ENACTING CUTTING-EDGE PRACTICES IN HIGH SCHOOL STEM EDUCATION: A NARRATIVE INQUIRY

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Acknowledgements

I am a patchwork quilt created from my varied experiences, made possible by many giving, intelligent, and supportive folks. When reading dissertations, the first thing I do is turn to the acknowledgments so that I can get to know the scholar whose work I am about to read. The glimpse into the scholar’s past helps me to see them through their patchwork quilt—to see what led them to their terminal degree. Perhaps my patchwork quilt will help you, dear reader, to see me beyond my research.

A quilt is made of three major components—the pieced quilt top, batting, and binding—that are stitched together by a strong thread. My father, Gary, has been my strong thread for many, many years. A practical mechanical engineer and tinkerer, he provided me with my intellectual foundation. Dad and I raced to see who could finish Atlas Shrugged first when I was in high school. He remembers more of the calculus problems I solved than I do, and he introduced me to reverse Polish notation. One story I often tell is that of all the things I’ve done in my life, my dad was probably most proud of my drill sharpening skills. He’d put my drill bits in his pocket protector and take them to work to show his fellow engineers what his daughter could do. Sharpening drill bits is a skill I learned in an agricultural engineering shop class after transferring out of mechanical engineering in college. I often think of what those sharpened drill bits cost in tuition payments, but the knowledge of his pride in my drill bits and other work propels me forward even today.

My husband, Paul, and two boys, Sam and Ben, are my quilt’s batting. Batting adds structure to a quilt. From it, warmth is created. A quilt is simply not a quilt without the batting. I am not me without my family. My husband, an inventor and engineer, has supported so many of my endeavors that have taken time away from him and our boys. This dissertation is just one of the many endeavors that I’ve undertaken with his full support. It was Paul’s idea that I become a teacher—and this acquisition of new skills mid-career required much from him and our boys. My family was often left with an exhausted wife and mom who gave much of her energy to her teaching and learning. Paul also indulges my great desire to be a fly fisherman. Maybe one day I’ll actually catch a trout. Our oldest son, Sam, has shown me what it means to be a scholar and to excel while tackling the big challenges that face our world. My youngest son, Ben, has shown me what it means to struggle as a different learner but to persevere and excel as a compassionate teacher of children like himself. Thanks Paul, Sam, and Ben for adding structure and warmth to my life.

My quilt top is a patchwork of experiences made possible by so many different people in various chapters of my life’s book. Dr. Gupta had confidence in my technical abilities and John Galvin gave me freedom to roam around the country as a young research analyst. Bill Schmidt was the first person to ask me if I’d have fun working in a new R&D position—have fun working has been my mantra ever since. If you’re having fun doing what you do, it won’t seem like work. I definitely have fun working today, thanks to Joshua Schuler and Professor Merton Flemings. They took a chance that a vocational technical teacher would excel running a K-12 outreach program at MIT. Both encouraged me to earn a terminal degree, which brought me into Professor Chris Unger’s world. Professor Unger has urged me to tell my stories of exceptional STEM teaching throughout the doctoral process, thus creating another quilt piece in my patchwork of experiences.

Do not fear, dear reader, that I’m about to embark on yet another research project to explain why all of my acknowledgements have been to males who have been significant to the
design and construction of my patchwork quilt. There is one last material that finishes the quilt — the binding. My mother, Pete, is my binding. Binding is necessary for strength and she is a pillar of strength in my life. I marvel how my mom developed her efficacy growing up in Kansas. She lost both of her parents before she was out of high school and raised herself with the help of friends. One of my favorite stories is how Mom, just out of high school, drove by herself from Kansas to Nantucket in the early 1950s. Why? She wanted to see the ocean. After seeing the ocean on one coast, she moved to the other coast. Mom joined the Navy and utilized her early IBM keypunch training in San Diego. There, she met my dad. She went on to raise small children and help support our family as a keypunch operator while Dad went to college on the GI Bill. Later, she relied on her STEM skills and Navy experience to join a college campus police force. She befriended and guided many students, never carried a weapon, and sewed her own uniforms because the men’s uniforms were ugly. Through her job, Mom paid for my college education and I was introduced to higher education as a high school student taking college classes for free. It was then that I decided to earn my doctoral degree, which I am now realizing decades later. Mom never offers me advice on how to live but rather shows me by example. Through the years of watching Mom, I adopted her sense of adventure. I developed her knack for chatting and love of others. And, I endeavor to be the great director that she is. Thanks, Mom, for being my binding. I’ll call you tomorrow at 8:15 to share our morning coffee.

Postscript: Mom and I didn’t share many more cups of coffee. I wrote these heartfelt acknowledgements many months before my research was completed and just days before she passed away. She was eulogized as our family’s binding. Even without my doctoral degree, she was proud of my family, my work, and me.
To Dolly Lemelson

Her vision for youth and support through the Lemelson Foundation brought me into the storied lives of Chelle, Randa, Rachel, and many other great teachers.
Abstract

This qualitative study using narrative inquiry methodology contributes to the understanding of how great high school teachers have built their self-efficacy and teacher efficacy, ultimately enacting cutting-edge practices in STEM (science, technology, engineering, and mathematics) education. The study participants facilitated technological product invention projects that were ultimately showcased at a White House Science Fair. The study found that these great STEM teachers have many outstanding performance accomplishments and strong beliefs about teaching. They are extremely gritty and resource-savvy teachers. They have enacted changes in their schools through project-based, hands-on classes and programs, such that students are engaged in learning while solving real-world problems. The exploratory study cannot be generalized to all STEM teachers; however, new knowledge was created that may influence how teachers can experience and learn to enact cutting-edge practices—such as technological product invention—with confidence.

Key words: teacher’s experiences, teacher’s self-efficacy, STEM education, invention, invention education, technological product invention, White House Science Fair, performance accomplishments, grit, confidence, hands-on, project-based, real-world problems
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Chapter I: Introduction

Problem Statement

High school science, technology, engineering, and mathematics (STEM) educators are being tasked to change the way they teach by adopting different pedagogical practices, such as inclusion of inquiry-based learning, crosscutting science domain concepts, student-centered classrooms, and multi-disciplinary capstone projects. All of these cutting-edge pedagogical practices are exemplified in the domain of technological product invention—a precursor to innovation—currently undertaken by a very small fraction of high school STEM educators in the United States. The researcher has observed that the STEM educators who have tackled invention projects have a highly-developed sense of self-efficacy, coupled with a high capacity of output, without prior experience in inventing a product.

There is very little formal education, pre-service training, or in-service professional development on how to undertake technological product invention in high schools. Yet, some high school STEM teachers have pursued these practices and have been highly successful in facilitating teams of students engaged in invention. InvenTeams, a national grants initiative administered by the Massachusetts Institute of Technology (MIT) School of Engineering’s Lemelson-MIT Program, exemplifies successful teachers facilitating technological invention projects. Teachers apply for a competitive grant to facilitate teams of student inventors. Since 2003, approximately 15 high school teams per year have identified real-world problems and engineered extremely creative inventions to address those problems, with funding of up to $10,000. Inventions were showcased at MIT at the end of each grant year (which coincided with the school year). Ultimately, 11 of these inventions have been showcased at White House Science Fairs hosted by the Office of Science and Technology Policy for President Barack
Obama. The teachers involved have successfully supported their students in gaining hands-on experience in STEM to design and build their projects in the integrative domain of technological product invention, where no one—neither students nor teachers—had prior knowledge or experience.

**Significance of the Problem**

The President’s Council of Advisors on Science and Technology (PCAST) (2010) reported to President Obama that STEM education “will generate the scientists, technologists, engineers, and mathematicians who will create the new ideas, new products, and entirely new industries of the 21st century” (p. vii). The same report, however, posited that a lack of student interest and proficiency in STEM might be attributed to an ill-prepared, ineffective, and uninspiring STEM teaching force that hinders the development of scientists, technologists, engineers, and mathematicians. PCAST (2010) summarized that “[t]he most important factor in ensuring excellence is great STEM teachers, with both deep content knowledge in STEM subjects and mastery of the pedagogical skills required to teach these subjects well” (p. xi).

While acknowledging the importance of great STEM teachers, PCAST (2010) referenced a five-year study on preparing teachers, conducted by the National Research Council (2011), that failed to outline *how* STEM teachers become great STEM teachers. PCAST (2010) lamented the lack of rigorous research and stated that it may require 20 years of research to know how to “recruit, prepare, and retain” (p. 65) knowledgeable and inspiring STEM teachers. Without guidance on how best to prepare great STEM teachers, the President’s council relied on common sense and summarized to Mr. Obama that K-12 STEM teachers must have a strong command of the content and pedagogy.
STEM content and pedagogical practices that effectively engage learners are discussed in federally-funded reports (Fenichel & Schweingruber, 2010; National Research Council, 2009; and National Research Council, 2012). Brody (2006) assembled common STEM program elements “in spite of a lack of really definitive research about what works” (p. 1). Tytler, Syminton, and Smith (2011) qualitatively documented elements of high-quality and novel STEM practices in Australia by closely examining case studies and identifying commonalities of best practices in STEM programs. The novel STEM practices “led to a steep but satisfying learning curve” for teachers, many of whom “talked of renewed confidence and interest in their teaching” (Tytler, Symington, & Smith, 2011, p. 29). Tytler et al. (2011) did not expect the effect on teachers of the novel STEM practices and their study’s research questions did not include expectations of teacher professional development (Tytler et al., 2011). Examples of professional development programs for STEM educators—designed to increase teachers’ confidence and self-efficacy—are found in the literature (Albion & Spence, 2013; Hynes & Dos Santos, 2007; Morgan, 2012; Nadelson, Seifert, Moll, & Coats, 2012); however, explorations are found lacking on how teachers develop throughout their careers to become great STEM teachers who prepare and inspire students.

The economic growth and competitiveness of the United States may be jeopardized by the lack of exploration on how STEM teachers become great, such that their students are prepared and inspired to be the creators of new ideas, products, and industries. Creation of new ideas, products, and industries is the creation of value, and commonly referred to as innovation. Fagerberg (2005) stated that “[i]nnovation is a powerful explanatory factor behind differences in performance between firms, regions, and countries…. Innovative countries and regions have higher productivity and income than the less innovative ones” (p. 20). Increased technical
innovation capacity in the United States has been one of the key drivers by policymakers to expand and improve STEM education. The National Academy of Engineering and the National Research Council’s committee report (2014) on Integrated STEM Education noted that disparate education, policy, and business groups have issued multiple reports calling for improved STEM education since 1990, with the case resting “on the idea that a STEM education can lead to productive employment and is critical to the nation’s innovation capacity” (p. 13).

The importance of innovation, and therefore the need for a STEM-educated citizenry, is also a global concern. The Organization for Economic Co-operation and Development (OECD), a forum of 34 governments that work to address challenges of globalization, reported in *Innovation and Growth: Rationale for an Innovation Strategy* (2007) that “the capability to innovate and to bring innovation successfully to market will be a crucial determinant of the global competitiveness of nations over the coming decade” (p. 3). Many OECD nations have implemented policies to support innovation, and call for education systems that produce “highly skilled human resources in science and technology” who possess “skills such as entrepreneurial ability, communications skills, [and] adaptability” (Innovation and Growth, 2007, p. 18). OECD did not call for more spending on STEM educators, but rather a shift in how equitable education is delivered, which includes less uniform and more individualized learning and less compartmentalization between theory and practice (p. 18-19).

Representatives of OECD’s 34 members and 31 participating economies make up the governing board of the Programme for International Student Assessment (PISA). Starting in 2000, PISA began assessing the mathematics, reading, and science competencies of 15-year-old students—typically high school students in the United States—every three years. The assessment results often make headlines in the United States because of students’ low
performance in comparison to students in other countries (Resmovits, 2014; Sedghi, Arnett, & Chalabi, 2013; and Strauss, 2013). Programme for International Student Assessment’s Country Note for the United States (2012) reported key findings for 15-year-old students that included:

- Mathematics score was below the 34 OECD countries’ mean average, ranking 27 out of 34;
- Students were weak in test items that required higher cognitive skills, including translating real-world situations into mathematics terms;
- Reading and science scores were not significantly different from the OECD average, with rankings of 17 and 20 out of 34, respectively; and
- The math, reading, and science results for 15-year-old students in the United States have been consistent since the inception of PISA in 2000. (pp. 1-2)

Results from another global assessment instrument, Trends in International Mathematics and Science Study (TIMSS), are broadly in agreement with the 2012 PISA results. TIMSS is under the direction of the 50-year-old International Association for the Evaluation of Educational Achievement (IEA). IEA has administered TIMSS for the past 20 years through Boston College’s TIMSS & PIRLS International Study Center in the Lynch School of Education. Funding sources for TIMSS include entities such as the U.S. National Center for Education Statistics and the World Bank, as well as self-funding countries (Martin, Mullis, Foy, & Stanojc, 2012). The recent TIMSS assessment of content and cognitive dimensions with published results was conducted in 2011 with 600,000 students. TIMSS 2011 results did not find U.S. students as top performers in Grade 4 or Grade 8. Rather, top-performing students were from Korea, Singapore, Finland, Japan, Russian Federation, and Chinese Taipei in Grade 4 and Singapore, Chinese Taipei, Korea, Japan, and Finland in Grade 8 (Martin et al., 2012, p. 7).
The TIMSS assessment went beyond student performance and collected information on home environment support, school resources for teaching science, school climate, teacher preparation, and classroom instruction. Information on their confidence to teach science was even gathered from teachers whose students took TIMSS 2011. Teachers provided their confidence in teaching science using five different instructional strategies. Martin et al. (2012) reported that

> [on average across countries, a larger percentage of [Grade 8] students had teachers who were Very Confident (73%) than fourth grade teachers, and unlike fourth grade, students who had teachers who were Very Confident had higher achievement … than did students who had teachers who were Somewhat Confident. (p. 313)

In addition to assessing teachers’ confidence, TIMSS assessed student engagement and reported “[e]ngaged students had higher achievement than their counterparts who reported being only Somewhat Engaged, and students Not Engaged had the lowest achievement.” (Martin et al, 2012, p. 378). It is this information that completed the circle back to STEM teacher efficacy and the students’ engagement, which is being explored in this research.

Summarizing the significance of the problem, STEM education is vital to producing a workforce capable of undertaking technological invention and innovation, which fuels national economies. U.S. students are outperformed on international assessments of mathematics and science in the preparatory grades (fourth and eighth) and this is confirmed in secondary school with 15-year-old students. Martin et al. (2012) reported that confident teachers affect student performance in science going into high school—with students of highly-confident teachers being higher achievers—and that engaged students have higher achievement. While one high-quality and novel approach that engages students in their STEM education has been observed by the
researcher through the InvenTeam grants initiative, there is a dearth of published research on how high school STEM teachers develop the self-confidence to facilitate teams of students in cutting-edge STEM practices.

**Research Questions**

With the problem of practice and significance presented above, three research questions guided this study:

1. How do highly-effective secondary school STEM teachers involved with InvenTeams perceive their capacity and sense of self-efficacy?
2. How have teachers’ experiences with InvenTeams contributed to their students’ engagement and learning in STEM?
3. How have the teachers’ experiences with InvenTeams impacted their capacity and self-efficacy to enact cutting-edge change in STEM education in their schools?

**Theoretical Framework**

**Historical perspective.** John Dewey, president of the nascent American Psychological Association in 1899, was not apologetic for addressing psychologists instead of educators in discussing the “fundamental importance for both psychology and social theory” (p. 106), and urged a linking of the scientific laboratory with the real world (Dewey, 1900). Psychologists at the turn of the twentieth century wanted to differentiate themselves from real-world practitioners who were “identified with philosophy, education, social work, or psychiatry” (Barone, Maddex, & Snyder, 1997, p. 6). Barone et al. (1997) noted that Dewey had observed “the problems from teachers’ attempts to apply highly specific laboratory findings to the classroom” (p. 5) and saw the great need for this linking.
Barone et al. (1997) charted the early history of social cognitive psychology when they listed John Dewey along with James Mark Baldwin and George Herbert Mead as the founders of social cognitive psychology and determined four generations of development across four traditions: (a) social gestalt, (b) social learning, (c) constructivism, and (d) information processing. According to Barone et al. (1997), “the social learning tradition is at its best when explaining the integration of behavior and cognition” (p. 22).

Julian Rotter was a major contributor to social cognitive psychology in the social learning tradition starting in the 1950s. Rotter’s (1966) psychological construct within a social learning tradition involved internal and external loci of control. The RAND Corporation first used the term *teacher’s sense of self-efficacy* in a 1977 report funded by the U.S. Office of Education on the sustainability of education programs, and based their survey questions about efficacy on Julian Rotter’s (1966) psychological construct within a social learning theory. Albert Bandura emerged in the literature of self-efficacy at about the same time as the RAND study, with another strand of social learning theory in which he identified and defined teacher efficacy. Barone et al. (1997) discussed Bandura’s self-efficacy construct within the constructivist tradition, but did not list Bandura as a major contributor to the history of social cognitive psychology. Bandura’s work developed more fully from his social learning theory in 1977 and he renamed it as social cognitive theory in 1986. Bandura’s work is most relevant to this research on teachers’ self-efficacy.

Bandura’s (1977) social learning theory is the theoretical framework that informs this study. His social learning theory purports that people learn and move toward action when they believe they can be successful. Feltz, Short, and Sullivan (2008) introduced the theoretical basis of self-efficacy for practitioners with Bandura’s self-efficacy construct within his social learning
theory, and noted that it has remained “relatively unchanged” (p. viii) since its inception. Using a stable construct to explore how educators develop a belief in their abilities—to not only become knowledgeable about technological product invention, but also to develop their abilities to facilitate and engage a team of students to conceptualize, design, and build a successful invention—may inform the practice of inclusion of invention and other project-based approaches in high school STEM education.

Bandura (1977) conjectured four major sources of efficacy expectations and their different modes of induction. These four sources, ranked by potential effect on efficacy expectations, included: (a) performance accomplishments, (b) vicarious experiences, (c) verbal persuasion, and (d) emotional arousal (p. 80). Feltz et al. (2008) described efficacy beliefs as being formed by a “process of self-appraisal and self-persuasion that relies on cognitive processing” (p. 7) of the four sources. These four sources are discussed in the subsections below.

