. While they recognized the benefits to human societies, these students expressed ambivalence about whether STEM was helpful to the Earth. I interpret these trends as indicating an increasingly critical characterization of STEM as something that might not be intrinsically positive for all, despite its ubiquity in contemporary life. This characterization speaks to the fact that these students may share some researchers' concerns regarding the "STEM-ification" of science education (e.g. Carter, 2016), namely the celebration of technoscientism at the expense of examining the negative outcomes of STEM (e.g. Zeidler, 2016). Given that this critical perspective was not the primary focus of my study, further research on this aspect is warranted, especially in relationship to the moral aims of Montessori education (Lillard, 2007; Montessori, 2000).

Lessons Learned

Stake (1995) notes that instrumental case studies involve research on a case "to gain understanding of something else" (p.172). Thus, my selection of student STEM characterizations also illuminates a larger issue in science education: conceptualizing integrated STEM at the elementary level. This case study is a unique encounter (Stake, 1995). First and foremost I sought to understand students' characterizations of STEM on their own terms, rather than as evidence of misconceptions or inaccurate knowledge (see Walls, 2012). While I examined stereotypes and normative definitions in this chapter, it was my overall goal to document students' evolving constructions within their learning context. I cannot generalize the meanings developed and discussed by the children I interviewed, as these are situated in the configuration of their unique learning context, social interactions, and individual backgrounds. However, I do believe that their characterizations have something to teach other educators and researchers working to make their own sense of a top-down reform.

Thus far, I have demonstrated how, in the context of integrated STEM instruction, students in two Montessori environments constructed characterizations corresponding both to aspects of consensus definitions of disciplines, and the purpose of integrated STEM as communicated in national research reports (e.g. Honey et al., 2014). In Vygotsky's (1978) terms, their "bottom up" experiential understandings showed evidence of alignment and integration with the "top-down" abstractions communicated by teachers and discussed in the language of aforementioned documents. However, some older students also expressed a critical awareness of STEM as an educational initiative, extending E1 students' view of this mysterious acronym to acknowledge it was a term developed by adults and "job people" to promise school and work success (UE6026.Nov). This suggests that students distinguished the ways of knowing and activities that involved schooling and those they undertook subconsciously in their daily lives. As Jordi explained, "STEM" was different from "science-technology-engineering-mathematics" (UE6101.DecIn). The lesson here is to consider how much of STEM reform really is *for* students in the here and now, and to think about how to present the idea of integrated or interdisciplinary education in elementary contexts where students are already making their own connections.

Students in this study also demonstrated an expanded sense of the moral responsibilities they attached to STEM activities. While they recognized that STEM helped people get good jobs and was useful in everyday life, many felt that it was not intrinsically positive for the Earth. The lesson here is that a focus on STEM as an economic competition engine and workforce development tool can miss some of students' legitimate concerns about the in/humane role of STEM as a transformative agent in global development. Alternatively, an uncritical depiction of STEM as a common human inheritance may in fact reify this view so that students think that STEM is *what* defines the contemporary world, rather than being one way of knowing among many. In the following implications for practice, I suggest leveraging this critical awareness and deepening existing understanding through expanded opportunities for hands-on group projects. In my implications for research, I suggest alternative study designs and sampling methods, as well as moving beyond correspondence with normative characterizations to examine students' identities and processes of negotiating with these norms.

Implications for Practice

Science: from "experimentation" to inquiry. E1 students' characterizations of science showed limited views of scientific practices, as almost exclusively experimentation and to a lesser extent, observation and using tools like microscopes. This was shown in their STEMQ, MM-DAST(E) and interviews. Given the emphasis on inquiry even for young children and Rinke and colleagues' (2013) finding that not all elements of inquiry are currently supported in Montessori classrooms, I recommend that future Montessori STEM efforts expand opportunities for students to engage in a wider range of scientific practices such as asking questions, and identifying and using evidence. Similarly, E2 students' universal perspective on science demonstrated an encompassing scientific worldview, but students did not often identify individual practices beyond studying and observation of natural phenomena and model construction. While students carried out investigations during their lessons and were engaged and motivated by working with peers, future Montessori STEM integration could provide both lower and upper elementary students with more structured opportunities to gain competence in the full range of scientific practices in the course of independent STEM investigations.