**Performance accomplishments.** Bandura (1977) purported that “[p]erformance accomplishments provide the most dependable source of efficacy expectations” (p. 81). Repeated successes in one’s actions raise expectations of future accomplishments. Conversely, repeated failures reduce the expectations. However, Bandura (1977) also stated that patterns of success could overcome occasional failures and help to build one’s persistence and sustain efforts “in the face of obstacles and aversive experiences” (p. 80). The importance of performance accomplishments can be found in the literature with respect to sports and music. There was also a crossover in the literature to sports coaching and teaching in education. For example, Stanley, Lane, Beedie, Friesen, and Devonport (2012) conducted research with runners and reported that 12% of runners recalled past performance accomplishments (p. 159). Feltz et
al. (2008) compiled a reference text that included a multitude of studies on efficacy beliefs and performance accomplishments within sports from the individual, team, and coach standpoint. De Vries (2013) reported that Australian primary school teachers who were responsible for teaching music without assistance from music specialists achieved high self-efficacy in teaching music through “music teaching accomplishments” (p. 375).

**Vicarious experiences.** Vicarious experiences—modeling behavior of others—may reduce the fear or trepidation of an action when no negative consequences are observed. Vicarious experiences result in a perception that “if others can do it, so can I.” Modeling behaviors in education are observed in pre-service teaching and professional development.

**Verbal persuasion.** According to Bandura (1977), “[p]eople are led, through persuasive suggestion, into believing that they can cope successfully with what has overwhelmed them in the past” (p. 82). This type of persuasion is easy and widely used. Verbal persuasion, however, is a weak way to build efficacy because it lacks “an authentic experiential base” (Bandura, 1977, p. 82). Types of persuasive techniques include “verbal persuasion, evaluative feedback, expectations on the part of others, self-talk, and other cognitive strategies” (Feltz, Short, & Sullivan, 2008, p. 10). Pep talks by coaches who are involved in competitive arenas are a type of verbal persuasion.

**Emotional arousal.** The last major source of efficacy expectations discussed by Bandura (1977) is emotional arousal. He stated that people are more likely to expect success when they are not afraid or ridden with anxiety. Bandura has been a major researcher in this area. Bandura and Adams (1977) reported study findings from two experimental tests regarding phobics, desensitization, and behavioral change. Lan and Gill (1984) supported Bandura’s assessment
that self-efficacy could mediate fear through a quantitative study of female subjects in stressful laboratory situations conducted a few years after the Bandura and Adams research.

**Bandura’s social learning theory renamed.** Bandura (2006) told his own story of why he ultimately renamed his social learning theory to social cognitive theory in 1986, noting that there were many theories called social learning theory but with “divergent tenets” (para. 69) that caused confusion in the literature. Specifically, Bandura called out Miller and Dollard, Rotter, Gewirtz, and Patterson as a few researchers with similarly named theories. Bandura (2006) referred to these researchers’ theories as having the “same appellation” (para. 69), which created confusion in the literature. Besides correcting the appellation of the theory, Bandura (2006) also renamed his social learning theory to encompass a broader theory—beyond the descriptor learning—because

[the theory] not only addressed how people acquire cognitive, social, emotional and behavioral competences, but also how they motivate and regulate their behavior and create social systems that organize and structure their lives. In the more fitting appellation as social cognitive theory, the social portion of the title acknowledges the social origins of much human thought and action; the cognitive portion recognizes the influential contribution of cognitive processes to human motivation, affect, and action. (para. 69)

This researcher utilized Bandura’s work from the period prior to his renaming of this theory and, therefore, utilized the theoretical framework as “social learning theory”; however, it is important to consider Bandura’s broader theory implications beyond learning, which include how people motivate and regulate their behavior with respect to the research.

By utilizing aspects of Bandura’s social learning theory related to the development of efficacy, this research explored how high school teachers confidently adopted change in STEM
pedagogy. In the United States, pedagogical change is implicated in the Next Generation Science Standards (NGSS) introduced in 2013. NGSS seeks to weave together science and engineering learning so students develop a contextual understanding of the content they are learning, which they can apply in real-world settings. More specifically, this exploratory research may inform pre-service and in-service professional development practices for high school STEM teachers, resulting in increased teacher self-efficacy in new pedagogical practices to enact cutting-edge practices that weave together STEM disciplines with real-world applications.
Chapter II: Literature Review

The literature review for the qualitative research using narrative inquiry methodology traverses many topics that may seem disparate but are pertinent to how teachers’ stories will be “coproduced in a complex choreography—in spaces between teller and listener, speaker and setting, text and reader, and history and culture” (Riessman, 2008, p. 105). Teachers’ efficacy and how it is developed is first explored in the scholarly literature to help set the stage for STEM teachers. A review of the ambiguous but popular term, “STEM,” follows along with a survey of STEM pedagogical practices. Successful STEM pedagogical practices lead into visions for STEM education and inquiry-based technological product invention education that is interdisciplinary and weaves together disciplines.

Definitions of Self-Efficacy and Teacher Efficacy

Definitions of self-efficacy and teacher efficacy can be traced back almost 40 years to a large quantitative study conducted by the RAND Corporation and prepared for the U.S. Office of Education. The study assessed continuation of educational programs focused on change once federal seed funding ceased. Research conducted and reported by Berman, McLaughlin, Bass, Pauly, and Zellman (1977) used the term teacher’s sense of efficacy (p. 136) as an attribute that had a significant positive effect on “project goals achieved, the amount of teacher change, improved student performance, and continuation of both project methods and materials” (p. 137). The RAND researchers had based their questions about efficacy on the psychological construct within a social learning theory conceptualized by Julian B. Rotter and published in 1966, which involved the internal (within oneself) and external (in the environment) loci of control. In 1977, Albert Bandura added another conceptual strand to social learning theory firmly rooted in psychology, identifying “teacher efficacy as a type of self-efficacy—a cognitive process in
which people construct beliefs about their capacity to perform at a given level of attainment” (Tschannen-Morgan, Hoy, & Hoy, 1998, p. 203).

Tschannen-Morgan, Hoy, and Hoy (1998) provided a thorough review of the first 23 years of teacher efficacy from 1974 and 1997 that used either Rotter or Bandura’s theoretical framework. They approached their research with the aim of clarifying the two intertwined conceptual strands as well as the many quantitative efficacy-measuring instruments that grew out of the two strands. One such instrument, developed in the 1980s and known as the Gibson and Dembo instrument, referred to two factors: PTE (personal teaching efficacy), which reflects self-efficacy and GTE (general teaching efficacy), which deals with outcome expectancy. These two expectancies are similarly found in Bandura’s strand (Tschannen-Morgan, Hoy, & Hoy, 1998). Bandura continued working on his social cognitive theory and developed a Teacher Self-Efficacy Scale. This is of interest to this research because Bandura’s instrument with 30 items contained seven subscales that informed the question-development interviews utilized in this research. Bandura included school/environment context effects in his construct. The seven subscales as listed by Tschannen-Moran, Woolfolk Hoy, and Hoy (1998) were:

- Efficacy to influence decision making,
- Efficacy to influence school resources,
- Instructional efficacy,
- Disciplinary efficacy,
- Efficacy to enlist parental involvement,
- Efficacy to enlist community involvement, and
- Efficacy to create a positive school climate. (p. 219)
Development of Self-Efficacy and Teacher Efficacy in STEM

Teachers’ sense of self-efficacy continued to be widely researched during the first 23 years after its identification. Personal teaching efficacy (PTE) tended to not be questioned; however, general teaching efficacy (GTE) measurements were questioned regarding whether this was, in fact, Rotter’s external influences and not Bandura’s outcome expectancy. Tschannen-Moran et al. (1998) introduced their own integrated, cyclical model of teacher efficacy that related to PTE and GTE and included Bandura’s four sources of efficacy information: (a) mastery experience/performance accomplishments, (b) physiological arousal/emotional arousal, (c) vicarious experience, and (d) verbal persuasion (pp. 228-230). These four sources of efficacy information also informed the development of interview questions for this study.

Tschannen-Moran et al. (1998) published an extremely thorough review of teacher self-efficacy theories, studies, and instruments that yielded their own model and identified one area rife for future research: the transference and changing of efficacy beliefs. Tschannen-Moran et al. (1998) recommended that “qualitative research could explore what events and influences teachers attribute to the development of their efficacy beliefs” (p. 242) and went on to lament that “qualitative studies of teacher efficacy are overwhelmingly neglected” (p. 242). In the 18 years since Tschannen-Moran et al. (1998) made this recommendation, qualitative studies have not been forthcoming. This research will add the rich, thick description of the development of teacher efficacy that these researchers had envisioned, albeit focused specifically on STEM teachers’ self-efficacy.

Self-efficacy research continued into the 1990s and received much attention in educational research related to motivation. According to Pajares (2003), this research focused on the influential nature of efficacy beliefs on individuals’ career choices, especially in science and
mathematics, the relation of students’ academic progress to teacher efficacy, and the correlation of students’ self-efficacy to their academic achievement. Reviewing current research—specifically looking at STEM teacher self-efficacy—revealed mostly quantitative studies though one mixed-method study was uncovered. The largest study was conducted in Singapore, examining teacher efficacy and changing pedagogy in primary schools, and concluding that teacher self-efficacy should be promoted but with no recommendations on how this should be accomplished (Nie, Tan, Lia, Lau, & Chua, 2013). Two additional quantitative studies with elementary school teachers and changes in STEM pedagogy focused on specific programs to increase teacher efficacy (Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013; Albion & Spence, 2013). Two studies in the United States involving some high school STEM teachers were reviewed. These studies focused on specific programs that introduced changes in pedagogy, including the use of inquiry-based instruction (Powell-Moman & Brown-Schild, 2011; Annetta et al., 2012). One study was quantitative while the other utilized mixed methods, generating some qualitative richness with extracted statements from teachers’ reflective blogs. However, the qualitative data was subordinate to the quantitative analyses of self-efficacy.

**STEM in Context**

STEM—science, technology, engineering, and mathematics—is an amalgam of interrelated disciplines and often referred to as a single, joined entity because of the acronym. The acronym has grown in popular use since the 1990s. According to Rep. Vernon Ehlers (R-Michigan) in his reflection upon leaving Washington, D.C., “[when he] came to Congress in 1993, the phrase ‘STEM’ education did not exist” (2010). Lore has it that the term began collectively as SMET. Rep. Ehlers, a physicist with a terminal degree, sponsored the House of Representatives bill that became the National Science Education Act of 2002 (Public Law 107-
The act provided funding for the National Science Foundation (NSF) to build workforce skills by expanding opportunities and increasing enrollment rates in science, mathematics, and engineering in postsecondary education. Interestingly, the National Science Foundation Authorization Act of 2002 only sought to support “improving the quality of mathematics and science education, particularly in kindergarten through grade 12” (p. 3) and did not address engineering and technology below postsecondary education. While the law did not refer to science, mathematics, engineering, and technology as SMET, the terms were consistently listed in this order when all four disciplines were named together.

SMET did not become a popular acronym. At about the same time that Rep. Ehlers introduced the original bill in the House of Representatives in 2001, an assistant director of the Education and Human Resources Directorate at the National Science Foundation, Dr. Judith Ramaley, coined the STEM acronym. Dr. Ramaley said she coined STEM “because science and math support the other two disciplines and because STEM sounds nicer than SMET…. The older term [SMET] subtly implies that science and math came first or were better. The newer term suggests a meaningful connection between them” (Chute, 2009, para. 6).

The acronym STEM and its focus on economic competitiveness originated through a federal funding stream. Much of the information that can be found on STEM education initiatives is found in federal government reports. Yet, the U.S. Department of Education stated that education is not its responsibility, but rather belongs at the state and local level. In 2011-2012, only 12.3% of funds for elementary and secondary levels came from Federal sources (The federal role, n.d., para. 1). The two-fold mission of the Department of Education is: (a) to promote student achievement, and (b) to prepare students for “global competitiveness by fostering educational excellence and ensuring equal access” (The federal role, n.d., para. 10).
Their mission is carried out through engaging in dialogue about educational challenges facing the nation, sharing what works in education, and helping communities find solutions to difficult educational problems. The President’s Fiscal Year 2013 Budget of the U.S. Government (2012) request of $69.8 billion in discretionary spending for the Department of Education—an increase of $1.7 billion over 2012—highlighted only two specific investment requests related to improving STEM education:

- Invests $1.1 billion in a reauthorized Career and Technical Education program, that will prepare students for the future by aligning what they learn in school with the demands of 21st Century jobs. The Budget also provides support for establishing new highly-effective career academies.
- Prepares America’s students for the 21st Century workplace by providing $260 million in funding for science, technology, engineering, and mathematics (STEM) programs. (p. 93)

President Obama highlighted improving STEM education in his 2013 budget request but there was a very small percentage of funding attached to the highlighted activities. The specifically earmarked funding for STEM in the budget highlights was around 2% of the Department of Education budget and less than the department’s increase over 2012.

The President’s Fiscal Year 2016 Budget provides $70.7 billion in discretionary funding for the Department of Education. There were no highlights listed in this most recent budget—making it difficult to ascertain funding specific to STEM—and the summary on the budget proposal for the Department of Education did not call out STEM. Rather, the “[b]udget proposes to [make sure we are leading the world with highly skilled workers] through improving access to early education; preparing elementary and secondary education students for success; increasing
access to quality, affordable high education; and continuing to build the evidence base for what works to improve student outcomes” (p. 29-30). One area where STEM was specifically mentioned in the 2016 budget was found under improvements to our nation’s high schools. The budget established a paltry $125 million competitive program to “promote the redesign of America’s high schools by integrating deeper learning and student-centered instruction, with a particular focus on … STEM-themed high schools that expand opportunities for girls and other groups underrepresented in STEM fields” (President’s Fiscal Year 2016 Budget, 2015, p. 31).

The researcher acknowledges that the President and the Office of Science and Technology Policy have provided an unprecedented national venue for young scientists and inventors to be recognized through White House Science Fairs. President Obama has offered a showcasing opportunity, has told the stories of a small but impressive fraction of youth successful in various STEM endeavors, and publicized the fairs as if the students were trophy-winning sports teams. STEM education, while important to President Obama, has not received strong federal funding via discretionary expenditures in the federal budget. President Obama has, indeed, fulfilled his commitment “to directly use his bully pulpit to inspire more boys and girls to excel in mathematics and science” (Holdren, 2013, n.p.).

Shifting the focus from STEM education as national funding or policy perspective to examine its roots in educational research, a literature search was conducted through the Education Resources Information Center (ERIC). The Institute of Education Sciences (IES) in the U.S. Department of Education sponsors ERIC. A search of peer-reviewed journal articles on STEM education yielded 1,623 articles in the last 20 years. However, over 70% of these articles have been published in the last five years, indicating a slow growth of the term within the field of education, but with a recent steep incline. This uptick in published research corresponded to the
establishment of the Race to the Top Fund under the American Recovery and Reinvestment Act of 2009. As mentioned in TIMSS 2011 Encyclopedia (2012), “The $4.35 billion Race to the Top grant program has been directed to ensure a competitive preference to states that commit to improving science, technology, engineering, and mathematics (STEM) education, among other goals” (p. 979). Common Core Standards in mathematics were adopted by 43 states since 2010. The Next Generation Science Standards were introduced in 2013.

The Elementary and Secondary Education Act was reauthorized as the No Child Left Behind Act (NCLB) in the same year as the National Science Foundation Authorization Act of 2002. As a comparison of effect on publication between STEM education and the assessment-focused NCLB, queries in ERIC retrieved over 45,000 peer-reviewed journal articles on assessment in the last 20 years. Clearly, STEM education has not been a major focus within educational research, even with the federal discussion on the amalgam of the four disciplines (STEM), and while PISA and TIMSS assessments continued to indicate that students in the United States are outperformed and therefore less competitive with their peers by age in many parts of the world.

**STEM Pedagogical Practices**

Less than a year before the U.S.S.R.’s Sputnik satellite made its infamous low Earth orbit, propelling the United States into reactionary scientific and technological research, Washton (1956) questioned whether “the teaching of science in elementary and secondary schools would be different or better if teachers were informed of research work in science education” (p. 383). His questioning was brought about from his review of the science teaching literature from 1938 to 1955, in which he found in Review of Educational Research “almost one thousand studies” (Washton, 1956, p. 383). His review found that teachers thought the studies
too technical to understand and the recommended changes were difficult to apply to the classroom. However, some studies that Washton (1956) reviewed noted changes in secondary school science teaching that produced better outcomes, with the caveat that “better instruments and methods of evaluation still need to be developed” (Washton, 1956, p. 384). Washton’s (1956) findings of change that would lead to a “more economical, effective, and inspirational program of science” (p. 386) in science education are as pertinent today as they were in the pre-Sputnik era. They included:

- In teaching high school physics, pupils will learn and understand more science if the pupils plan the laboratory studies of their own choice.
- Students must be taught directly for problem solving ability, understanding scientific principles and their applications.
- Pupils who are members of high school science clubs excelled non-members in terms of scientific knowledge.
- In selecting content for a physical science course, it is suggested that no one specialized area of science is more important than materials taken from other areas [implying a multidisciplinary approach to teaching and learning].
- Favorable results were reported … when a high school chemistry course offered community problems such as food supply, science in agriculture, and control of the water supply.
- In the area of human relations, it was reported that significant changes can be produced in student attitudes when biology and social studies classes were brought together in comparison with separate classes.
• Pupils in high school biology achieved greater scores in the ability to interpret data, in learning principles and facts of biology and in problem solving ability when pupils and teachers planned the course cooperatively.

• The [science] content should be organized around large units of experience based upon the needs and interests of the pupils.

• Competent and qualified science teachers…. affected pupil interest and the decision to specialize in science. (p. 385-386)

Major education reforms have occurred over the past 50 years that sought to improve the U.S. students’ “disappointingly average” (Finley, 2000, p. 2) achievement scores. Reforms that began with Sputnik were reignited in 1983 with the seminal publication by the National Commission on Excellence in Education of A Nation at Risk. The nation’s governors banded together a few years later in 1989 for an education conference that produced a call for states and the federal government to “take a role in improving education” (Finley, 2000, p. 2). Two reform efforts were spawned, including a movement for national educational standards with Goals 2000 and a Restructuring Movement that placed school-based decision-making below the district level. These reforms made way for systemic school reform in which the teacher had very little involvement.