Literature informing my study has sought to address the "nature of" complex social constructed concepts such as science by comparing the views of research participants against an *a priori* consensus list of attributes of, for example, the Nature of Science (e.g. Lederman & Ko, 2004; Murphy et al., 2011; Walls, 2012). Most previous research on NoS suggests that an explicit teaching approach is most effective in producing more informed NoS views (Lederman et al., 2002). There was no explicit NoS instruction in this Montessori classroom. However, as Murphy and colleagues (2010) point out, students who received explicit NoS instruction did expand their ideas about scientific practices. Incorporating more NoS instruction into Montessori STEM might be one way to help students expand their repertoire of scientific practices; explicit opportunities for scientific inquiry by adapting reform-based science teaching methods (Carlone et al., 2011) to the Montessori context could be another.

Engineering: opportunities for hands-on, product-oriented learning. The Montessori elementary students in this study remembered STEM lessons in which they engaged in hands-on work with materials and got to build or create; however, they did not consider these experiences to be a regular part of their classroom activities. I recommend that, given that these activities appeared to be motivating and memorable for students, within the constraints of the schedule, Montessori teachers working to integrate STEM should intentionally balance informational presentations and opportunities for hands-on follow-up, particularly with engineering lessons. Aside from developing their knowledge of engineering as a social problem-solving process by using the EDP to address classroom logistical challenges, E1 students might benefit from opportunities to use the EDP for product design and creation for a client, rather just than in building challenges (Stohlmann et al., 2012).

Similarly, E2 students characterized engineering as designing creative products but did not discuss the iterative nature or the purpose of engineering work, nor the use of design constraints influencing the design process (Lachapelle & Cunningham, 2014). Providing further opportunities for problem solving in "real-world contexts" beyond the immediate social environment of the classroom might bring greater awareness to the types of complex problems engineering takes on (Stohlmann et al., 2012). Students already had a sense of the creativity and teamwork that are important to engineering and also acknowledged the trade-offs that occur when engineering and technological development adversely affect the environment; thus, opportunities to further extend their learning in real-world contexts would likely be motivating, as demonstrated in the case of the pollination problem in China.

STEM beyond general inclusivity. I recommend that Montessori teachers continue to provide diverse role models and images of STEM workers, and that they explicitly discuss bias and stereotypes associated with STEM. Both E1 and E2 students identified general connections between STEM disciplines and demonstrated understanding of how STEM could be connected to their daily lives, but continued to represent scientists and engineers in stereotypical ways despite stating that anyone could enter a STEM career. Montessori teachers should continue to support a "STEM for all" mentality, while also explicitly addressing students' concerns about stereotypes and making them known.

In the same vein, students expressed a universal characterization of science and engineering as important to all of humanity. While some suggested that different people might "think differently" about different STEM fields, they did not elaborate on the geographical, historical, or sociopolitical particulars of what a more pluralistic view of STEM might entail. Future work in Montessori STEM integration could build on Atwater's (1996) insights regarding the role of power in science learning, and complement existing multicultural education practices in Montessori schools. This work would support Montessorian values of respect for the contributions of others (Ibes & Ng, 2011, Polk Lillard, 1996), while supporting current efforts to bring an explicit social justice perspective into Montessori schools (Banks & Maixner, 2016).

Implications for Research

Characteristic features of Montessori schools, such as hands-on inquiry, collaborative learning, differentiated instruction, and the cultivation of caring relationships, have been shown to support learners (Honey et al., 2014, Lillard, 2007, Rinke et al., 2013) and correspond to best practices in integrated STEM education (Stohlmann et al., 2012). Despite a history of elitism on the periphery of mainstream educational approaches, Montessori schools are becoming more accessible and relevant (Whitescarver & Cossentino, 2008). Therefore, I argue that my study supports future research into a variety of Montessori school environments as a meaningful context to further explore and develop integrated elementary STEM education. Based on findings from my exploratory small-scale study, I offer the following recommendations for future research including methodological, sampling, and theoretical/topical considerations.

A more extensive multi-instrumental approach. Bonnie Shapiro (1994) used written questionnaires, drawings, and interviews to compile lengthy lists of students' "personal constructs regarding science learning", which could include statements such as: "You know what you're doing and can do it; Just writing down the answer; Hard work; [or] Working on your worksheet" (e.g. Shapiro, 1994, p.97). She also videotaped the students attempting learning tasks and talked to them about their actions and reasoning process, in order to document how students' ideas evolved over time. Walls (2012) also used multiple instruments to help better distinguish children's aspirational views of scientists from their views of real-life professionals. Given the constraints of time and access for my study, it was not possible to collect these additional data sources. However, such methodological insight would be a valuable addition to future studies, especially given alternative contexts and sampling approaches as described below.

Comparison between Montessori STEM and non-STEM Montessori environments. This study was conducted in two classrooms where both teachers had participated in extended STEM training. Findings demonstrate that students' experiences in STEM lessons played a role in their characterizations, but also suggest that many elements of STEM thinking and pedagogy are already present in the Montessori environment. A comparative study examining a classroom in which teachers have STEM training with one where teachers do not, might shed light on what Montessori STEM brings to the Montessori curriculum and student understandings of STEM.

Increased diversity of student sample. This study was conducted in an independent school with a relatively homogeneous population in terms of racial and socioeconomic diversity. Thus, it is difficult to separate the entanglement between students' general statements about inclusivity but hesitancy to talk about race; the stereotypical images that existed in their drawings; and their own STEM identities. It would be worth administering these tasks with a larger and more heterogeneous sample.

Longitudinal study. While I did not set up my analysis to carefully track change over time, a more intentional longitudinal analysis (e.g. Calabrese Barton et al., 2012; Carlone, 2012) would provide better information on how students' characterizations evolve over the course of three years in the same classroom. My analysis did not show substantial differences in characterizations between second and third-year students, or fifth and sixth years; however, I examined a relatively short time period and students often discussed recent events; therefore, it is unclear how much of students' experiences from previous years informed their current characterizations—unless they explicitly stated as such.

Aside from these sampling and contextual considerations, findings from this thesis suggest two other directions for future research. The first more explicitly examines the influence of cosmic education in Montessori student identities, and the second expands upon the nascent critical characterizations of STEM I observed in older elementary students.

Cosmic perspective. This study provided implicit evidence of a link between students' characterizations and the principles of cosmic education such as gratitude for all beings, a broad interdisciplinary approach to knowledge of the world, and a historical dimension of STEM knowledge (Ibes & Ng, 2011; MacDonald, 2008). While the study was not originally designed to explicitly analyze the relationship between STEM and cosmic education tenets in depth, future research into areas of complementarity, divergence, or potential enhancement would be of interest to the Montessori community as well as educational researchers. Finally, the comments by students questioning the purpose of STEM, reminding me about the devastating effects of global warming and illegal pipelines, reminded me how much passion and insight young people bring to their learning. Future research could investigate this critical aspect of students' thinking and their evaluations of STEM, perhaps working with young people themselves to co-construct opportunities where they can use their knowledge to make a positive impact.

Conclusion

This multiple instrumental case study offered an exploration of elementary students' characterization of STEM in an alternative school environment: two Montessori classrooms in which students experienced integrated STEM instruction. While they recognized that "STEM" can be read as a mysterious acronym or a top-down educational initiative, I demonstrated that these elementary students are engaged in the process of constructing their own bottom-up understanding of STEM through their classroom experiences, social ties, and outside of school pursuits; thus, each individual's characterization is constructed within their wider social context. In E1, this understanding is inclusive, connected, helpful and agentive. In E2, this understanding is universal, connected, creative and increasingly critical. Complementarity between these characterizations and aims identified by STEM integration experts suggests that

Montessori classrooms are appropriate contexts for further research in elementary STEM integration, and that their critical and moral perspectives on STEM offer a promising space for future inquiry into identity development and the potential role of a cosmic education perspective in transforming STEM integration.

References

American Montessori Society. (2017). Introduction to Montessori Method. Retrieved from https://amshq.org/Montessori-Education/Introduction-to-Montessori

Amherst H. Wilder Foundation. (2016). *STEM Pathways small group interview findings*. St. Paul, MN.