Knapp (1997) sought to move beyond reform rhetoric and reviewed qualitative investigations on large scale, systemic, pre-collegiate mathematics and science reforms undertaken by states and the federal government through funding from the National Science Foundation. He argued that the systemic reform included: (a) alignment, (b) coherent policies, and (c) standards-based reform, and that these three terms “rest on common beliefs about the way such policies can influence educational practice” (Knapp, 1997, p. 228). Knapp concluded
that math and science teachers have been affected by systemic reforms in many different ways. Teachers attempted to realize aspects of the reforms in classroom practice, but in a piecemeal manner, and not wholly integrated across the curriculum. Teachers relied heavily on what they knew best. Thus, Knapp (1997) concluded, classroom use of reform-advocated practices may or may not support reform and teachers are often unaware of changes in their practice (p. 255-256). Knapp (1997) noted in his conclusion that there was a need to document how individual math and science teachers’ capacities grow and, in an organizational sense, how the growth in capacities is transferred to impart a change in the organizational culture.

Shifts toward a constructivist view for student and teacher learning were evident in Washton’s 1956 list of changes with respect to students and teachers co-creating classes, real-world connections, and integration of concepts across subjects. The constructivist view, according to Finley (2000), is foreign to teachers who learned how to teach from the prevalent behaviorist view with an additive perspective versus a transformative perspective (p. 9). Finley (2000) maintained:

Constructivism is a multifaceted theory that suggests that knowledge is personally and actively constructed…. Students are, thus, better able to construct meaning and develop deep understanding when teachers create opportunities for students to have hands-on experiences, to go into depth on important topics, to work with other students in varied groupings, to make real-world connections, to purposefully access their own prior knowledge, and to integrate concepts across subjects…. This view of learning is a radical departure from the behaviorist view of learning that was prevalent when many of today’s teachers were preservice students. (p. 9)
In short, Finley alluded to the idea that teachers teach how they were taught. Teach teachers with presentations and lectures, and they will teach their students with presentations and lectures. Finley referred to this as *additive learning*; OECD referred to this as *direct transmission*. Knapp found that teachers relied heavily on what they knew best. Finley and Knapp’s combined research suggests a need for teacher training utilizing a constructivist approach to build teacher efficacy such that teachers are aware of the changes that can transform STEM education and how they can implement the changes in the classroom.

The National Research Council report (2011), *Successful K-12 STEM Education*, focused on STEM practices that could guide schools to develop quality STEM instruction and learning. The report noted two key aspects of practice found in successful schools: (a) “instruction that captures students’ interest” and (b) “school conditions that support effective STEM instruction” (p. 18). Successful K-12 STEM education, as reported by the National Research Council, was found in all types of schools including selective STEM schools, inclusive STEM schools, STEM-focused career and technical education, and STEM-focused programs in comprehensive schools striving for STEM excellence for all students. Successful STEM education has students working on real-world problems, carrying out scientific inquiries, and designing engineering projects. After discussing successful schools, STEM programs, and pedagogy, the National Research Council (2011) concluded that “[t]his type of STEM instruction remains the exception in U.S. schools. It is typically facilitated by extraordinary teachers who overcome a variety of challenges that stand between vision and reality” (p. 19). The number one key element to help bridge the gap between vision and reality is “teachers with a high capacity to teach in their discipline” (National Research Council, 2011, p. 20). However, the report was weak on concrete
actions, did not specify what the challenges were, or describe how teachers overcame the variety of challenges.

Besides having teachers with a high capacity to teach in their discipline, the National Research Council’s report (2011) elaborated on the necessity of supportive school culture and conditions. The National Research Council’s report (2011) noted that culture and conditions mattered just as highly as a teacher’s high capacity (p. 23). The report cited a large-scale, longitudinal study conducted in Chicago with elementary schools that had undergone systemic reforms to improve student learning in mathematics as well as reading. The schools that showed improved learning had five elements in common, including “school leadership, professional capacity, parent–community ties, student-centered learning climate, and instructional guidance” (National Research Council, 2011, p. 24). Once again, while these common elements were listed, the report summarized that “additional research is needed on the effects of STEM teacher development on student achievement and on which elements of school culture contribute to STEM learning” (National Research Council, 2011, p. 24).

Systemic reform in education has produced changes within mathematics and the sciences as well as technology and engineering. STEM, as mentioned previously, is an amalgam of interrelated disciplines. Referring to STEM as a single entity is a misnomer. Each discipline has its own set of standards and guiding organizations, and has been on different reform trajectories. Mathematics in K-12 has seen major and, at times, contentious, reform since the early 1980s. A Nation at Risk highlighted the shortcomings and defined some of the problems of mathematics and science education in the United States with particular emphasis on teenage youth (The National Commission on Excellence in Education, 1983, para. 4). Today, mathematics reform is taking place under the voluntary yet widely-adopted Common Core State Standards (CCSS),
which includes math standards, topic sequences, and performances that “encourage students to solve real-world problems” (Mathematics Standards, 2016, para. 5).

Science reform is currently being driven by the Next Generation Science Standards (NGSS). The standards are composed of three dimensions: practices (engagement in scientific inquiry and engineering design), crosscutting concepts (explicit application and linking across domains), and disciplinary core ideas grouped in four domains (physical sciences; life sciences; earth and space sciences; and engineering, technology and applications of science). NGSS embeds standards for engineering and technology.

Education associations, museums, and educational organizations led the focus on engineering and technology prior to NGSS. The International Technology and Engineering Educators Association (ITEEA) published technology literacy standards between 2000 and 2007 and sold companion curriculum as well as engineering curriculum. Engineering curriculum has also been developed through science museums and, most notably, by the Museum of Science (MOS) in Boston. MOS focused on elementary and middle school curriculum, sold its products, and engaged in professional development for teachers. Project Lead the Way, a non-profit organization, emerged in the early 2000s to meet the growing demand for STEM content. It touts itself as “the nation’s leading science, technology, engineering, and math (STEM) solution in over 8,000 schools across the U.S.” (“About PLTW”, n.d.).

Scholarly research with this recent activity in STEM education is convoluted, ranging from national fiscal support to new standards development to voluntary acceptance of standards on the state level to the plethora of educational business activity focused on various approaches to STEM education and integration. A recent committee at the Federal level was charged “with developing a research agenda for determining the approaches and conditions most likely to lead
to positive outcomes of integrating STEM education at the K-12 level” (National Academy of Engineering and National Research Council, 2014, p. 22). One committee member and an editor of this report, Schweingruber, previously co-authored *Surrounded by Science: Learning Science in Informal Environments* (Fenichel & Schweingruber, 2010), which was based on the National Research Council’s report *Learning Science in Informal Environments: People, Places, and Pursuits* (2009). Even Schweingruber and her illustrious committee that researched integrating STEM for two years noted that the National Academy of Engineering and National Research Council’s report (2014) “raises more questions than it answers regarding integrated STEM education” (p. 24). This indicates a great need for empirical research to inform and prepare scholar-practitioners and educators to integrate STEM.

**Visions of Exemplary STEM Learning and Teaching**

This review of scholarly literature on exemplary STEM learning and teaching sought empirical studies that reported evidence of teaching practices, strategies, and implementation, as well as learning outcomes for students. While the majority of students in the United States are educated in non-STEM-focused public schools, the literature review yielded scant studies that were program-focused in both formal and informal education, international, spanning across K-16, and with no one S-T-E-M discipline combination. *Exemplary* is a subjective word, and while the researcher sought a clear definition by which to search the literature, none existed. Therefore, the subtitle of this section reflects this subjectivity as *visions* of exemplary STEM learning and teaching.

Programs that provided visions of exemplary STEM learning and teaching through peer-reviewed research included formal (during school) and informal (out-of-school) learning with the following common key terms (Fenichel & Schweingruber, 2010; Marshall, 2006; Morgan, 2012;

- Problem- and/or project-based learning;
- Student engagement;
- Real-world problem, connection, and/or context;
- Community connections;
- Educators as facilitators and/or coaches; and
- Confident educators.

Most of the research that reviewed STEM programs utilized qualitative methodology. Fenichel and Schweingruber (2010) utilized case studies to “show how the principles and strategies emerging from research on learning can and are being employed by informal science educators across various settings” (p. xiv). In order to support learning, Fenichel and Schweingruber (2010) noted two very important factors that determined a transfer of knowledge to students: time and the quality of teaching. Informal science-learning settings like museums, nature centers, and aquariums—which tend to include experiential, hands-on learning—often provide in-service professional development for teachers but “little is known about whether professional development provided by informal science settings is more effective than that offered by other providers” (Fenichel & Schweingruber, 2010, p. 180). Fenichel and Schweingruber (2010) reported on research conducted by Anderson that utilized another qualitative methodology, focus groups, in which teachers were brought together after participating in professional development at an aquarium. The teachers’ focused discussion included effects of the experience on their self-efficacy and the “recognition of the power of hands-on experience in learning science” (Fenichel & Schweingruber, 2010, p. 181).
Research in teaching STEM in exemplary programs included both qualitative and quantitative methodologies. Qualitative methods included stories as told by Marshall (2006) to illuminate the type of teaching necessary for student engagement in STEM learning. Case studies described by Symington & Smith (2011) and by Gourgey, Asiabanpour, Crawford, Grasso, and Herbert (2009) elaborated on the types of professional development needed by STEM teachers, which included partnerships with STEM professionals in collaborative, field-based situations and over a period of time.

Quantitative methodologies were less common in the research but one mixed-method study on teacher implementation of engineering content (Page, Lewis, Autenrieth, & Butler-Purry, 2013) and one survey-based study focused on in-service STEM teacher professional development (Nadelson, Seifert, Moll, & Coats, 2012) were pertinent to the topic of exemplary STEM learning and teaching. Both of these studies were based on summer institutes held on higher-education campuses. Page et al. (2013) summarized that NSF-funded, multi-year, 4-week residential engineering enrichment experiences for teachers in Texas with 137 high school teacher participants between 2003 and 2012 “had a positive benefit for high school STEM teachers related to their experiences in teaching and promoting the field of engineering to students” (p. 27). Nadelson et al.’s (2012) research of a residential, 4-day summer program for teams of 239 Grade 4 to 9 teachers in Idaho, of which 7.5% were high school teachers, “revealed perceptions of efficacy for teaching STEM to be related to comfort with teaching STEM, pedagogical discontentment with teaching STEM, and inquiry implementation” (p. 79).

**Invention as Inquiry-Based Integrated STEM Learning**

Invention education requires the adoption of inquiry-based pedagogical practices, integration of STEM knowledge, and inclusion of the ultimate authentic assessment of
conceptualizing, designing, and building a useful and unique physical contrivance: an invention. A review of the literature on the topic of teaching invention to youth yielded very little. Plucker and Gorman (1999) reported the lack of intensive research on invention education, and little was found in the literature in the following two decades. Plucker (2002) individually noted the same lack of attention to invention in science curricula in the United States.

There were overlaps and discrepancies in definitions of invention and innovation, along with inclusion of the concepts of design and creativity in the literature review process. For this review, technological innovation was defined as when “the R&D invention is converted into a socially useful and commercially successful product” (Martin, 1982, p. 225), a definition that has been constant over time. Fagerberg (2005) stated “invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice” (p. 4). Both definitions indicate that an invention is the precursor to innovation and that an innovation is more fully developed for the marketplace.

Michel et al. (2010) and the Google Books Team developed the NGram Viewer to analyze the corpus of words written in various languages, including English, and printed in books in between 1500 and 2008. Using NGram Viewer to count the frequency of the use of invention and innovation as nouns between 1900 and 2008 indicated the terms have changed in predominance (see Figure 1). Invention was the more popular word until 1972, but it has steadily decreased in usage since 1950, whereas innovation has increased in usage. The peak usage of the word invention during the 20th and 21st centuries was in 1934; the use of innovation had not yet reached the same level. The usage of the two words as nouns is important to note in this research, as is acknowledgment that popular press often uses the two words interchangeably. This literature review was expanded to include both technological invention and innovation since
many researchers, too, used the words similarly even though distinct definitions exist. The NGram Viewer indicated trends in the use of the words “invention” and “innovation” as nouns, as shown in Figure 1.

![NGram Viewer](image)

*Figure 1. Use of the words “invention” and “innovation” in books printed in English from 1900 to 2008 created in NGram Viewer*

Published peer-reviewed research only included a few attempts to teach invention at the secondary level in the United States. One invention curriculum has been developed for the secondary level, but in Malaysia—not the United States. Invention was discussed in elementary, secondary, and post-secondary literature, while innovation was discussed only in the post-secondary literature. This conforms to the idea of invention being the precursor to innovation. Innovation at the post-secondary level typically is considered in the social sciences and humanities, as well as in technical disciplines.

Gorman and Kagiwada (1995) discussed the design of a multidisciplinary course at the University of Virginia that included students in engineering, education, and history. Invention was introduced heuristically, followed by group-oriented, hands-on opportunities as “inventor apprentices” (Gorman & Kagiwada, 1995, p. 629) where the invention process was experienced from the conception of an idea to the writing of a patent application. Researchers at the University of Colorado at Boulder created a course for engineering students as a hands-on
introduction to product design that was team-based so that students could experience invention and innovation firsthand (Sullivan, Carlson, & Carlson, 2001). Washburn (2011) identified four learning milestones to incorporate innovation into engineering curriculum at Carnegie Mellon University:

1. Identify opportunities for establishing intellectual property within a defined technology area.
2. Search patent databases and read patents.
3. Apply technical skills to develop ideas for new technologies.
4. Work in teams to refine ideas and propose new technology. (pp. 58-59)

Similar learning milestones to those found in Washburn’s research were also found in the earlier two research articles (Gorman & Kagiwada, 1995; Sullivan et al., 2001).

Plucker and Gorman (1999) researched how to prepare future inventors and modified Gorman and Kagiwada’s post-secondary course for a three-week summer enrichment camp for gifted high-school-aged youth associated with the University of Virginia. The course was “designed in response to [the] lack of comprehensive programming in invention education” (Plucker & Gorman, 1999, p. 141). The same researchers followed up with the students a year later. From their qualitative research, Plucker and Gorman (1999) reported that the students perceived benefits from the group interactions and noted “the informal aspects of invention and the creative process left a significant mark on the students” (p. 146).

Sharif and San (2001) published a monograph on the establishment and success of an invention curriculum for upper secondary school youth in Malaysia. Malaysian upper secondary school corresponds to Grade 10 and Grade 11 in the United States. The curriculum was piloted in 1995 in 14 schools and expanded to 211 schools by 2001 with Ministry of Education
expenditures of U.S. $4.65 million (Sharif & San, 2001, p. 5). The aim of this curriculum, according to the Malaysian Curriculum Development Centre in 1996, was to “produce students who are creative, innovative, inventive and are capable of adapting themselves and participating in current technological changes and development through creating inventions that contribute toward the technological development of the nation” (Sharif & San, 2001, p. 19). This literature review did not uncover a high-school-level invention education curriculum, other than the widely implemented one in Malaysia.

Little peer-reviewed published research was found regarding elementary students and invention. Plucker (2002) noted that while there was an increase in attention given to invention in college and K-12, there was a “dearth of research on students’ preexisting conceptions of invention” (p. 149). Plucker (2002) researched Grade 6 U.S. students’ perceptions of invention and found that students had “few or simplistic conceptions of the invention or patent process” (p. 149), though the young adolescents had exposure to invention instruction or experience. Plucker (2002) unfortunately did not note what the instruction or experience was and concluded, “to dispel … superficial implicit theories, educators involved with invention programs should consider the use of active, situated teaching techniques such as project- and problem-based learning” (p. 149).

**Invention and Innovation as Interdisciplinary Team Endeavors**

Research stressed the necessity of collaboration and teamwork for successful invention and innovation. Jones (2008) stated, “[t]he innovator, wrestling with a creative idea, working with colleagues, and bringing an idea to fruition, seems at the very heart of the innovation process” (p. 283), indicating that working with colleagues is necessary at the post-secondary level. Jones (2008) concluded that innovators undertake significant education since they are not
“born at the frontier of knowledge” (p. 283) and that the “frontier of knowledge varies across fields … and over time” (p. 283). McNair, Newswander, Boden, and Borrego (2011) referred to innovators as being “T-shaped people” (p. 384). The vertical axis of the “T” is the disciplinary expertise and the horizontal axis is the ability to work collaboratively with a broad range of people. Taylor and Greve (2006) discussed that “deep-level” (p. 727) diversity of knowledge is necessary for innovation because cross-fertilization of ideas can result in a greater number of creative outcomes.

At their multi-week summer camp on invention at the University of Virginia, Plucker and Gorman (1995) researched the team endeavors or “group interaction” (p. 258) of the gifted high school students, and noted that invention activity is “ideally suited to division of labor based on multiple intelligences and talents” (p. 259). Besides technical and scientific knowledge, invention activity is a good focus for groups since it “involves verbal, logical, kinesthetic, and visual-spatial skills or intelligences and involves divisible tasks” (Plucker & Gorman, 1995, p. 260). Plucker and Gorman (1995) found that while technological success at some level was achieved, “delegation and compromise were almost nonexistent in almost every group” (p. 262). Given that group interaction and collaboration is integral to invention and innovation at the post-secondary, firm, or career level (McNair et al., 2011; Taylor & Greve, 2006), the efficacy of educators facilitating teams will be important to assess for determining best practices of teaching technological product innovation to high-school-aged youth.

Combining diverse knowledge is necessary for successful innovation (Taylor & Greve, 2006, p. 737). McNair et al. (2011) noted that creativity happens “in the crack between … different areas [disciplines]” (p. 383). Gorman, Richards, Scherer, and Kagiwada (1995) noted that post-secondary curricula compartmentalized learning, and this is not real world. They
described four hands-on projects based on historic inventions that included students from different disciplines in engineering, social sciences and humanities. Building upon this research, Gorman, Plucker, and Callahan (1998) noted in the only instance of teaching invention to secondary students that the modules helped break down the barriers to disciplines, allowing for students to learn the science and design while working in a group. Interdisciplinarity and teamwork required for invention and innovation are well researched at the post-secondary level. However, there is much to be learned about both at the secondary level, especially since NGSS includes crosscutting, interdisciplinary concepts.