Anyon, J. (1980). Social class and the hidden curriculum of work. *Journal of Education*, *162*(1), 1–13.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2010). "Doing" Science Versus "Being" a Scientist: Examining 10/11-Year-Old Schoolchildren's Constructions of Science Through the Lens of Identity. *Science Education*, *94*(4), 617–639. Retrieved from 10.1002/sce.20399

Aschbacher, P. R., Li, E., & Roth, E. J. (2009). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564–582. http://doi.org/10.1002/tea.20353

Association Montessori Internationale. (2016a). Association Montessori Internationale global presence. Retrieved April 26, 2017, from http://ami-global.org/ami/what-is-ami/global-presence

Association Montessori Internationale. (2016b). Biography of Dr. Maria Montessori. Retrieved April 26, 2017, from http://ami-global.org/montessori/biography-dr-maria-montessori

Atwater, M. M. (1996). Social Constructivism: Infusion into the multicultural science education research agenda. *Journal of Research in Science Teaching*, *33*(8), 821–837.

Banks, K. H., & Maixner, R. A. (2016). Social justice education in an urban charter Montessori school. *Journal of Montessori Research*, *2*(2), 1–14.

Bryan, L. A., & Atwater, M. M. (2002). Teacher beliefs and cultural models: A challenge for science teacher preparation programs. *Science Education*, *86*(6), 821–839. http://doi.org/10.1002/sce.10043

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. Arlington, VA: NSTA Press.

Calabrese Barton, A., Kang, H., Tan, E., O'Neill, T. B., Bautista-Guerra, J., & Brecklin, C. (2012). Crafting a Future in Science: Tracing Middle School Girls' Identity Work Over Time and Space. *American Educational Research Journal*, *50*(1), 37–75. http://doi.org/10.3102/0002831212458142

Capobianco, B. M., Diefes-Dux, H. A., Mena, I., & Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering ducation. *Journal of Engineering Education*, *100*(2), 304–328.

Carlone, H. (2012). Methodological considerations for studying identities in school science: an anthropological approach. In M. Varelas (Ed.), *Identity Construction and Science Education Research* (pp. 9–25). Rotterdam: SensePublishers.

Carlone, H., Haun-Frank, J., & Webb, A. (2011). Assessing equity beyond knowledge- and skills-based outcomes: A comparative ethnography of two fourth-grade reform-

based science classrooms. *Journal of Research in Science Teaching*, *48*(5), 459–485. http://doi.org/10.1002/tea.20413
Carlone, H., Scott, C. M., & Lowder, C. (2014). Becoming (less) scientific: A longitudinal study of students' identity work from elementary to middle school science. *Journal of Research in Science Teaching*, *51*(7), 836–869. http://doi.org/10.1002/tea.21150
Chambers, D. W. (1983). Stereotypic images of the scientist: The draw-a-scientist test. *Science Education*, *67*(2), 255–265.
Committee on Science and Technology. (2008). *STEM education before high school: shaping our future science, technology, engineering and math leaders of tomorrow by inspiring our children today*. Washington, D.C.: U.S. Government Printing Office.
Cossentino, J. (2005). Ritualizing expertise : A non-Montessorian view of the Montessori method. *American Journal of Education*, *111*, 211–244. http://doi.org/10.1086/426838
Cotabish, A., Robinson, A., Dailey, D., & Hughes, G. (2013). The Effects of a STEM Intervention on Elementary Students ' Science Knowledge and Skills. *School Science and Mathematics*, *113*(5), 215–226.
Crotty, M. (1998). Constructionism: the making of meaning. In *The Foundations of Social Research: Meaning and Perspective in the Research Process* (pp. 42–66). Thousand Oaks, CA: SAGE Publications, Inc.
Daugherty, M. K., Carter, V., & Swagerty, L. (2014). Elementary STEM education: The future for technology and engineering education? *Journal of STEM Teacher Education*, *49*(1), 45–55.
Debs, M. C., & Brown, K. E. (2017). Students of color and public Montessori schools: A review of the literature. *Journal of Montessori Research*, *3*(1), 1–15.
Dohrmann, K. R., Nishida, T. K., Gartner, A., Lipsky, D. K., & Grimm, K. J. (2007). High school outcomes for students in a public Montessori program. *Journal of Research in Childhood Education*, *22*(2), 205–217. http://doi.org/10.1080/02568540709594622
Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: learning and teaching science in grades K-8*. Washington, D.C.: National Academies Press.
Elkin, M., Sullivan, A., & Bers, M. U. (2014). Implementing a robotics curriculum in an early childhood Montessori classroom. *Journal of Information Technology Education: Innovations in Practice*, *13*, 153–169.
Elkind, D. (1967). Piaget and Montessori. *Harvard Educational Review*, *37*(4), 535–546. http://doi.org/http://dx.doi.org/10.17763/haer.37.4.n60v725054564376
Ernest, P. (2010). Reflections on theories of learning. In B. Sriraman & L. English (Eds.), *Theories of Mathematics Education: Seeking New Frontiers* (pp. 39–48). New York, NY: Springer Books.
Fosnot, C. T., & Perry, R. S. (2005). Constructivism: A psychological theory of learning. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (pp. 8–38). New York, NY: Teachers College Press.