**Summary**

According to a review of the literature, U.S. students are not competitive in their knowledge base of science and math, as compared to students in other developed countries based on PISA and TIMSS test scores over the past 20 years. Without a competitive knowledge base in science and math, U.S. students are less prepared for STEM careers and to be the inventors of the future that spurs economic growth. Great teachers are confident and have a highly-developed sense of self-efficacy regarding their content knowledge and engaging pedagogical practices, which may include inquiry-based, real-world projects that integrate STEM disciplines. Reports have stated that great teachers are the most important factor in ensuring excellence in STEM education. However, the research on how great teachers develop their confidence and self-efficacy is scant. There is much more evidence in the literature that describes successful schools and programs with a focus on STEM, and it can be surmised that there are great teachers behind these successful schools and programs, but their stories were not found.

This narrative inquiry focuses on STEM teachers. These teachers have facilitated inquiry-based, integrated STEM projects through invention with teams of high school students.
Invention necessitates the integration of STEM disciplines; however, developed curricula and professional development does not readily exist for invention. Additionally, these teachers’ students have showcased their inventions at MIT and at White House Science Fairs. The teachers’ stories may help illuminate the efficacy development of great STEM teachers and inform educational researchers, practitioners, and policymakers about how more great high school STEM teachers may be developed.
Chapter III: Research Design

Methodology

The purpose of this qualitative research using the narrative inquiry methodology was to explore how three high school STEM educators developed the capacity and self-efficacy that supported them to participate in InvenTeams, a nationally competitive grants initiative, and to facilitate technological invention projects. Their student teams conceptualized, designed, and built useful and unique inventions, each showcased at MIT and at a White House Science Fair. Their teams’ representation in these showcases served as evidence of the STEM educators’ efficacy. The research questions guiding this study were:

1. How do highly-effective secondary school STEM teachers involved with InvenTeams perceive their capacity and sense of self-efficacy?
2. How have teachers’ experiences with InvenTeams contributed to their students’ engagement and learning in STEM?
3. How have the teachers’ experiences with InvenTeams impacted their capacity and self-efficacy to enact cutting-edge change in STEM education in their schools?

Research Design

Ontological, axiological, methodological, and epistemological assumptions strongly align this research to the qualitative tradition. Creswell’s (2013) outline of these four philosophical assumptions and their implications for practice clearly positions the research as a qualitative study (p. 21). Ontologically, reality will be viewed and reported from several perspectives, including both the teaching and learning perspectives. Axiologically, the researcher will fully disclose her positionality and biases to inform the reader of the lens through which the data will be interpreted and findings summarized. The researcher was not neutral; her personality came
through (Rubin and Rubin, 2012, p. 15). Methodologically, the researcher used inductive reasoning throughout the research. Reflection of the data and revision of additional interview questions was an iterative process based on discoveries from each participant. The participants were not asked the exact same questions and in the same order. The goal of the research was to be fresh and “discover new themes and explanation” (Rubin & Rubin, 2012, p. 16).

The fourth philosophical assumption of epistemology, as noted by Ponterotto (2005), anchored this study within the constructivism-interpretivism research paradigm because it involved a dynamic relationship between the researcher and the participants. Dialogue and a construction of meaning took place between the researcher and participants over time. Epistemologically, the researcher was not isolated from the research participants; she closely collaborated with them. Participants’ quotes aided in the analysis and are utilized to report the findings. This assumption was a key determinant to the researcher’s decision to conduct this study utilizing a qualitative design.

Qualitative methods of research are contextual and “designed to describe and interpret the experiences of research participants,” (Ponterotto, 2005, p. 128) often using participants’ words to illuminate experiences. Narrative inquiry was one of five qualitative methodologies outlined by Creswell (2013) that he “most frequently see[s] in the social, behavioral, and health science literature” (p. 11). Narrative research projects contain features that include co-constructed chronological stories of lived experiences based on interviews, observations, and document collections. Stories are often then thematically analyzed and include turning points or epiphanies within the phenomena being researched (Creswell, 2013).

Huber, Caine, Huber, and Steeves (2013) explored narrative inquiry and its emergence as a research methodology in education from Dewey’s “conceptualization of the nature of
experience [that] engendered a way to explore experience” (p. 220) in the early 20th century to Connelly and Clandinin’s ongoing development and use of narratives in the early 21st century. Connelly and Clandinin (2006) noted that narrative inquiry “is a new methodology in education and the social sciences” (p. 477) and postulated that the method has now been accepted, since the method was included in the 2nd edition of the Handbook of Complementary Methods in Education Research. The two researchers authored the method’s chapter; the method was not included in the first edition of the same handbook published 18 years earlier. While perceived as a new method, the first reference of an article with a subject term of “narrative inquiry” as a research method was in 1895 in the Journal of Education (“The child’s interest,” 1895, p. 93). The method only became popular, however, a century later—beginning with Connelly and Clandinin’s seminal publication in 1990.

Narrative inquiry was selected as the most appropriate research approach because of its storytelling nature. Holley and Colyar (2009) noted that the role of researcher is that of a storyteller, and that this role was “fundamental to academic culture” (p.680). The researcher remains responsible for the trustworthiness of the findings, while positioning the text “as an informed reflection of the participants’ reality” (Holley & Colyar, 2009, p. 680) to engage the audience with selected and constructed stories.

Researcher’s Positionality

The researcher has been employed for almost a decade as the invention education officer for a high school outreach program from a school of engineering at a highly selective technical institute of higher learning. The program has been generously funded for over twenty years by an outside foundation headquartered in another geographic region of the United States. The
funding foundation was established by one of the most prolific inventors in the United States, Jerome Lemelson, and his wife, Dorothy.

The first part of the researcher’s career was in corporate new product development positions, conducting consumer research and developing innovative new products. After a hiatus from the corporate world to raise young children, she transitioned to teaching secondary school at a vocational technical high school where her business and technical background were relevant to students transitioning into the workforce directly from high school. After six years of teaching high school, the researcher’s family relocated and, at a technical institute of higher learning, she accepted a hybrid position that included new product development, engineering and invention, and K-12 education. The researcher’s real-world experiences, coupled with her knowledge of education in secondary schools, melded seamlessly into promoting the importance of educating the next generation of STEM leaders and young inventors. The researcher perceives herself as having a highly-developed sense of self-efficacy in line with Bandura’s (1977) four major sources of efficacy expectations and their diverse modes of induction.

The researcher aspires to help students make a difference in the world by promoting careers in STEM fields, with a focus on leading creative and inventive lives, which is aligned with her employer’s aims for the funded program. In her current position as the invention education officer, it has become evident that enriching the STEM learning experiences of students with technological product invention is made possible through their teachers. Teachers apply for program grants; students do not. Her work is laborious when recruiting and encouraging teachers to apply for a grant that requires them to do something they have never done before: utilize new practices of project-based learning, learn new hands-on skills, apply knowledge in different ways, work beyond the traditional school day and year, and manage
student-centric team learning endeavors. It is not uncommon for teachers to tell the researcher that fulfilling the grant requirements was the hardest thing they have ever done in their teaching career and an experience that they would not trade for anything.

As a scholar-practitioner in education, the researcher seeks to understand her positionality toward teachers, teaching, and doing things in new and different ways. Briscoe (2005) listed three dimensions of positionality: (a) demographics, (b) ideology, and (c) identity (p. 37). The effect of the work the researcher does is as great for the teachers as it is for the students. She feels that she can speak for a teacher as an inclusive co-participant, since she is similar in demographics, ideology, and identity to them. Not only is the researcher uniquely qualified in her job, she is also uniquely qualified as a qualitative researcher with a role as a co-participant. Since the teachers and researcher have shared similar experiences and have built strong rapports, the researcher understands their world and has the utmost respect for the work they do every day to engage their students in learning while fulfilling mandated assessment responsibilities, attending to myriad classroom management needs, supporting district strategies, and serving as mentors and coaches. Connelly and Clandinin (1990) quoted an unpublished work by Hogan (1988) that elaborated: “empowered relationships involve feelings of connectedness that are developed in situations of equality, caring, and mutual purposes and intention” (p. 4). The notion of equality, caring, and mutual purposes and intention is present in the storied lives of the participants and the researcher.

Before moving forward with the results of the research, the researcher wants to disclose her predisposition to qualitative research even though she works in a school of engineering where qualitative is not often a part of the lexicon. The researcher’s performance accomplishments early in her career—while working in R&D positions at corporations—were
heavily focused on quantitative consumer research. In her first professional job after college, the researcher found herself mired in statistics while working for a global producer of carbonated beverages in the throes of introducing a new product. She was aghast when one controversial product decision was made based on quantitative data that she helped collect and analyze. The numbers and the analyses were correct—for the survey questions asked—but consumers said much more about the products during testing. Unfortunately, there was no way to collect and share their words; consumers’ qualitative reactions were not taken into account. Their words had no voice.

Because of that early career experience, it is not uncommon for the researcher today to be the voice of teachers in the “living, telling, retelling, and reliving stories of experience” (Huber, Caine, Huber, & Steeves, 2013). Lopez (1990), a children’s book author, implored readers to take good care of the stories that come to them “and learn to give them away where they are needed” (p. 60). The researcher seeks to be a good storyteller for the teachers who participated in this research and others with whom she works; she gives their stories away where they are needed.

**Participants**

Three participants were recruited through a stratified purposeful sampling strategy. The researcher selected “individuals and sites for the study because they can purposefully inform an understanding of the research problem and central phenomenon in the study” (Creswell, 2013, p. 156). The participants in the study were employed by different school districts in three U.S. states as high school STEM teachers, and worked with teams of students on yearlong technological product invention projects through the grants initiative, InvenTeams. Each team had culminating experiences in national showcases of the inventions at MIT and at a White
House Science Fair. Participants were female high school STEM teachers who single-handedly facilitated InvenTeams from schools in which over 40% of students enrolled are eligible to receive free and reduced-price meals.

Twenty-five high school students representing 11 Lemelson-MIT InvenTeams have been invited to showcase inventions at the five White House Science Fairs hosted for President Obama by the Office of Science and Technology Policy. Only about 100 students—a tiny percentage of students—from across the country are selected to showcase projects at the White House from all STEM competitions. Quiriconi and Larson (2008) estimated that two million K-12 students are involved in STEM competitions each year. Besides InvenTeam students, the Office of Science and Technology Policy invited to the White House winners from competitions like the Google Science Fair, Intel International Science and Engineering Fair, Discovery Education 3M Young Scientist Challenge, Future City Competition, Broadcom MASTERS Competition, the National Youth Entrepreneurship Challenge, and the FIRST Robotics Competitions (Stone, 2015).

The participants for this research were recruited from the 11 educators whose students have been to a White House Science Fair as representatives of a Lemelson-MIT InvenTeam. None of the participants met President Obama during the fairs. Only their students had the opportunity to meet the President and engage him in discussion about their project; the students’ educators were offered remote live video streaming of the science fair in the Eisenhower Executive Office Building next door to the White House.

**Recruitment and Access**

The participant pool of high school STEM teachers was very small but accessible to the researcher. Select STEM teachers were asked to participate via an e-mail (Appendix 1) that fully
described the narrative inquiry; noted the approximate duration of time that the study required; and asked for access to documents, images, and video chronicling the invention process. The communication also asked that the participant be willing to edit and clarify qualitative summaries. The informed consent form was included as an attachment to the letter for the participants’ signatures (Appendix 2). The participants were not offered incentives to participate in the study.

Data Collection

The strength of the research came from one-on-one interviewing that produced accurate and credible results. Rubin and Rubin (2012) noted that accuracy “requires great care in how you obtain, record, and report what you have heard” (p. 64) and that this involves “laying out a process with such clarity and understanding that participants in the research recognize themselves and their world in the portrait [the researcher has drawn]” (p 65). The interview protocol can be found in Appendix 3. At the beginning of each interview and in accordance with the IRB, participants were given the option for the researcher to use their first names and not pseudonyms. The researcher could not guarantee anonymity since showcases at MIT and the White House had been public affairs with heavy media attention. All participants gave the researcher permission to use their first names throughout this research.

All semi-structured interviews began similarly through dialogue about each participant’s youth and education, educational philosophy, engaging teaching practices, and development of these practices. Next, the interviews included discussions about perceived self-efficacy before and after the invention process at their school. Finally, the interviews included discussion about the national capstone event at the White House. The researcher delved into the participants’ teaching history, professional development, educational background, and early developmental
years, all while probing for relationships between events, actions, and results that led to the development of their capacity and self-efficacy through performance accomplishments, vicarious experiences, verbal persuasion, and emotional arousal (Bandura, 1997). During the interviews, the researcher probed into the school conditions that supported the educators’ STEM instruction.

Data collection included a maximum variation of sampling and data collection approaches detailed by Creswell (2013). These included:

1. Semi-structured web-based or one-on-one interviews (recorded and transcribed);
2. Document collection including correspondence as well as documents provided in support of the invention process and selection for InvenTeams, such as resumes and statements of interest in invention;
3. Audiovisual materials that chronicle the process of inventing and the showcase of inventions at MIT and the White House.

A dedicated, password-protected, non-networked computer was utilized for this research. Data backup and storage was on a dedicated external hard drive.

This narrative inquiry study produced

- verbal interview responses, digitally recorded;
- written, verbatim transcripts of all interviews;
- handwritten notes produced by the researcher;
- archived data provided by participants to the Lemelson-MIT Program; and
- related and relevant images and videos.

**Data Storage**

All data was saved and accessed on a non-networked computer. Audio files were transcribed into verbatim text files and saved electronically on the dedicated hard drive. Data
was not shared. However, if the researcher shares the data in the future, she will adhere to the requirements of the Common Rule (45 CFR Part 690) for the protection of human subjects, and assign unique identification numbers to each case ("The Common Rule for the Protection," n.d.). The document that links the identification numbers with the individual names will be kept in an encrypted file on the secure hard drive should the data ever be shared.

Electronic files that contain all research data—including the text, audio, video, and image data—were created during the course of the research. All research data will be retained for a period of three years after the conclusion of the research, and thereafter, electronic data will be deleted from the external hard drive.

**Data Analysis**

Data collected from 90-minute semi-structured interviews with each participant and artifacts of the invention grant application and invention process were analyzed and organized to “reveal a specific plot that tells a story” (Holley & Colyar, 2009, p. 683) about developing capacity and self-efficacy. The researcher manually transcribed the interviews. Transcripts were then analyzed in the seven-step responsive interviewing model outlined by Rubin and Rubin (2012) that included first and second cycle coding. First cycle coding included in vivo coding and summarizing individual participants’ data, comparing across all participants’ data, and weighing and integrating descriptions. Second cycle coding combined themes, allowing for generalizations to the other participants within each research question.

**First cycle coding.** Manual coding of data was cyclical. Saldana (2013) stated that qualitative data are not coded but rather “recoded” (p. 58) in a cyclic, non-linear nature. The first cycle coding method began with in-vivo coding utilizing actual words and phrases to “honor
the participant’s voice” (Saldana, 2013, p. 91). These first codes were not generated or interpreted by the researcher; rather, there were “participant inspired” (Saldana, 2013, p. 93). Outstanding data was noted in analytic memos and thoughts were recorded. Saldana (2013) noted that researchers often use more than one coding strategy “to capture the complex process or phenomena in the data” (Saldana, 2013, p. 60). Therefore, the researcher also utilized narrative coding often used to explore identity development with some of the sub-coding schemes suggested by Saldana (2013) including

- tone including optimistic/pessimistic;
- setting including locale, environment, and supports within schools and communities;
- time including year, order, and specific mentions of use of time;
- storyline including turning point and rising action; and
- characterization including motivations, change, and transformation. (p. 135)

First cycle code development began by reading through the transcription of the interviews several times prior to and during the data analysis phase that included the development of the chronological individual profile stories found in the next chapter. The transcribed interviews included areas of emphasis indicated by bolding and italicizing words. Pauses and emotions were also included in the transcribed interviews. The participants’ voices, words, and terms were retained in the in vivo coding. These were noted in the right margins of the hardcopy transcripts. The in vivo codes identified major experiences and transitions as perceived by the researcher. Handwritten memos, notes, and thoughts were added to the hardcopy transcripts of the interviews and aided in the development of questions for follow-up conversations.

The researcher staggered the participants’ interviews with transcription based on the availability of each participant. In vivo coding and memo writing taking place over two months.
Member checking by all three participants followed the transcription. Member checking of the transcribed interviews were deemed accurate; two of the three participants added edits and clarifications to their transcribed interviews. The researcher’s in vivo coding and memo writing then took place following the participants’ edits of the transcribed interviews. Follow-up conversations took place via the telephone with two of the three participants; an in-person conversation took place with the third participant due to the researcher visiting the participant’s geographic region. The researcher took physical notes of all three follow-up conversations.

**Second cycle coding.** Summative essence capturing into categories or themes occurred when identifying patterns in the participants’ experiences. Second cycle coding followed Saldana’s (2013) axial coding strategy, which related categories to subcategories from the identified patterns in their stories (p. 218). The axial coding method supported the data analysis of the stories told by teachers of their lives, and aided the researcher in determining how participants developed their capacity and sense of efficacy to take on the challenges to conceptualize, design, and build an invention with a team of students assisted by mentors—thus enacting cutting-edge STEM practices. Themes were identified in relation to each research question.

**Trustworthiness**

Miles, Huberman, and Saldana (2014) suggested that trustworthiness through verification could be built into the data collection (p. 299). It was important in this narrative inquiry to experience the triangulation of data from three independent measures “to shed light on a theme or perspective” (Creswell, 2013, p. 251). The independent measures were different data sources of person, place, or time; different methods of data collection that included observation,
interviews, and documents; and different types of data collection such as audio, video, and text. Triangulation of data added validity to the study.

In addition to the triangulation of data, there was ongoing collaboration between the researcher and the participants to confirm findings through member checking. Participants had two opportunities to check findings. The transcribed 90-minute interviews provided the first opportunity for member checking; the participant profile stories offered the second. Member checking enhanced the trustworthiness and aids the study’s validity.

Credibility was ensured by careful research reported in a transparent manner. As noted by Rubin and Rubin (2012), “[a] transparent report allows the reader to assess the thoroughness of the design as well as the conscientiousness, sensitivity, and biases of the researcher” (p. 68). Transparent reporting included examples of coding, sorting of data, and memos noting probes during interviews that caused a revision in questions. Coding samples supporting the research findings are included in Appendix 4. Many notable quotes are included in the participants’ profile stories in the research results and summary.