Glasersfeld, E. Von. (2005). Introduction: Aspects of constructivism. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (pp. 3–7). New York, NY: Teachers College Press.

Glenn, C. M. (2000). *Montessori longitudinal assessment study: Eighteen year follow-up*. Portland, OR.

Hainstock, E. (1986). *The essential Montessori*. New York, NY: New American Library.

Hamilton, L., & Corbett-Whittier, C. (2014). *Using case study in education research*. London: SAGE Publications, Inc. http://doi.org/http://dx.doi.org/10.4135/9781473913851

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. (M. Honey, G. Pearson, & H. Schweingruber, Eds.). Washington, D.C.: The National Academies Press. Retrieved from www.nap.edu

Ibes, C. F., & Ng, Y. (2011). Engineering in a Montessori environment. In *AC 2011-1775*. American Society for Engineering Education.

Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science and Mathematics*, *113*(8), 367–368.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(11), 1–11. http://doi.org/10.1186/s40594-016-0046-z

Kier, M. W., Blanchard, M. R., Osborne, J. W., & Albert, J. L. (2014). The development of the STEM career interest survey (STEM-CIS). *Research in Science Education*, *44*(3), 461–481. http://doi.org/10.1007/s11165-013-9389-3

Lachapelle, C. P., & Cunningham, C. R. (2014). Designing engineering experiences to engage all students. In S. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices* (pp. 117–140). West Lafayette, IN: Purdue University Press.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521. http://doi.org/10.1002/tea.10034

Lederman, N. G., & Ko, E. (2004). Views of nature of science elementary version, Form E (VNOS-E). Chicago: Illinois Insitute of Technology. Retrieved from http://www.csss-science.org/downloads/VNOS_E.pdf

Lillard, A. (2007). *Montessori: The science behind the genius*. New York: Oxford University Press.

Lillard, A. (2012). Preschool children's development in classic Montessori, supplemented Montessori, and conventional programs. *Journal of School Psychology*, *50*(3), 379–401. http://doi.org/10.1016/j.jsp.2012.01.001

Lillard, A., & Else-quest, N. (2006). Evaluating Montessori education. *Science, New Series*, *313*(5795), 1893–1894.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: SAGE Publications, Inc.

Lopata, C., Wallace, N. V., & Finn, K. V. (2005). Comparison of academic achievement

between Montessori and traditional education programs. *Journal of Research in Childhood Education*, *20*(1), 5–13. http://doi.org/10.1080/02568540509594546
MacDonald, G. (2008). The unity of cosmic education: Integrating the subject areas through a synthetic view of the natural world. *The NAMTA Journal*, *33*(3), 4–7.
McNamara, J. (2016). How the Montessori upper elementary and adolescent environment naturally integrates science, mathematics, technology and the environment. *The NAMTA Journal*, *41*(2), 83–97.
Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco: Jossey-Bass Publishers.
Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook*. Thousand Oaks, CA: SAGE Publications, Inc.
Montessori, M. (1965). *The advanced Montessori method, Vol. II: The Montessori elementary material*. Cambridge, MA: Robert Bentley Inc.
Montessori, M. (2000). *The Montessori method*. Ridgefield, CT: Roger A. McCaffrey Publishing.
Montessori, M. (2007). *To educate the human potential*. Amsterdam, the Netherlands: Montessori-Pierson Publishing Co.
Murphy, C., Murphy, C., & Kilfeather, P. (2011). Children making sense of science. *Research in Science Education*, *41*, 283–298. http://doi.org/10.1007/s11165-010-9165-6
National Center for Montessori in the Public Sector. (2017). About Montessori schools. Retrieved April 26, 2017, from https://www.public-montessori.org/montessori/#schools
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, D.C.
NGSS Lead States. (2013). Next generation science standards: For states, by states. Retrieved April 27, 2017, from https://www.nextgenscience.org
Plano Clark, V., & Creswell, J. (2010). *Understanding research: A consumer's guide*. Thousand Oaks, CA: SAGE Publications, Inc.
Polk Lillard, P. (1996). *Montessori today: A comprehensive approach to education from birth to adulthood*. New York: Schocken Books.
Rathunde, K., & Csikszentmihalyi, M. (2005). Middle School Students' Motivation and Quality of Experience: A Comparison of Montessori and Traditional School Environments. *American Journal of Education*, *111*(3), 341–371. http://doi.org/10.1086/428885
Renton, A. (2002). Cosmic education: A multicultural perspective. *Montessori Life*, (Spring), 45–48.
Rinke, C. R., Gimbel, S. J., & Haskell, S. (2013). Opportunities for inquiry science in Montessori classrooms: Learning from a culture of interest, communication, and explanation. *Research in Science Education*, *43*(4), 1517–1533. http://doi.org/10.1007/s11165-012-9319-9
Saldaña, J. (2016). *The coding manual for qualitative researchers*. London: SAGE Publications, Inc.
Scott, P., Asoko, H., & Leach, J. (2007). Student conceptions and conceptual learning in

science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 31–56). Mahwah, NJ: Lawrence Erlbaum Associates.

Shapiro, B. (1994). *What children bring to light*. New York, NY: Teachers College Press.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: SAGE Publications, Inc.

Stephenson, S. M. (2015). Cosmic education: The child's discovery of a global vision and a cosmic task. *The NAMTA Journal*, *40*(2), 150–163.

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28–34. http://doi.org/10.5703/1288284314653

Taber, K. S. (2006). Constructivism's new clothes: the trivial, the contingent, and a progressive research programme into the learning of science. *Foundations of Chemistry*, (8), 189–219. http://doi.org/10.1007/s10698-005-4536-1

Tippins, D., Tobin, K., & Nichols, S. (1995). A Constructivist Approach to Change in Elementary Science Teaching and Learning, *25*(2), 135–149.

Trudeau, C. M. (2002). The emergence of cosmic education. *Montessori Life*, (Spring), 24–28.

Vygotsky, L. S. (1978). Interaction between learning and development. In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in Society: The Development of Higher Psychological Processes* (pp. 79–91). Cambridge, MA: Harvard University Press.

Walls, L. (2012). Third grade African American students' views of the nature of science. *Journal of Research in Science Teaching*, *49*(1), 1–37. http://doi.org/10.1002/tea.20450

Walls, L., Buck, G., & Akerson, V. (2013). Race, Culture, Gender, and Nature of Science in Elementary Settings. In J. A. Bianchini, V. L. Akerson, A. Calabrese Barton, O. Lee, & A. J. Rodriguez (Eds.), *Moving the Equity Agenda Forward SE - 9* (Vol. 5, pp. 131–151). Springer Netherlands. http://doi.org/10.1007/978-94-007-4467-7_9

Whitescarver, K., & Cossentino, J. (2008). Montessori and the mainstream: A century of reform on the margins. *Teachers College Record*, *110*(12), 2571–2600.

Yin, R. K. (2014). *Case study resarch: design and methods*. Thousand Oaks, CA: SAGE Publications, Inc.

Yoon, S. Y., Dyehouse, M., Lucietto, A. M., Diefes-Dux, H. A., & Capobianco, B. M. (2014). The effects of integrated science, technology, and engineering education on elementary students' knowledge and identity development. *School Science and Mathematics*, *114*(8), 380–391. Retrieved from https://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1046767&site=ehost-live%5Cnhttp://dx.doi.org/10.1111/ssm.12090

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education*, *11*, 11–26. http://doi.org/10.1007/s11422-014-9578-z

Appendix A: MM-DAST(E) Protocol

Note: *The original M-DAST protocol (provided to the PI by author Dr. Leon Walls, who gave permission for it to be used with Montessori students) was designed to be administered to third graders. Therefore, the protocol is adapted to meet the needs of this research project.*

1. Preparation:
The researcher will meet with the participating teachers to discuss MM-DAST(E) procedures. Half of the students in the class will be randomly selected to draw a scientist. Half of the students will be randomly selected to draw an engineer.