Profile stories from the three participants produced rich, thick descriptions to add confidence to the generalizations of the researcher and may allow for the transference of information to other similar settings. However, Miles et al. (2014) cautioned that the generalizations are from one case to another and should not be considered a generalization to the “larger universe” (p. 34). With respect to this research, generalizations were not made to be the larger universe of all STEM educators in the United States, and the study’s limitations are discussed in Chapter V.

The potential threats to the internal validity of the research were addressed. Concerns regarding internal validity included the researcher’s experiences and biases. The positionality of
the researcher has been thoroughly discussed to clarify the researcher’s experiences and biases, which shaped this study in the first place. The accuracy of the narrative inquiry was documented by utilizing the accepted validation strategies of triangulation of data, member checking, prolonged engagement, rich and thick description, and clarified researcher bias (Creswell, 2013, p. 250).

**Protection of Human Subjects**

The protection of human subjects is of paramount importance. Their protection is ensured in several ways that include an institutional review of the proposed research by a board (IRB) at Northeastern University, training of the researcher, and informed consent of the subjects. The researcher’s Doctoral Thesis Proposal and the “Application for Approval for Use with Human Subjects” were reviewed and approved by Northeastern University’s Office of Human Subject Research Protection through an institutional review board. No collection of data from any human subject took place prior to IRB approval. The National Institutes of Health (NIH) Office of Extramural Research certified that the researcher successfully completed a Web-based training course, “Protecting Human Research Participants.” The researcher’s certificate was submitted with the “Application for Approval for Use with Human Subjects.” The research did not involve vulnerable subjects; English-speaking adult subjects offered their consent to voluntarily participate in the research by signing and returning an “Informed Consent Form” to the researcher (Appendix 2). The form included the potential risks and benefits of participating in the research and communicated that the subjects may opt out of the study at any time. The researcher offered subject confidentiality but the three participants gave the researcher permission to use their first names throughout the study.
Chapter IV: Research Findings

The purpose of this narrative inquiry was to explore how three high school STEM educators’ capacity and self-efficacy developed through participation in the InvenTeams competition, a nationally competitive grants initiative in which teachers facilitate technology-based invention projects with students. Their student teams conceptualized, designed, and built useful and unique inventions that were showcased at MIT and at a White House Science Fair. These national showcase events for students’ work serve as evidence of the STEM educators’ efficacy.

The exploratory research was guided by three research questions:

1. How do highly-effective secondary school STEM teachers involved with InvenTeams perceive their capacity and sense of self-efficacy?
2. How have teachers’ experiences with InvenTeams contributed to their students’ engagement and learning in STEM?
3. How have the teachers’ experiences with InvenTeams impacted their capacity and self-efficacy to enact cutting-edge change in STEM education in their schools?

The research findings are presented after a review of the study’s context to situate the reader in the participants’ worlds. The context is followed by narrative profile stories presented in chronological order for the three participants. Following the stories, each research question is revisited, accompanied by themes that emerged and generalized across the three participants. A conclusion summarizes the research findings and transitions to the final chapter, which discusses the research findings.
Context

The order in which the participants are presented in the research findings is chronological, based on when the participant received an InvenTeam grant from the Lemelson-MIT Program; the earliest grantee’s story is presented first. The three participants followed the same InvenTeam grant application process. They do not know each other personally, nor do they interact with each other. The known and apparent commonalities of the three participants before the research included:

- white female high school STEM teachers;
- teachers at schools where over 40% of the students were eligible to receive free and reduced-price meals;
- teachers of underrepresented minority students in STEM by race and ethnicity;
- Lemelson-MIT Excite Award recipients and finalists invited to submit a final grant application;
- InvenTeam grantees;
- student representatives of their InvenTeams showcased their inventions at a White House Science Fair after being presented by the Lemelson-MIT Program to the Office of Science and Technology Policy, who ultimately selected the representatives; and
- the researcher was the invention education officer during all three grantees’ experiences.

The InvenTeam grant process is a two-step process with application deadlines in the spring and fall. First, a STEM educator must submit an application that offers a preliminary discussion of an invention project that the educator, students, and mentors would like to build. The educator’s resume, a statement of interest in invention, and a letter of recommendation from
an administrator accompany the initial application. The Lemelson-MIT Program selects 35 Excite Award recipients from initial applicants and requires educators to attend EurekaFest in June at MIT—all expenses paid—where they receive professional development on invention education, feedback on their team’s project proposal, and information on how to complete the final application, due at the beginning of the school year in September.

While attending EurekaFest, educators observe the useful and unique inventions that the current year’s InvenTeams showcase at MIT. There is ample time for the Excite Award recipients to interact with other educators, InvenTeam students, and MIT faculty and staff. The Lemelson-MIT Program personnel and master educators affiliated with the program consult with Excite Award recipients during EurekaFest and continue to consult over the summer to assist teams in completing the final application. The final application, written by students with educator oversight, requires a thorough identification and discussion of the real-world problem that the team wants to solve with technology, and must clearly state the usefulness and uniqueness of the invention. The proposed invention in the final application must be positioned outside of protected intellectual property, have a well-defined beneficiary or end user, and provide images of early prototypes and the team. The team submits a budget for up to $10,000 and presents the project management plan for building a working prototype to showcase at MIT at the next EurekaFest. The Lemelson-MIT Program does not pay for the team’s travel to MIT at the end of the grant, so potential teams often include their fundraising plan in the final application. InvenTeam grantees are notified in October. They must be fully-functional teams at that time to build a working prototype to showcase at MIT at the end of the school year. This two-step application process overlaps two school years.
Participants were made aware that anonymity could not be guaranteed, given the public relations efforts of the Lemelson-MIT Program. The InvenTeam grantees are announced through a national press release. EurekaFest at MIT garners publicity in teams’ local communities and at MIT. The White House Science Fairs are extraordinary media events orchestrated by the Office of Science and Technology Policy. Pseudonyms were offered to the participants, but each gave the researcher permission to use her own name.

The individual participants’ data are chronologically summarized through narrative stories for Chelle, Randa, and Rachel. Their narrative stories have been created from various sources, including supporting documents submitted for their teams to receive InvenTeam grants, press releases and public documents, video components, and interviews with the three STEM teachers. The narrative stories begin with the researcher as a co-participant with the teachers in some aspect of their facilitation of an InvenTeam grant. The narrative stories are retold chronologically, offering views into their experiences in childhood and adulthood, their development as teachers, their pursuit of and participation in the InvenTeam grant, and finally, their current teaching practices.

The researcher has worked with all three teachers in a grantor/grantee relationship and had maintained an open line of communication with them since their grant year. The researcher presented each of their teams to the Office of Science and Technology Policy for the Lemelson-MIT Program; they were exemplary InvenTeam facilitators. The researcher has known the three women to be outstanding teachers dedicated to their students and theirs students’ successes. Their three stories are awe-inspiring.
Providing experiences Chelle

Growing up. Chelle grew up all over the world. Her dad was in international business working as a technical representative for turbine engines. The company’s hub was located in Phoenix, Arizona. Her story, as told to the researcher, was circuitous when asked how she was taught when she was younger. She replied, “I went to classes and did what I was supposed to do,” adding, “I started school in Iceland, moved to the states for most of elementary and then finished all but my last year in Europe, at an international school.” Her mother sought to give Chelle and her sister things that she did not have as a child growing up in a small Ohio town—a variety of different lessons, enrichment sessions at the library, and Girl Scouts. Chelle’s mom encouraged her and her sister to read, but she preferred playing with her racing set much more as a child. She referred to growing up as “fantastic” and “exciting.”

Chelle also talked about her father’s role in her formation. For example, she mentioned that she had had a difficult time in high school while reading a college-level textbook about German history, and went to her dad for help. She remembered that after he had read it over, he asked her what she did not understand. His ability to read and understand this material despite the limitations of growing up and receiving a high school education in a small town in rural America inspired her to work harder to make sense of the text. Rather than asking questions and merely waiting around for her dad’s answers, Chelle remembered responding to her dad,

“Never mind, I’ll go back and I’ll figure it out,” because I figured if he understood it so easily, then I could, too—neither of my parents pursued a college education—and, so I figured that if he could read this book then I could figure it out. And I went back and with hard work and determination...
Chelle mentioned how her dad taught her practical lessons. She explained, “I often got to help my dad fix things around the house when they broke. I haven’t thought about it before, but my mom didn’t have new appliances, so my dad had to keep things running.”

Chelle’s family relocated to Phoenix from Germany when she was in Grade 11. Having been in what she referred to as “rigorous international schools where students were much more aware of the world, spoke multiple languages, and discussed politics,” she found the transition to an American high school to be difficult. “I hated school and graduated early,” she said. Her mom and dad relocated to Egypt, Japan, and Taiwan while she stayed in the United States and attended Arizona State University (ASU). She remembered entering college after the term had begun and being disenchanted with a professor she thought had little interest in teaching and less interest in student outcomes. To her dismay, she got an “A” in that first college class.

Perhaps going to a reputed party school was not the best choice, as Chelle remembered, but ASU was the local college. She made comparisons with the “uniform system in Germany” and noted the non-uniformity of schools in the United States. Chelle mentioned being inspired by the film All the President’s Men, especially Woodward and Bernstein’s influential reporting of the Watergate scandal that led to the end of the Nixon presidency. She initially wanted to study political science and communications and planned to become a lawyer. She took a communications class in which the professor “prescribed a specific way to write and do things,” which disappointed her because there was no ingenuity or creativity involved. However, when one of her peers gave a presentation about the shortage of physics teachers, Chelle remembered that a high school physics teacher had once told her class, “You will never want for a job if you become a physics teacher.” Concerned for her future, she transferred to the School of Education
and to Physics and Mathematics, where her professors encouraged creativity and application of content through real-world experiences.

**A big experience changing out a transmission.** A significant life event that occurred during Chelle’s college years was changing out a transmission in a “new” car with her father. She retold this story of working and learning alongside her dad:

My first car was in need of repair all the time, which was frustrating at the time, but it was one of the best things that ever happened to me. We probably shouldn’t have bought it, but because my dad had made the decision [to buy the car], he felt obligated to help me fix it all the time (even after a full day’s work), and I learned a ton from him…. One time, we were putting this new transmission in and I realized that the bolt pattern wasn’t the same—the pins, holes, and bolts didn’t match up. So I asked my dad, “Isn’t that kind of essential?” and thinking “Why would we put something in that didn’t fit?” In response, he assured me that, “We’ll make it work. It’ll be fine.” So, we made it work … kind of.

A few days later, I came home one night and said, “Second gear won’t work.” And he asked, “Does first work?” When I responded, “Yeah,” he continued, “Does third work?” When I repeated, “Yeah,” he simply concluded, “Well, skip second.” In this simple interaction my father taught me both that there is almost always a solution to a problem and that in order to find it you must sometimes think outside the box. My father’s wealth of mechanical knowledge and life experience allowed him to do just that.

As in high school, Chelle graduated early from college. She earned an undergraduate degree in Physics and Math Education from Arizona State University. Graduating at just 20 years old, however, Chelle did not think she should go directly into teaching because she was so close in age to her potential students. Instead, she did a year of voluntary service with the
Franciscans, which she used as an opportunity to reflect on the purpose of life and her experiences up to that point; she also took a series of jobs as a substitute teacher, directed an after-school drop-in center for teenagers, and then did another year of volunteer service at a Catholic soup kitchen and shelter. There she got to know people “on the edge of society” while assisting with car and house repairs.

Chelle stated that when growing up, she “didn’t know people who were less fortunate,” although her parents were good role models for helping others. She recounted two stories in which her parents were concerned about helping others. One time, her father stopped to help a stranded motorist on the Long Island Expressway, even though her mom was worried about his safety. She also remembered a time when she, her mom, and some other people saw a group of hungry people in Jordan rifling through trash for food. When someone mentioned that the people needed money, Chelle’s mom observed that what they needed right then was a bag to carry the food they were gathering.

A big experience teaching up on the reservation. After this early period of varied positions, Chelle moved into the more traditional world of teaching on the White Mountain Apache Reservation three hours northeast of Phoenix. She elaborated on the experience, saying that she could “write a book” about teaching on the reservation that year. It was a “challenging” year, as she immersed herself in the traditional Apache culture while overcoming many obstacles. She was hired to teach junior high school science and math, but ended up being assigned Chapter One Math and eventually led the gifted and talented program for first through eighth graders. Meanwhile, the accommodations ended up being quite unique: she shared vivid stories about some of the living conditions she endured. Teachers normally lived either in a nearby town just off the reservation, or on “teacher row,” a series of small houses on the edge of
the school’s campus which housed non-Native American school personnel. There was insufficient space available on “teacher row,” so the principal arranged for Chelle to live in what she described as a “rustic apartment” in a barn-like building behind a Catholic church. She made a point of trying to arrive home early each day to chop enough firewood to heat her apartment and provide some for the priest who was not as adept at chopping wood. By October, temperatures dropped below 40 degrees and she had to repeatedly restock the woodstove during the night. She cautiously spoke up, explaining, “I valued working with the Apache and did not want people to think otherwise by asking for better accommodations.” The president of the school board was furious and she was relocated to a house on teacher row that was still under investigation by the FBI as a possible crime scene. “Adversity makes you stronger,” Chelle concluded.

Chelle valued this teaching experience. She received guidance from a Franciscan priest who lived in the reservation’s capital city. The “slower and simpler pace” on the reservation appealed to her. Years later, Chelle and her husband bought land near the reservation and built a cabin on it. She says she “would love to return to working with the Apache people.” She felt privileged to learn their culture, language, and traditions. After teaching on the reservation and visiting her parents who were living and working in Asia, Chelle returned to Phoenix to earn her master’s degree in preparation for renewing her teaching certification. She simultaneously began work in the Phoenix Union High School District.

**Teaching and learning.** The first big projects that Chelle did with her students involved converting gas-powered cars to electric cars. Thinking back to her earlier experiences of working on cars with her father as a teenager and young adult translated into her rookie years as a teacher. She believes that her teaching style is shaped by her own learning style, stating that
While I can learn by reading, that’s not my preference. I prefer to learn by observing and doing. I enjoy taking things apart to see how they work and then putting them back together. I enjoy watching videos about something I want to learn. I also learn by listening to people’s stories and experiences.

She added that when she started teaching there was “quite a bit of emphasis on diverse methodologies in instruction using specialized teaching strategies: kinesthetic, auditory, visual, and spatial,” so she tries to differentiate her instruction to include all students. She works with students to determine what type of learner they are. Chelle elaborated, “I try to incorporate a variety of learning styles in my teaching but it’s the spark in students’ eyes that lets me know when they’ve got it (in addition to the work they do).”

Chelle has now been teaching for 25 years. She teaches 100 to 150 students in a two-year-old integrated STEM program called Science Seminar and Engineering at a comprehensive high school with a student population of about 2,800 students, located southwest of downtown Phoenix. The area around the school used to be rural farm and ranching land but has become a residential section of Phoenix. Students come to her high school from three geographic areas: South Phoenix, Laveen, and a small town in the nearby Pima Indian reservation. The school was built in 1999; she came to the school at that time to help open it “under an alternative leadership style.”

A big experience opening a new school. The high school’s leadership structure was to be a collaborative effort between the school’s administration, certified teachers, and classified employees called the Educational Action Council. This council was to be responsible for leading the school, but she added, “It never really got off the ground.” There was also a staff senate in which representative groups of teachers, classified personnel, and administrators could come to
discuss issues, make policies, and resolve differences. She explained that other schools operated under a negotiated professional agreement and that there were rules about what groups could and could not do. Some educators came to believe that these rules made it difficult to try new things. By contrast, it was hoped that this new structure could lead to innovative changes in education because the staff senate could transition from proposal to policy in two weeks. It even responded to parent requests just as quickly. She shared one issue brought forward by parents who requested regular grade updates from teachers every three weeks. She reported that this change “was enacted and is still in effect to this day as a result of the previous organizational structure.”

The organizational structure “didn’t work out so well.” Chelle “joined a mass exodus” and transferred to another school in the district but then returned eight years ago when there was a change in administration. The organizational situation at the high school’s inception was explained as follows:

The leadership council was ineffective from the outset. Administration would make agreements to enact measures when they were in meetings with district personnel, and then return to campus and refuse to do so…. A small group of us decided to push the issue, so I ran for the lead teacher position in an attempt to help pull things together. When it became evident that the administration had no intention of fulfilling the mission of the school … we [the faculty and staff] decided to revert back to the professional agreement system that the rest of the district follow[ed]…. By the ten-year anniversary [of the school], there were fewer than ten original teachers still at the school. There are remnants of the failed leadership system still in place at the school aside from the three-week grade reporting. The school was designed and built for the collaboration and curriculum integration that facilitated Chelle’s current efforts to develop and teach an Integrated
STEM program. She credits the principal who just recently left the high school for bringing back curriculum integration so “students would really understand what they were doing—be able to put context to academic concepts they were learning.”

**A big experience with an InvenTeam project.** Chelle applied for a Lemelson-MIT InvenTeam grant “to provide students experiences that they wouldn’t have otherwise had” after seeing the grant described on an ASU Department of Physics LISTSERV (C. Myrann, personal communications, Dec. 12, 2015). She mentioned one freshman in particular who was interested in engineering and wanted to go to a prestigious university. She wanted to create experiences that would set her students apart from other students. In thinking back to when she applied for the grant, Chelle paused when asked how confident she was in her ability to lead students through an invention project. Eventually she said, “I thought we would figure it out … maybe 80%-90% confident.” She mentioned being concerned about how to make some parts of the invention—a physical therapy chair for fragile youth in their school—move: “I didn’t know how to make that work” and was “a little concerned.”

The InvenTeam grant application requires a letter of recommendation from a top administrator at the applicant’s school. The principal wrote Chelle’s letter of recommendation for an InvenTeam grant. He stated that she “is one of the finest educators I have come across in 30 years of service as an educator” (S. Gayman, personal communication, April 22, 2009) and that she consistently modeled what an educator should be.