On a selected day, the teacher will gather the class for a short conversation and assign the MM-DAST(E) as a follow-up work. The teacher should not provide any guidance as to the gender, race, occupation, or location of the scientist, nor the activity in which that the scientist/engineer is engaged. If students ask about this, the teacher may tell them that they can put the scientist/engineer anywhere they imagine their character to be.

The teacher should have the following materials available:

- Blank sheets of letter-sized paper
- Colored Pencils (including a range of skin tones)
- Basket for finished drawings

2. Instruction:
Suggested Lesson Script (Lower Elementary):

> *This is a very small lesson, but with a very important follow-up. Raise your hand if you have heard of the word "scientist/engineer"* [acknowledge the number of responses, but do not probe further]. *This year, we will be discussing the work of scientists/engineers and their contributions to the human story. Before we begin, I am interested to know what you think about what scientists/engineers do and what they look like. I would like you all to show me with a drawing. Please use the materials to draw the picture you have in your head of a scientist/engineer. Each of you may have a different idea in your heads, so there is no correct or incorrect response. When you are finished with your drawings, you can give your scientist a name and provide a little story as to what your scientist is doing. Please write your name on the back of the paper now. Please do your best individual job on this work; we will talk about this as a class later.*

Lesson Script (Upper Elementary):

> *This year, we will be discussing the work of scientists/engineers and their contributions to the human story. Before we begin, I am interested in how you represent scientists/engineers. I'd like to give you the opportunity to express yourself through drawing. Please use the materials provided to draw the picture you have in your head of a scientist/engineer. Each of you may have a different*

idea in your heads, so there is no correct or incorrect response. This is an individual work; since you all have unique minds and brains, you should draw your own idea of what a scientist/engineer looks like. Imagine that you are creating a sort of character profile. Give your scientist/engineer a name. Imagine that your scientist is a real person; what short story could you tell about their life for someone that wanted to know? One thing: please write your names on the back of the paper.

Once all students have completed their drawings, the teacher will obscure student names with stickers with individual student codes and turn them into the PI. To reduce bias and maintain anonymity, the teacher will not pre-select any drawings. The researcher will identify any drawings that stand out and use these drawings in combination with STEMQ responses to select students for follow-up interviews.

3. Follow-up Interview Questions: (with the second half of the group, substitute the word **engineer** for **scientist**)

Eight students from each classroom will be selected for follow-up interviews (10-12 from each class should be identified as potential subjects in case not all students consent). Subjects will be sampled for maximum variation based on PI review of the questionnaire answers and M-MDAST(E) results from the entire dataset of each class. Selected students will ideally include 4 males, 4 females and 2-3 students from each grade level. However, 4 students must have drawn a scientist, and 4 must have drawn an engineer. A short time following her introduction to the class, first full-day observation, and administration of the questionnaires and M-MDAST(E), the PI will be invited to the classroom to talk to students. Here is a sample script.

Hello [students]; I haven't seen you for a little while, but your teachers have let me know about some of your recent activities. Thank you all so much for your hard work. I appreciate how honest and thorough you were in sharing your opinions. Your teacher and I have been using your responses to help us understand your views and prepare some exciting lessons for you this year. We were very interested in learning a little more about what you said and drew. Do you remember the follow-up assignment you had recently where drew a scientist or an engineer? I would like to be able to ask all of you about them, but unfortunately given time I can only ask a few folks. I will be working in your classroom all fall, so it's totally okay if you are not asked to participate. Remember, everything you do for this project is your choice, so if I ask you about being interviewed and you don't wish to participate, you can say so. I also want you to know that so I can remember exactly what you said, I will be recording your voice while we talk.

The PI will administer the following interview to each selected student during class time, in a quiet corner of the room with as few distractions as possible. This process may take several days. The interview will be audio-recorded. No student names will be used by the PI in the interviews. [see questions in following appendix].

Appendix B: STEM Questionnaire (STEMQ1/STEMQ2)

[EXTRA SPACES HAVE BEEN REMOVED]

Directions to students: *Write your answers to the following questions. This is an individual work. Please write clearly so that you can communicate effectively, but no need to worry about spelling or perfect sentences! There are no correct or incorrect answers to these questions; we want to know what you think.*

What is science?

Do you do science in your classroom?

What do you do?

What is technology?

How do humans use technology?

How do you use technology?

What is engineering?

Do you do engineering in your classroom?