Chelle approached facilitating the invention project analytically. When she attended EurekaFest at MIT as an Excite Award recipient and grant finalist, she talked with the current grantees about the process they had used. She calculated that 11 hours a week would be necessary to “replicate or engage in this program.” She then worked with students to determine
that the team would need to work on an InvenTeam invention two days after school, two Saturdays a month, and the rest of the time would be in her classes. Therefore, the project was both an in- and out-of-school project.

Communications and interface between the sub-teams working on the invention turned out to be the biggest challenge for Chelle and the team. She shared a story about the difficulties that were created because the CAD team leader did not understand scale. To begin with, learning CAD by using a reading-based, self-paced tutorial was not appropriate for Chelle’s students. She remarked that most of the students attracted to her program at that point were not kids who learned by reading, so she would work one-on-one with students as necessary. However, the CAD leader on the InvenTeam project was working independently and he progressed to the point where other students commented that he was doing “amazing things.” Looking at the CAD work, Chelle remarked, “Oh, that’s cool,” and inquired about the dimensions of the parts that he had drawn, only to learn that he “drew the whole thing and put all the pieces together but didn’t know that scale was an issue.”

Without dimensions and scale, the invention could not be fabricated using his model, which created “a bit of a problem.” Embarrassed, the CAD leader disappeared for a couple of weeks and only returned to the team after she went looking for him. Explaining how they got past this situation and came together as a group after talking individually with the one student she shared,

We met as a group and said, “OK. What are we going to do?” We decided that everybody was going to take a part of [the design] and [the CAD leader] was in charge of everybody drawing a part and then we put it together. We needed the measurements for each piece, so all we really needed to do was re-scale each piece and then assemble it.
Chelle determined her students’ engagement in the invention project by talking with them. She organized regular lessons and assessments early on, but there was so much to do as the project came to life that component completion became formal assessments. The students, she remembered, “were comfortable talking with people, for example … when they had the open house and they displayed their models.” They talked to the physical therapist and staff who came to offer input on the project. The team showed three physical therapy chair models. The chair attributes that were appealing to Chelle and the students did not appeal to the therapist so the team had to learn to accept the desires of the potential user and modify their design accordingly. Chelle remembered,

The models were made out of a variety of materials like wood, particleboard, hinges, foam, PVC, pool floaties, vinyl, velour, and Spandex fabric. Eventually, aluminum angle iron, steel, foam of various densities, and a barber chair base were used to make the chair prototype.

Chelle was initially overwhelmed by the idea of teaching invention. She neither agreed nor disagreed with the term “facilitator” when referring to her role on the team. She did agree that she did not teach invention early on; rather, she said, “We just did it.” She remembered doing a lot of research about the engineering design process and that the team used the invention handbook [from the Lemelson-MIT Program]. She invited people from the community to come into the school and help the team design. When asked if her confidence in facilitating the invention project stayed the same throughout the project, Chelle did not answer with a yes or a no. Rather, she responded, “I didn’t know what we were going to do when it came to raising funds to go back to EurekaFest [at MIT] because students wouldn’t engage in that conversation at all.”
A big experience making tamales to raise travel money. Things did not always go smoothly with the invention project. “When things weren’t working and I couldn’t think of anything else to try, I pulled people together.” At one low point in the project, when the invention design and build was progressing but fundraising was not, Chelle called a meeting with all of the parents. She remembered telling the students, “Your parents have to come.” She sent home notices and the parents came. The students presented their invention project to their parents and Chelle followed with, “You know, we need to fundraise.” She remembered that there was “a long period of silence and nobody said anything.” She continued her recollection of that night:

I told the parents all the information that I needed to tell them. They said nothing back to me. There was just silence which is pretty common in this culture, but pretty scary if you’re the one in charge. So, then Diego’s mom came late … the other parents were milling around looking at things in the classroom. And she went up to one of the other moms and said, “What was the meeting about?” They told her about the lack of fundraising and she said, “Oh, that’s no big deal. We’ll just make tamales. What’s the big deal about that? No big deal.”

The tamale-making story then unfolded in great detail. Chelle had never made tamales and did not know what ingredients were needed to make them. Chelle asked the moms to provide her with a list of ingredients, how much she needed to buy, and where she could purchase the ingredients that were unfamiliar to her. She remembered the rest of the evening in her classroom to be lively with the moms cutting in and out of Spanish and “laughing up a storm.” She surmised,
They had a great time looking at the white lady trying to figure it all out. I had no idea how much work was in store for all of us. They knew and didn’t mention that part … they just smiled knowingly.

With the moms’ list of tamale ingredients, Chelle called on a former teacher who opened the school with her in 1999—whose husband worked for a large food service company—to ask for recommendations on where to purchase the amount of meat needed for the tamales. Within minutes, the friend networked with vendors who donated the meat; Chelle’s contacts were integral to the tamale fundraiser. She asked the foods teacher at the school for the use of the kitchen.

The process to make tamales is extensive and requires special stoves. Parents brought in their big burners and the pots needed to steam the tamales. Chelle reiterated the process of how they prepared the tamales, starting on a Friday afternoon and ending at 11 p.m. that night. The next morning started early, at 7 a.m., when the cooked meat was put into a sauce with chopped dried peppers. She continued,

We made the masa (corn-flour mixture that is spread on the inside of the corn husk).

Javier’s mom was the leader and the assembly person. She put the meat mixture on top of the masa and people rolled them up. Then, we put like a tin can in the middle of a big pot and stacked the tamales in a cone shape around the can to cook them.

Chelle mentioned another “cultural disconnect” that occurred after the tamales were cooked. Parents and students took the cooked tamales and sold them without regard for the students who had already taken orders and payment in advance. Initially, there was no record of who took tamales to sell, how many they took, or how much money they were charging. When she tried to get specific selling information from the parents, they did not provide it. Chelle simply thought
the parents “didn’t know what they needed to tell me because they don’t know people who are unfamiliar with the process involved. It’s just what they do.” The tamale making had to be repeated on a subsequent weekend to fill all the orders because parents sold too many tamales on Saturday without leaving any for the pre-orders.

Selling tamales raised most of the money needed to attend EurekaFest in June. Another significant fundraiser was organized by one of Chelle’s colleagues for matching contributor funding with a dollar-for-dollar tax credit. This colleague wanted to help but did not think he could offer anything to the invention process so he set out to raise funds for the team. The two fundraisers in April—late in the grant year—provided the funds necessary for EurekaFest attendance for five team members and Chelle. She noted that the parents were proud to be involved with the fundraising. She thought that the parents were proud to be involved because, often in high school, parents do not know how to be involved with their children’s education. Chelle also remembered that this was a very difficult time economically and parents were “so busy and working so hard … just to make ends meet so that their kids could have more than what they have.”

**Connections in the community and the auto shop.** Once the hurdle of fundraising was over, Chelle mentioned, the team did not have confidence that the invention was going to get finished. She could not directly answer why the students lacked the confidence; they had experience working on a number of complicated robotics projects that involved last-minute things coming together. She conjectured that they were not seeing things come together because the move from prototype to building the full-scale physical therapy chair was difficult for them. However, the students’ confidence returned when she took the students, by van, five miles from the school to the auto shop where she worked “when we did the cars [conversion from gas to
electric].” The auto mechanic greeted Chelle with “Hey, teach! What’s goin’ on?” She said the shop people were “punking [sic]” her. She remembered the experience:

They knew more about how to build these types of things and I forget exactly what was said, but something like, “Why aren’t you clamping that up so we can get going?” or “What are you waiting for?” Years earlier I had worked with students at the shop. The owner had given me keys and the alarm code to $1,000,000 worth of tools and equipment … but that was years ago. He [the shop owner] still treats me as though we could come tomorrow, but this was new to the kids and they thought he and his crew were just going to do things for them. They became part of the shop in an instant. I wasn’t going to walk into his business after having been gone for so long and just presume to make myself at home. We were all down to business and having fun creating in no time. My students were surprised that the fellas would tease me and joke around … they don’t see me around my peers outside a classroom setting.

She surmised that the real confidence builder for the students was when they welded aluminum to make the design’s different arm and leg-support pieces come together and it started looking like a chair.

A big experience attending EurekaFest. School recessed for the summer in May but some of Chelle’s student team members kept coming to school to prepare for EurekaFest in mid-June. She remembered that the students worked an additional two weeks after school was out. There was more to prepare for EurekaFest than just the invention: the team needed a presentation. All of the students who put in the extra time to complete the invention and presentation attended EurekaFest. Chelle was “pretty excited” once at EurekaFest. She remembered being “nervous about our presentation materials because we did not have them
professionally done. The kids made everything.” However, the nervousness dissipated when a reporter from TIME, as Chelle remembered, wanted to talk about the project during the showcase at MIT. Unfortunately, the reporter stopped to talk when the students who were prepared for doing interviews were eating dinner; Chinese food was being served.

When the reporter showed up at their showcase table, Chelle offered to get the students—including Diego, their spokesperson, “who was really taken with the Chinese food…. It was a treat for the students, so to pull them away from the Chinese dinner was really hard.” There was an exchange between Diego and Chelle that began with this argument from Diego:

“Miss, really?” And I responded, “Dude, I will take care of you! I’ve been taking care of you for years. I will take care of you. Don’t worry about dinner … you will get to eat.”

He was just nervous about losing his Chinese food…. and the reporter was leaving. “You gotta go right now.” And so, he and a couple of kids went back [to the showcase area] and did the interview…. I thought they did really well. They finished their dinner between the interview and attending a presentation.

A big experience at the White House Science Fair. Chelle mentioned another incident later that year in Washington, D.C. that illustrated her pride in and care of her students. Two representatives from Chelle’s team were asked to attend the first White House Science Fair through an invitation organized between the Lemelson-MIT Program and the Office of Science and Technology Policy. On their own and without Chelle’s guidance, Diego and Antonio presented to President Obama the physical therapy chair invention that they had showcased at MIT. She said she had worried whether they would be “OK” in the White House, and whether they would have access to electricity and everything they needed to show the details of the chair. She also mentioned that she worried about the little things, “like I wanted to make sure their
shirts were tucked in and looking like sharp young men to represent us well…. and that they’d
give credit to the team.” She concluded that she was proud of them. Their presence and
participation in the first White House Science fair “floored” some of the teachers at her school,
especially the history and government teacher.

The White House Science Fair was new the year that Chelle’s team was invited to
participate. The science projects and inventions generated by award-winning programs were
showcased throughout the White House; the White House website described Chelle’s team’s
invention first on their list of exhibitors:

Student Team Invents Motorized Chair for Classmate with Disabilities – Diego Vazquez
and Antonio Hernandez hail from Phoenix, Arizona and represent Cesar Chavez High
School’s InvenTeam, one of fifteen schools selected nationwide. They won a grant from
Massachusetts Institute of Technology to develop a motorized chair for positioning
medically fragile students during therapies and daily living activities. InvenTeam is a
national grants program designed to excite the next generation of inventors and problem
solvers through hands-on learning, while encouraging an inventive culture in schools and
communities (The White House, October 18, 2010, para. 16).

President Obama visited only some of the displays, but one of those included Chelle’s
team. The showcase was followed by President Obama’s address on the state of STEM
education in the East Room, where students, along with VIPs, were seated. During this
inaugural White House Science Fair, teachers and parents were located in the Eisenhower
Executive Office Building next door, without access to the White House Science Fair but
connected through a closed-circuit viewing area with speakers from the Office of Science and
Technology Policy. President Obama called out Diego and Antonio’s names at the end of his
address and shared the story of the tamale-making fundraising that was necessary to attend the event at MIT (during his walk-through, the students had shown a short video of how they made tamales). There was a live link and the President’s remarks were webcast, so some of the teachers at their school watched in real time. Diego and Antonio returned from Washington, D.C. “as celebrities,” Chelle recalled.

Changes in teaching. The invention project changed the way Chelle teaches. She said that it “totally changed her expectations of kids.” She used to think that there were limits on what the students could do and that inventing was “something that you had to have really sophisticated education or experience to do.” The upward limit continued to change for Chelle as she had students with literacy issues looking at U.S. patents and reading to comprehend claims in patents. One of the parents put Chelle in contact with a patent lawyer who offered to work with her and the students to apply for a patent on their physical therapy chair. In the end, students Antonio, Diego, Javier, Juan Carlos, and Marcos, along with Chelle, the classroom teacher of the physically fragile students, and the physical therapist were granted a patent for their physical therapy chair (Hernandez et al., 2014).

Another way that the invention project changed the way she teaches is that she is more open-minded today. As a physics teacher, she used to correct students if they offered a solution that defied the laws of physics. She would speak up if she knew something would not work. After the invention project she said, “I want them to experience it working or not working.” One more way that she has changed her teaching is in making sure everyone is understood. She asks more clarifying questions “so that everybody could understand…. everybody could build that mental model in their head—if they couldn’t articulate as well as others.”
Chelle has been building a new set of articulated courses since her InvenTeam year. At the time of the invention, she was teaching physics, physical science, and science seminar. She has now expanded the course offerings for Grade 9-12 students. These offerings include two sections of science seminar to freshmen, two sections of engineering sciences, and one section of advanced science seminar (FTC robotics, invention, and EPICS). When asked what her plan is, she mentioned that she is trying to put the words of Professor Wallace [of MIT] into action. “Engineering is informed craft. So, I’m trying to integrate physics, math, engineering, and design skills with instruction on how to use tools and then asking students to go out and find problems that they, we can solve,” Chelle remarked.

Chelle tries to create experiences in which students can encounter real-world problems. She shared that sometimes teachers design learning so that “everything works out” and “all experiments yield meaningful measurements,” but that is not realistic. “Most of the time when something is novel, it’s because the unexpected happens and the search for understanding begins.” She stated that she wants students to experience difficulties to develop resiliency so “they don’t give up later in life.” Chelle uses STEM situations so the students can search for understanding while she and they “work together towards solutions.” She will bring in experts in STEM fields, when needed, to help move students toward solutions.

The equipment and facilities that Chelle’s school now has for invention projects include four CNC (computer numerical control) machines and a traditional machine shop with drill presses, band saws, sanders, drills, pipe benders, chop saws, and a variety of hand tools plus a spot welder, lathe, and mill. She now has ample floor space: a 1,100 square foot shop, a 1,640 square foot classroom, and 400 square feet of storage. The former principal who wrote the letter of recommendation for Chelle’s InvenTeam grant application first supported her use of this
space and equipment, which she and “the last CTE (Career and Technical Education) teacher” had lobbied to save even when CTE classes were cut. She worked well with the former principal, and remembered:

In the past, I would research current STEM curriculum and draw up ideas about areas of focus we could develop. I would then schedule a meeting with the principal to set program goals and develop a scope of projects to make sure we were working together towards a common end. It is important to me to uphold, stretch, and enflesh [sic] the school mission. I don’t want to operate in a vacuum. I also consulted with engineers in the field to ensure our program is relevant to the real world. He [the principal] had definite preferences about these things and his input was valuable. And, so, he would give me some input, um, but basically he gave me the freedom to do whatever I concluded should be done. It’s an empowering leadership style to give people who want to create the freedom to innovate. He would support these efforts with space, but I have always needed to reach out to the community for support or write grants.

This principal transitioned to a different position in the district and Chelle received a new principal in the summer of 2015. The new principal—who used to be a business teacher at the school—also supports the Integrated STEM program that Chelle put in place. As Chelle described the situation, “[The current principal] was one of the people I went to help me do … robotics and … had her help me practice with the kids to do presentations…. now she’s back with her PhD.” Chelle noted that the administrators do not “rally around what we do” but “they’ve just given me the keys and said, ‘Focus on innovation and inventing.’”

**Support at home.** Chelle has a supportive husband who teaches at a parochial elementary school. Prior to marriage, Chelle estimated that she worked 80 hours a week. When
asked how many hours a week she currently works, after a long pause she answered, “at least 60 hours a week.” Chelle and her husband adopted their first baby during her InvenTeam year, then adopted a second baby four years later. With young children, Chelle is worried about working too many hours and wants to “focus now on finishing projects and paying attention to all the details necessary for excellence.” Chelle concluded the interview with, “I’ve had a pretty fantastic life.”

*Be careful what you apply for Randa*

**Growing up.** Randa was born in Syria. Her Armenian parents lived in Lebanon but were visiting Syria when she was born. Just a week after her birth, her parents returned home to Lebanon with her. Randa’s father was a certified public accountant who worked for an American company in Lebanon after attending American University of Beirut (AUB); he spoke English. Thinking back to her childhood, Randa reminisced, “I feel like I had a *Leave it to Beaver* childhood in Lebanon, in Beirut.” She has no concept of what it would be like to live in a war-torn country since she lived there before the civil war broke out. Randa attended a French Catholic elementary school in Beirut. She spoke French and Arabic in a Lebanese dialect. She remembered loving her first grade math teacher, and that she loved learning. She wanted to be a teacher since the first grade.

Her father applied for and was denied Lebanese citizenship. This was at a time when labor laws changed to favor Lebanese citizens. Sensing that he would have difficulties remaining employed in Lebanon, he applied for and was granted a U.S. “green card.” The family moved to south Florida in 1971. Her father selected the location because a former professor of his at AUB was from south Florida. She specifically remembered moving to the United States in “November of the 6th grade.” When enrolled in school, she was placed in a
“low class” and remembered missing math. Randa’s family spoke only English at home after moving to the United States. She quickly learned English and was moved into regular classes by the next year when she was in the seventh grade.

**Teaching career.** Besides being a teacher, Randa’s choices for careers were park ranger, neuroscientist, and, later in life, a bookstore owner. Her dad discouraged her from careers with low pay that would not allow her to easily support herself. Teacher and park ranger fell behind a career as a neuroscientist. Her curriculum vitae submitted as part of the InvenTeam grant application indicated that Randa earned a B.A. in Psychology from the University of Florida, followed by an M.S. in Biology from Florida Atlantic University. She reflected that she became tired of school while working on her Ph.D. This was also when she met her husband-to-be. Not knowing what to do for a career at that point in her life, Randa answered an advertisement to teach at a private school. She took a teaching job at a Christian school and took classes to become a certified teacher. The professor of her last course was the then-assistant principal at the public high school where Randa teaches today. The professor/assistant principal encouraged Randa to apply for an open science teaching position. She did and is still there. Teaching at her high school “just happened,” she said.

Randa loves teaching science and is not ready to retire after teaching for 33 years, although her husband of 31 years wants her to think about retiring. Thirty of her thirty-three years of teaching have been in public schools in south Florida where a high percentage of students were eligible to receive free and reduced-price meals, and approximately one-third of the student population was white.

She has only taught at two public high schools since beginning her teaching at the private school; after three years there, Randa changed jobs to her current public high school. She had
taught at the current school for nine years when she said she was “surplused [sic]” to another nearby school because enrollments went down. The current school called her back when enrollments increased again. She added that she “ran back,” and when asked why, she remarked that she “loved the culture of the school,” where she felt there was kindness and appreciation for the teachers. The culture included hardworking teachers “that got along well.” The public high school where she taught in the interim had nearly identical student population demographics but she remarked,

The culture was completely different…. There was a lot of dissension amongst the teachers and between teachers and administrators…. my classes weren’t bad—but the hallways … it just had a different feel…. And the kids, there were fights, and you know, things that you don’t see [here].

Throughout the many years at her current high school, Randa has observed the increase in students who live in poverty. “At one time we were less than 40% free and reduced lunch and now it’s much higher. It’s changed significantly—the SES has really changed.” However, the ethnic and racial makeup of the school has always been Hispanic, African American, and white. In addition, Randa noted that while the number of poverty-stricken students has changed over time, the school’s culture has remained about the same. She has had only five different principals at her school; she’s had seven principals throughout her teaching career. Her most recent principal, whom she regarded highly, wrote her letter of recommendation for the InvenTeam grant. He recently left the school after accepting a district promotion. His written recommendation of Randa described her as outstanding, brilliant, professional, and resourceful. Regarding the new principal she said, “I think I’m going to love this man. I really like him.”

The new principal joined her school’s administrative team in the fall of 2015 from a nearby high
school, where he had stepped into the principal’s position from assistant principal on an interim basis. He has some, but minimal, experience as a principal.

Her current school has an enrollment of around 2,000. It is a magnet school in a town west and inland of Fort Lauderdale, Florida. The magnet programs include Latin and biotechnology. The entrepreneurship magnet school is being phased out next year to make way for a new alternative energy magnet program. The entrepreneurship curriculum is not unique to her school, though, and will remain but embedded in other courses. Randa elaborated that students apply to her school because of the magnet programs, and students must have a certain grade point average in order to apply to those programs. In the Latin magnet program, students “actually learn Latin and they have a Junior Classical League and we compete nationally,” Randa added to emphasize this magnet program’s importance to her school.

**Teaching and learning.** Randa elaborated on the philosophy that she’s developed in her years of teaching, mirroring how she likes to learn:

My philosophy of teaching is that I basically like to push students beyond what they perceive, um, is their own capacity because I believe that they usually don’t know what they are capable of doing…. I like to challenge them but I also like to, um, try to have fun doing it—not always, but—you know—learning can be painful…. But I also try to insert fun in discovery because I think it’s important for teenagers to explore and to do new things and to enjoy it.

She uses humor and a perception of choice in the classroom to help students enjoy learning. When describing how she learns, she said she “like[s] to read and then I like hands-on. So, I like to try things out but I also like to read first … and I like to work out problems by myself.”
Randa teaches AP Environmental Science and a research class. Randa began teaching research after becoming a Society for Science and the Public (SSP) Fellow and receiving a grant from that organization to establish the research class. As an SSP Fellow, she attended a training institute during the summer of 2010 at Portland State University. She elaborated, “[The] Society of Science and the Public … is the organization that plans the international science fairs or just science fairs, in general.” While at the SSP training, Randa met Mike, who had received a Lemelson-MIT InvenTeam grant previously. “Mike told me about it. Um, he’s also an SSP Fellow, so … we all worked together. We all shared information and he shared information about the Lemelson-MIT grant and encouraged me to apply.”

Randa admitted that she does not know why she applied for an InvenTeam grant. After some thought she added, “Actually, I like projects. And I think projects are fun. And I like the idea of a group project.” When asked how confident Randa was when she applied for an InvenTeam grant she responded,

I definitely thought that it was a real stretch, that it was a super long shot…. I was surprised that we even got the … I think it was called an Excite Award…. But once I went to the Excite … training, I loved it and I felt very grateful for all the learning and I definitely did not think we were going to get the grant after it seemed like everyone was super-duper engineers and wonderful teachers…. I definitely felt like I was, you know, the person who’s least likely to get the grant.

Randa had a similar modest response to her previous acceptance as an SSP Fellow and to receiving a grant that funded the expansion of the research program at her high school to support students’ science fair work. She thought it unlikely that she would be selected and was
“completely shocked and I just figured that hardly anyone applied” when notified of receiving the SSP grant.

Choice has become more important to Randa, especially in the research classes that she co-teaches with a Physics and Engineering teacher. The research class is organized so 50 students can do independent research or group invention projects; most students choose to do group invention projects using the EPICS framework. EPICS was founded in 1995 in Purdue University’s School of Engineering and focuses on the “role that engineering can play in the community” (EPICS Overview, 2015). “It stands for Engineering Projects in Community Services. And … it’s like doing a mini-Lemelson project but with a local issue,” offered Randa as a comparison to the scale of the Lemelson-MIT InvenTeam project. The district’s STEM coordinator introduced Randa to EPICS after the Lemelson-MIT InvenTeam project. Randa and the Physics teacher attended EPICS professional development and training in south Florida, and she said that neither of them knew anything about EPICS prior to training. She remarked, “When I went to the training, I fell in love with it.”

Randa submitted an extensive curriculum vitae to support her InvenTeam application. She earned a Bachelor of Arts in psychology and a Master of Science in biology. She’s certified in accordance with the National Board of Professional Teaching Standards. Randa brought four College Board Advanced Placement science courses into her school during a seven-year period when she co-chaired the Science Department. She was active in training institutes and served as a curriculum and assessment writer at local and state levels, an Advanced Placement biology trainer, contributing author and reviewer for textbooks, and a Society for Science and the Public Fellow. She is professionally affiliated with the National Science Teachers Association and the
National Association of Biology Teachers in addition to the Society for Science and the Public. Her references include district personnel as well as the principal at her school.

When Randa was applying for an InvenTeam grant from the Lemelson-MIT Program, her principal commented that she:

- is an excellent teacher who utilizes all of her resources to connect with her students by implementing activities in the classroom and after school that make learning interesting and fun;
- was our school’s Ecology Club sponsor in which the club planted a butterfly garden, relocated gopher tortoise burrows at Fern Forest, and collected unused telephone books for recycling;
- has taken students canoeing, snorkeling, hiking in the Everglades, and built birdhouses with elementary school students as a green outreach program;
- sponsored SECME, a competitive Engineering club, in which students made a bionic hand, designed a bridge, a water rocket, and a mousetrap car;
- demonstrates her dedication to the student body as a whole because she is known to stay after hours to tutor students, as well as offer her expertise to colleagues in assisting them with classroom preparation. (J. Williams, personal communication, February 28, 2011)

A big experience with an InvenTeam project. Randa and her team of students were notified about receiving an InvenTeam grant in October of 2012. It was a memorable day for her. Her team of 14 students worked on the invention project after school. Time was the biggest challenge for her; the team started out meeting two to three times a week, but towards the end of the grant, they met five times a week. Meetings lasted about two to three hours each, and she
and the team usually left the school by 6:00 p.m. When asked where they met, she answered, “in my Lemelson-MIT room,” which her administration had provided for working with the students on the invention. The room was in the science area of the school, approximately 600 square feet with center tables, perimeter cabinets, and countertop workspace. The room is still called the Lemelson-MIT Room.

When the grant was awarded, Randa had to manage the large amount of local publicity garnered from receiving the grant. Her team came to the attention of high profile people in local government and, in support of the team’s effort, the civic leaders invited the team to speak at various civic events. The amount of publicity actually became a problem, which Randa explained this way:

The community was so wonderfully supportive but to the degree that they wanted us to participate in all sorts of dinners … and speaking…. They weren’t meaning to be demanding … but they were trying to include us in so many rah-rah kinds of things—it’s what I call it—that it was keeping us from getting anything done. Plus, my students were all bright and taking AP classes so they were really getting stressed because they had calculus tests in the morning…. but we figured it out.”

Randa helped the civic leaders to understand how much work the team had to build the invention and asked one civic leader to come to an InvenTeam meeting and motivationally speak to the students about “how important it was to now get down and dirty … get busy working because there was so much to do.” Three of the community members remained active throughout the InvenTeam year and helped raise funds, participated in team building activities, and accompanied the team to MIT at the end of the grant year, when all InvenTeams showcase their inventions.
The physical facilities available to Randa were adequate for an InvenTeam project, though not extensive since her school was an academic high school, and not a comprehensive or technical school. Besides her classroom and the Lemelson-MIT Room, Randa had access to a welding lab on their school’s campus and described it in this manner:

It is only used at night for the night school and that was really helpful, helping us complete our project because we were going to have to go to a machine shop and do everything, but we were able to do it here.

She expanded on the importance of having the welding lab by stating, “Our welding teacher helped us, and taught us, and with his help [the water filtration invention] got welded.”

Support for Randa and the team was extensive. Aside from the support of the welding instructor, she had the assistance of the Physics teacher who still works with her in research classes. Randa also had the support of her entire administrative team, consisting of the principal and four assistant principals. Plus, Randa had support from technical mentors who came from the outside to talk to students. An oil engineer and MIT alumna was introduced to Randa during the InvenTeam project. Four years later, the mentor continues to talk to Randa’s AP Environmental Science students. Another MIT alumna has recently connected Randa to a local university with an engineering college, which is including Randa and her students on a computational science grant. Randa said that she has a great group of mentors from outside the school, but followed up with “we can always use more.”

When asked about the role she had on the InvenTeam, Randa used the terms “facilitate” and “coordinate” as being “right on the money because I know I probably knew the least about engineering in the group—now I shouldn’t say that—I definitely knew less engineering than two or three of my students.” She had a sense of knowing less with an invention project than with
the research projects where she actually taught students molecular biology and biochemistry. There was no real teaching with the InvenTeam project. “With the Lemelson-MIT project … we were all like discovering at the same time,” she said. In addition to technical learning alongside her students, Randa empowered the students to be leaders, instead of her. She noted that the team’s female project manager had the insight of a much-needed morale booster when Randa just wanted to continue working. Randa recalled, “I just wanted to stay and work but she was like, ‘we have to do this or we’re going to fall apart.’ And she was so right.” Randa remembered that team members “were butting heads” over work responsibilities. The student project manager planned an event one afternoon after school where the team went to a local park. One of the civic leaders “came and grilled hot dogs for us” and everyone played games. “It was a good stress reliever. It ended up making everybody kind of escape from the project and kind of brought us together again.”

Randa thought at the beginning of the InvenTeam grant year, “This should be someone else” and “I can’t believe I’m doing this.” However, she and the team had a boost in confidence when, still at school at 8 p.m., they got the invention to work for the first time. She remembered the evening like this:

[T]he first time we had water coming through and pumping I think it was just such a neat experience. Like, OK, we are going to get this done and it’s working and whatever we’re doing, we’re on the right track…. We were all high-fiving. We were on such a high, you know. Everybody was so excited.

Nevertheless, she was nervous when the team showcased their invention at MIT a few short months later. She said that she thought the other invention projects were “going to be perfect and super engineered.” Her team’s invention “was cool,” she thought. “I felt really good when
people came and looked at our [invention],” but she also stated that she was surprised by the number of people who stopped by her team’s showcase and looked at the invention.

**A big experience at the White House Science Fair.** A year later, Randa was contacted about the opportunity for representatives from her InvenTeam to showcase the invention at the third White House Science Fair in 2013. She remembered thinking, “Oh, gosh … I’m going to do all this work [updates on students and the project, plus gathering information for security clearances] … and it’s not going to be us, it’s going to be someone else.” About the White House experience, she says, “I still can’t believe—it’s surreal—everything.” Randa reflected on her experiences with the invention

I feel definitely that I am more confident, that, gosh, you just have to be willing that really no one is just a born expert at this stuff. You just have to be willing to work hard and learn. Things can get done and I think that for me, that’s the big take-away. 

After this reflection, she concluded with a warning to other educators who apply for grants—especially the InvenTeam grant. “Know what you’re getting yourself into,” she said. “I thought it was going to be a lot of work, but I think it was more work than I thought it was going to be.”

The InvenTeam students chose the invention project; Randa did not assign or influence the project selection. When thinking back to the InvenTeam experience, she mentioned that her InvenTeam students were motivated by their choice of invention. Had the idea not been theirs, she does not think that they would “have stuck with it as much.” Randa noted in her application for an InvenTeam grant that she had not taught invention but that she enjoyed “tinkering and creatively problem-solving for [her] classroom and laboratory activities.” She knew that her strengths were her “creativity, interest, enthusiasm, and commitment to bringing projects to fruition and to completion.”
Changes in teaching. Randa noted the importance of choice when reflecting on the expansion of the research class to include EPICS mini-invention projects. When she and the physics teacher, also referred to as the engineering teacher, put the mini-invention projects in place during the 2014-2015 school year, the two teachers “went out and found” the local projects from which the students could then select. These were not fully open-ended selections based on the students’ desire and she did not feel that the research classes were as successful as she would like. Pedagogically, Randa understands the need for students to have choices and options, and says,

If you can build in choices and options, students have the perception of then choosing to do something. I think they become vested. And I think, also, making things challenging makes them even more vested…. I feel like that is a motivation area that I … kind of knew but I didn’t know the extent to which it would motivate students.

When reflecting on the InvenTeam project, Randa said, “I don’t think [the team] would have stuck with it as much [had they not chosen the project]. They were really motivated by this project.”

Randa works to give students a lot of options “to demonstrate they understand something” and she works choice into this aspect of her teaching. Being an AP teacher where curriculum is prescribed, choice is much more difficult. Randa elaborated that she is experimenting with how to deliver material this year and is doing things “a bit differently.” She offered that she is trying to approach delivery in a more constructivist manner. After 33 years of teaching, Randa still tries new ways of teaching.

Randa’s teaching has had an effect on many, many students. Her students go to college—many with scholarships. She stays in contact with her students, including those who
were on her InvenTeam, and vice versa. Students send her text messages during the holidays.
She sends students text messages on their birthdays. She relies on Facebook and will “friend”
students as soon as they graduate from high school. She relayed the story of one female student
who represented the InvenTeam at the White House Science Fair, who calls Randa every week to
check up on her. The team leader from the InvenTeam will call Randa and ask if they can get
together; the former student still organizes picnics and reunions. Randa spoke proudly of “the
tech guy” who now works at a local technical high school, managing their IT. She sends him a
text when she has an IT problem and he responds to help her. When asked if she goes to former
students’ weddings, she answered, “Oh gosh, yes!” but added, “not InvenTeams yet.” Randa
continues to work 65 hours a week.

What’s a Breadboard? Rachel

Growing up. Rachel lives near the edge of the Mojave Desert in Southern California, an
hour and a half east of Los Angeles. When asked how she ended up living in the desert, Rachel
recounted her family’s move to the area and her first teaching position:

I lived by the beach until I was six, when my parents had the bright idea that they wanted
more land and … wanted to have animals … so they relocated our family—my brother
and I—to the desert when I was six and he was eight…. I grew up out here and went to
college, undergrad, in Montana and played volleyball up there…. After my first year
teaching in Montana, I decided I was ready to come home and I ended up getting
recruited back to my alma mater high school … They said, “You can coach both
volleyball programs, you can have the biology program, and the psychology program.” I
said, “Great!” and I taught there for 10 years.
Rachel credited her mother for helping to shape her life. Her mother was an elementary school educator for 38 years. “I grew up in her classroom,” Rachel said. She remembered that her mom was not strong in mathematics and that when she was in the fourth or fifth grade she would tutor her mom’s students in math.

Even though she grew up in her mom’s classroom, she never wanted to be a teacher because she did not want to be poor. “I was always going to be a doctor. Always.” She went to college with that aspiration. However, Rachel changed her life’s course coming out of her freshman year in college. She remembered thinking, “Man, I’m missing the mark. I’m supposed to be a teacher.” One of the reasons she changed course was that she recognized she had “workaholic tendencies” and knew that some day she wanted to have a family. She could not perceive herself as being both a doctor and “the parent that I want to be.” Rachel wanted to stay involved in the sciences and chose to major in biology.

**Teaching and learning.** Today, Rachel teaches at an early college high school. The high school is physically located on a community college campus. It is neither a magnet nor a charter school, but rather a public high school “composed of low socioeconomic students who display academic prowess through school work and extracurriculars [sic]” (R. Thibault, personal communication, April 3, 2013). In her personal statement on the initial application for an InvenTeam grant, Rachel offered that she had a “great deal of respect for inventions, especially ones that benefit the environment and humanity” (R. Thibault, personal communication, April 3, 2013). The principal who wrote a letter of recommendation for the grant noted that the STEM-focused school of approximately 400 students—one of the top 10 performing high schools in California—was only seven years old. The principal credited his teaching staff as well as the focused, eager-to-learn students for the school’s success. He elaborated that they wanted “the
Invent Team \[sic\] to be the next challenge for our students to apply the knowledge we teach and see how valuable what they learn can be” (M. Dutton, personal communication, March 28, 2013). Rachel, however, was not the focus of the letter of recommendation; the school was.

**Big experiences being recruited to teach—twice.** Rachel began teaching in 2001 at a private high school in Montana near where she had gone to college and received her Bachelor of Science degree in biology education with a teaching minor in psychology and another minor in mathematics. After one year, she was recruited to return and teach at her high school alma mater back in California. Rachel taught there for 10 years and thought she was ready to leave teaching. She earned a dual master’s degree of Public Health in Global Health and Maternal and Child Health. She recalled her transition of thought regarding her life as a teacher:

I needed something different and I thought I was going to join the Peace Corps and … go stomp around Africa or some place that was in need of my service…. After I went to graduate school … I came back to the classroom. I had a completely different appreciation for—my calling.

Rachel elaborated, “My students. I don’t know what it was. I saw them differently [after earning her master’s degrees]…. I wanted to give them what I knew and what I had experienced.” She also gave up coaching volleyball at this time and thinks that some of the energy she had put into coaching was transferred to her students.