What do you do?

What is math?

How do humans use math?

How do you use math?

Can you think of an example of people using science, technology, engineering and math all together?

Think of math, science, engineering, and technology. Which of these do you like? For your answer, tell why (or why not)?

Why might people think STEM (science, technology, engineering and math) is important?

STEMQ2 ADDITIONAL QUESTIONS:

Do you think STEM is helpful to people? Why or why not?

Do you think STEM is helpful for the Earth? Why or why not?

Appendix C: Student Interview Script

(M)MDAST-E Follow-up Interview Questions:

At least eight students from each classroom will be selected for follow-up interviews (10-12 from each class should be identified as potential subjects in case not all students consent). Subjects will be sampled for theoretical salience and maximum variation based on PI review of the questionnaire answers and M-MDAST(E) results from the entire available (consenting) dataset of each class. Selected students will ideally include 4 males, 4 females and 2-3 students from each grade level. However, 4 students must have drawn a scientist, and 4 must have drawn an engineer. These questions have been modified from the M-DAST interview (Walls, 2012).

Introduction:
Do you remember the work you had recently where drew a scientist or an engineer? I would like to be able to ask all of you about them, but unfortunately given time I can only ask a few people. I will be working in your classroom all fall, so it's totally okay if you are not asked to participate in this activity. Remember, everything you do for this project is your choice, so if I ask you about being interviewed and you don't wish to participate, you can say so, or you can set another time. I also want you to know that so I can remember exactly what you said, I will be recording your voice while we talk.

Student Code: **Level/Gender/Marker:** **Date:**

1. The follow-up assignment asked you to draw a scientist and write a little about your drawing. Can you tell me a little about what you drew?

2. You named your scientist _________________________, can you tell me why you named him/her that?

3. What is your scientist doing? Where does your drawing take place?
    a. Where is this happening?

4. Can you tell me a little about how you thought of this person? Where did you get your ideas?

5. What are some things your scientist does when he/she goes to work every day?
    a. Do all scientists do that?

    b. What else do scientists do?

    c. Who do you think can be a scientist?

6. One last thing. Everyone has a skin color right? If someone looked at your drawing and wanted to know the race or skin color of your scientist, what would you tell them?

7. I know that you also wrote a little about science, math, technology, and engineering. I have your paper here, and you can read it again if you would like to help you remember.

   a. Can you tell me a little more about what you mean when you wrote….[insert follow-up questions here, see below]

      i. Can you tell me more about….you have been doing in your classroom?

      ii. What does STEM mean to you?

      iii. Do you think STEM is helpful? To people? To the Earth?

      iv. Do you know people who do STEM?

   b. Is there any answer that you wrote before that you would like to change now?

Appendix D: Letter of Exemption, University of Minnesota Internal Review Board

Alaina Szostkowski <szost012@umn.edu>

1606P89682 - PI Szostkowski - IRB - Exempt Study Notification

1 message

irb@umn.edu <irb@umn.edu> Mon, Jul 18, 2016 at 10:57 AM
To: szost012@umn.edu

TO : jcbrown@umn.edu, szost012@umn.edu,

The IRB: Human Subjects Committee determined that the referenced study is exempt from review under federal guidelines 45 CFR Part 46.101(b) category #1 INSTRUCTIONAL STRATEGIES IN EDUCATIONAL SETTINGS.

Study Number: 1606P89682

Principal Investigator: Alaina Szostkowski

Title(s):
Montessori STEM Study (MSTEMS)

This e-mail confirmation is your official University of Minnesota HRPP notification of exemption from full committee review. You will not receive a hard copy or letter. This secure electronic notification between password protected authentications has been deemed by the University of Minnesota to constitute a legal signature.

The study number above is assigned to your research. That number and the title of your study must be used in all communication with the IRB office.

For research in schools: Any changes to this research must be approved by the IRB and school district involved before initiation.

If you requested a waiver of consent or documentation of consent and you received this email, approval for the waiver has been granted.

This exemption is valid for five years from the date of this correspondence and will be filed inactive at that time. You will receive a notification prior to inactivation. If this research will extend beyond five years, you must submit a new application to the IRB before the study's expiration date. Please inform the IRB when you intend to close this study.

Upon receipt of this email, you may begin your research. If you have questions, please call the IRB office at (612) 626-5654.