At the same time she finished her dual master’s degrees, her principal—the one who had recruited her back to her alma mater—was starting the new early college high school. He called her. She remembered him saying, “Rachel, I want you to start the anatomy and physiology program…. Would you be willing to transfer?” She answered him with, “Absolutely.” She expounded that she needed a change and, at that point, she knew that she was going to be an
educator for the rest of her life. Graduate school had “reopened” her eyes to the vocation that she loved.

**A big experience teaching in a new school.** The resume that Rachel submitted for an InvenTeam grant was not up-to-date; it did not include her current teaching position and school. However, it extensively listed her various related professional experiences, from attending the 2007 National Global Health Conference in Washington, D.C. to being a community health development volunteer in the Philippines and Peru during the summers. Prominent throughout Rachel’s resume was her volleyball coaching at the club and varsity level. Professional competencies included AP Environmental Science and Psychology Summer Institutes, AP Psychology Exam reader, committee memberships for school improvement, and various certifications within education and public health.

She described the 8th grade students that the new high school recruits as “underprivileged, low socioeconomic … first generation college student kids that are also middle of the road students.” The needs of her school’s students match with Rachel’s philosophy of teaching. She shared more on her philosophy:

> My philosophy of teaching ultimately is that I am a servant of my students. It is my job to serve them or provide them with … an education and hopefully a love of learning.

And I have found over the years, that I tend to gravitate towards teaching the things that I’m most passionate about, so my teaching has evolved over time. Now I get to teach anatomy and psychology. And those are the two things that … I most love to learn about and so in that I’m able to, I think, display that love to the students.

Rachel described the way she learns as “a kinesthetic learner” and by inspiration; she shares her inspiration with her students. She noted that she uses a varied model so that students can learn
by taking notes, or by touching through labs and activities. She thinks that her style of teaching “has evolved through my teaching years … because when I first started, I was 90% of a lecture teacher, but that’s what I received in my education, so I didn’t know any different.”

Admission to the early college high school requires that students fill out a lengthy application in addition to submitting transcripts from their current and previous grade. Three interviews by a team from the high school are also required; these interviews are conducted first with the student applicant, then the parent of the student applicant, and finally the student and parent together. It is a rigorous application process that “gives more points to the kids that are B or C students.” The school is considered an AVID school—Advancement Via Individual Determination. She explained that the foundation of her school, while STEM-focused, is AVID. AVID is a national program that teaches kids to be great students through organizational skills and study skills. AVID has been part of her school’s success since it began with five years of grant funding from the Bill and Melinda Gates Foundation in 2006. Because of the success of students, the high school district and community college now divide the cost of the school without support from the Bill and Melinda Gates Foundation.

The physical site of the early college high school is very small in terms of square footage on the 135-acre college site that serves approximately 2,000 college students. Rachel described the school within a school as “nine bungalows in a row” located across from the tennis courts and nestled between the softball stadium and the Automotive Tech Ed building. Reflecting on the setting, she said, “It’s a very humble setting for the kind of education these kids are getting.” There are only 13 full-time high school teachers at her school, plus one part-time teacher who teaches physics on her school’s campus. Since there are around 400 high school students, the
student-to-teacher ratio is close to 30 to 1. There is no teacher’s lounge, either. Rachel explained,

All of our rooms are open during lunchtime because we want [the students] to know if they want to hang out with us, they can…. We don’t congregate a lot as teachers because that’s not what we’re here for. We’re here for the students to have accessibility to us.

The high school students take community college classes, too. In the four years the students are at the early college high school, the B and C middle school students are transformed into serious students prepared for higher education. Rachel shared with great pride, “We had 84% of our seniors this year graduate with at least one AA [associate’s degree].”

**A big experience with an InvenTeam project.** Rachel opened up with background information about her application for an InvenTeam grant, which offered insights to her as a teacher, and to the engagement and independence of her students. Rachel explained that the students at her school tend to spend much of their nighttime on the Internet trolling for new things. They all do it…. I ask them, “Aren’t you exhausted? Don’t you want to sleep?” But I think that’s how a lot of them relax. They look at YouTube and they learn new things. They’re also … very competitive.

One student found the InvenTeam initiative “trolling the Internet” and thought that she and fellow students should invent something. The student approached Rachel with the idea to apply for InvenTeams since teachers apply for the grant. Rachel thought that the student asked her because the student knew she would not say no—not because she was the most qualified teacher to work with students on an invention. “My students know that … I am bound to help them with whatever they need” and the InvenTeam grant was perceived as a need.
“I had no idea about MIT and the InvenTeams initiative,” she said. Rachel recalled that she was leaving for spring break and a trip to Italy when one of her anatomy and physiology students asked her to be an advisor for InvenTeams. “Yeah, sure. That’s fine. Absolutely. Just put my name down and tell me what you need,” Rachel remembered replying. The very resourceful student managed to have the InvenTeam application submitted on time and with a letter of recommendation from the principal. Rachel recollected that she was notified of receiving an Excite Award in late May. Once news of the Excite Award registered with Rachel, she sought out the student to find out what “she” had applied for. She remembered being astounded. “I had no idea. I was clueless.”

The student and her friends had met over lunch and conceived an invention project to include in the initial application. After learning of her Excite Award and trip to MIT, where Rachel was to receive feedback on the invention project, she sat with the students to have them explain their invention. The situation was frenetic for Rachel. Students were trying to convey their idea for the invention, which involved hydroelectric power, and she remembered that her small son was sick at the time, which compounded the situation of not understanding the students’ invention. Rachel’s trip to MIT for EurekaFest was not exciting; rather, it was fraught with a lot of angst, questioning, and fear.

Rachel revealed, in detail, how she felt attending EurekaFest and the subsequent excitement about returning home. She shared,

I get to Boston and I’m around all of these incredible educators that know so much more about physical science and engineering…. They’re talking about Maker Spaces and Project Lead the Way…. I’m trying to Google what these things are. I have no idea what these things are. So, it was like this completely different language to me and I was
petrified of the Saturday morning meet-ups with our advisor [master InvenTeam
educator] because I knew he’d see right through me like this chick has no idea what she’s
talking about…. But before we go to that, there was the Friday day—it was a long day, I
remember—but I came out of that so inspired because … we weren’t being taught how to
do an invention. We were being taught how to inspire kids. And that’s my work. You
know, that’s what I do…. I felt inspired as an educator, being told by these incredible
people at MIT how to spark interest, and be creative, and how to reverse engineer stuff so
that [students] can understand the inner workings, and teamwork. And, oh man, it was
the best professional development I had been [to] in all my years of teaching. And it
lasted a day…. I wanted to go back and meet with my administrator … and tell him about
what I had heard and learned.

She returned home after attending EurekaFest as an Excite Award recipient, and met with
the students the very next day. Rachel remembered the situation:

I only had four students and I told them, “We got to start over with our invention idea
because this doesn’t even make sense.” … So we started over. And we recruited more
kids. And we worked all summer trying to come up with an idea that the kids felt
passionate about.

One 11th grade student had said he was interested in being on the InvenTeam but then had missed
a couple of the summer meetings. Rachel called him on the telephone even though she did not
know him personally—she just had a list of names—and said, “I really want to see if you want to
be involved with InvenTeams because we have got to nail down our team and then go on this
adventure, but we have to have people who are committed and reliable.” He did indeed want to
commit to the InvenTeam, and to show his commitment, he rode his bicycle to the school—his
parents were not home to give him a ride—to join a meeting in progress. Rachel implored him not to ride his bike in the middle of summer in the high desert, but he insisted. Rachel recalled him arriving a few minutes later “dripping in sweat and out of breath.” Since the young man lived close to Rachel, she picked him up for summer meetings every day after that hot, sweaty bike ride. Today, the young man is a first-year student at MIT.

Rachel shared that the team did not come up with the idea for the invention that they submitted on the final application (in early September) until nine days before the due date. She remembered, “We wrote that application and we all felt really confident.” The team thought that the idea was good because there was not anything like their idea on the market, it solved a problem, and it was something that the team could do. “So we all felt really confident that it was going to work,” she concluded about building a personal breathalyzer bracelet that could detect blood alcohol levels.

The journey from attending EurekaFest as an Excite Award recipient to having students showcase and present at MIT was, at times, arduous for Rachel, the InvenTeam, and her school. Rachel thought that “one of the biggest challenges was time because our kids are so spread thin already with their high school and college schedules that finding common time is nearly impossible.” Her team of 14 students ended up meeting at the school once a week at 7:00 a.m. and then most Sunday afternoons at her house after December break. The period of time between December break and February is known as the “build period” in the InvenTeam grant cycle. When the team had to start putting things together, “there was no class that allowed for the collaboration” so the team met off-site at her home; she was assisted by mentors. Rachel says that she could not have worked the hours that she did without her husband’s support. Her
husband would take their one-and-a-half-year-old son across town to nap at the grandparents’ home during Sunday meetings.

While time was her biggest challenge, Rachel also experienced many technical hurdles that she listed as subordinate. “Finding the correct mentors was essential,” she explained. Her team was fortunate to have a parent who was a software engineer and mentored the team from the beginning. However, the team also needed electrical and mechanical guidance. For this, Rachel enlisted the help of her sister-in-law who introduced her to mentors from Raytheon Space and Airborne Systems, located south and west of Los Angeles. These mentors would drive one and a half hours, work with groups of students on a technical aspect of the invention, and then drive home. The mentors helped the team to understand the small scale in which they needed to build. This understanding was key to the team’s success. The team began working on “breadboards that were big” to help them understand the wiring, electricity, and how to code messages to alcohol sensors. However, the team needed to get to a scale small enough for the electronics to fit into a wristband. This happened, she remembered, in February, at the end of the build cycle and just months before the working prototypes were due to showcase at MIT.

When queried whether she knew what a breadboard was before the InvenTeam project, she laughingly responded in detail about what she did not know, which led the discussion into her strength in organizing:

The kids said, “We need to order breadboards.” What’s a breadboard? And so they’d pull up a picture [on the Internet] and show me. Great, what does it do? I mean, the kids taught me through the process. And that’s a little inside joke between the technical team and me. They’d pat me on the back and say, “Oh, Miss [T], you’re learning so much!” I’d say something technical and I’d [ask], “How did I do, guys?” I mean, I had no idea
but through it all I knew what I’m really good at is organization, and pulling everybody
together to direct everyone in the same line. That’s what I’m good at.

Fairness and the amount of workload every InvenTeam member carried concerned
Rachel throughout the grant year. She recognized that with a team, some members carry a bit
more than others “whether it’s because of their specific skill set or their knowledge or just their
internal work ethic.” She wanted to be fair to all the kids so she kept track of who was doing
what, who was contributing how much time, and who needed to pick up slack. She mentioned
that in three instances she had to sit down with parents and students to gauge the amount of
interest to continue with the InvenTeam. Rachel said, “They all picked up and all got back
involved and did their part.” All 14 students who started the InvenTeam year completed it and
traveled to MIT.

When Rachel was asked if she had ever facilitated a project of similar scope to an
InvenTeam project, she answered, “Not even close. The only thing that is even comparable in
my experience is coaching club volleyball.” The club volleyball season was very long and ran
from the beginning of November through the first week of June. In that amount of time, Rachel
noted that you could see the growth as you build a team around a common goal. She concluded
that this was the most comparable in time and commitment.

When asked about her confidence, Rachel said that it stayed high for the entire grant
year. She attributed this to “being stubborn.” After the high-fiving and hugging, she recounted
what she told the kids when they had received the InvenTeam grant:

You guys, this is going to be a wild ride. I have no idea what we’re getting into. I have
no idea how this is going to come together. But I do know that when we get to MIT,
we’re going to have a working, functional bracelet.
Rachel showed her stubbornness when she added, “And there was no way that was not going to happen.” After overcoming technical hurdles like figuring out the scale of the components and 3D printing, she said her confidence grew even more. Like a good coach, she reset the team’s goal. “We’re not just going to go with one [bracelet], we’re going to go [to MIT] with one on every team member’s wrist.” They came close to reaching that goal with nine working bracelets.

Rachel’s InvenTeam had an extreme amount of support from the district office, the school’s administration, and the administration of the community college. This was a triad of support that rallied around her and the students. She felt the support and knew that she would have whatever she needed to help the team succeed. It was known from the beginning that if intellectual property came out of the grant, it would belong to students and not the college or the district. “They were all so supportive of it belonging to the kids but still giving us what we needed to make it happen,” said Rachel and thought that this support helped build her confidence.

**A big experience attending EurekaFest.** However confident Rachel and her students were, coming to MIT to present and showcase their invention was a fearful experience. She shared her students’ and her mental and physical condition at MIT: “We were all petrified … the kids were so nervous. We’re lucky they weren’t vomiting beforehand. And we had stayed up pretty much all night going over and over [the presentation].” She continued to tell how they worked on the presentation until about two in the morning, going over the various parts with the communications sub-team. After that, the patent sub-team was up the rest of the night to finish filing the provisional patent, so that by the time the team presented they could say, “We hold a provisional patent.” Rachel remembered the precise time of submission; the provisional patent was filed electronically “at 4:35 a.m.”
When asked what she knew about provisional patents before InvenTeams, her laugh was similar to how she had laughed about her knowledge of breadboards. She responded, “Nothing! Are you kidding? I had no idea. I thought that was for people like Einstein. I didn’t know a commoner or a group of kids could file a provisional [patent]…. I knew nothing. Absolutely nothing.” Again, she credited her stubbornness for not being put off by lack of knowledge. She attributed this stubbornness to her mother, who told her as a child that she could do anything she put her mind to. Rachel said, “For some reason, I always believed her.”

Rachel was appreciative of all the support she received from her various administrators. She shared several stories about the types of support she had. She needed a 15-passenger van “to drive down to Costa Mesa to meet with a 3D printing company” for the InvenTeam project, and her principal made sure a van was available on very short notice. One of the school’s founders, the dean at the community college, stopped by Rachel’s classroom just before the InvenTeam’s trip to MIT to showcase their invention. The dean quietly wrote a personal check for $500 so Rachel could treat the students to a nice dinner in Boston, sending Rachel off with wishes for a great time.

Rachel ended the discussion about the InvenTeam by saying, “I shed some tears when I got home from Boston, out of gratitude, and I felt so satisfied with the commitment that I had made and followed through as a professional.” She felt she had provided everything the students needed, including her time. Even though she mentioned that it was a taxing year for her family and the rest of her teaching responsibilities, she felt she did her best as a professional, and “to support those kids in reaching their full potential.”

**A big experience at the White House Science Fair.** Student representatives from Rachel’s InvenTeam were invited to present the team’s invention at the fifth White House
Science Fair on March 20, 2015—nine months after showcasing the invention during EurekaFest at MIT. The team had continued to work on the bracelet design and Rachel privately hoped that they had proven themselves worthy of an invitation to the White House. Reflecting back to when she told the team that they had received the InvenTeam grant, Rachel said she knew it was “shooting for the moon” but thought, “we’re going to try and carry ourselves so that MIT would be proud to choose us for the White House Science Fair.” She knew that the team had been successful and met their goals, and to be considered for the White House was an added honor. After a spurt of flurried activity managing logistics, security clearances, and submissions of many documents required by the Office of Science and Technology Policy, the White House exhibitors were finally announced. On the White House blog, Stone (2015) described Rachel’s InvenTeam as having designed and provisionally patented a unique blood alcohol content (BAC) detection wristband, called ëris. The apparatus, which sits on the underside of the wrist, is 1/8\textsuperscript{th} the size of traditional breathalyzer technologies, at $20, about 13\% of the price of comparable breathalyzers. Upon blowing onto a miniature sensor in the wristband, the presence of ethanol triggers an analog voltage charge that is converted into a light-emitting diode (LED) reaction. Easily discernible colors indicate blood alcohol results to the wearer; green indicates the user is safe to drive (below legal limit BAC), and red indicates the user is not safe to drive (above legal limit BAC). The wristband is designed to be an appealing, viable option for adults and of-age college students who wish to drink responsibly. The team is currently working to file a utility patent, with at least one company expressing interest in a licensing agreement (para. 28).
Bill Nye, the Science Guy, and Victor Cruz, a wide receiver for the New York Giants, were two of the first people to tour the exhibits that day at the White House. One of Rachel’s student exhibitors was a fan of Bill Nye, who, to their delight, spent about 30 minutes talking to Rachel’s students. When he moved on, he left his coffee cup behind on the team’s showcase table. Rachel mentioned that her student returned to California with a prized possession from the White House: Bill Nye’s coffee cup.

**Changes in teaching.** Rachel’s administrators continued to support her. After the InvenTeam grant year, Rachel asked her principal for a book published in the popular press—“a novel about a neuroscientist”—for all of her students to read because it was inspirational and linked anatomy and psychology to the real world. She came back to school after April break and discovered that a complete set had been ordered. She relayed another story about the classroom trailer in which she teaches anatomy: it had carpet in it with lab benches bolted to the floor though the carpeting. Carpeting is not appropriate, however, for an anatomy lab in which animal dissections take place. Rachel was vocal in describing the “disgusting” carpet. One mention to an administrator—the assistant principal she described as the “heart and soul of our school now”—was sufficient to have her lab space renovated this past summer, with the carpeting removed. She is very grateful for the carpet-less science laboratory.

Rachel made two changes in the way she approaches teaching since InvenTeams; she is more patient and she spends time building relationships with students. Rachel explained she used to go “hard and fast” with introducing new ideas, but she learned what it meant to be patient with the growth in students, and that you cannot push the process. Additionally, she thought that her relationship-building with her students has changed. She experienced what is possible
because of the amount of time she spent building relationships with her InvenTeam students. To explain what she meant, she reminisced:

You know, you spend that much time with 14 students and then I was asking myself, “Why don’t I spend this much time building relationships in the classroom?” … These InvenTeam kids, they’ve been gone at college for a year … and they still send me text messages…. If they come back home, they pop in…. I know I’ll be at some of their weddings…. That’s how much these kids mean to me and, I think, me to them. And so it really made me ask the question, “Why are you not investing a little more time in the classroom in that relationship because look what you can do when you have that relationship with a kid?” You get more…. There’s more interest and there’s more inspiration and there’s more, I think, willingness to trust that I’m taking them on an adventure. It’s going to be worth it. It’s not going to be too hard. They can do it.

Rachel is a hard worker and gives much of her time and energy to her students. She gave an extraordinary amount of time and energy during the InvenTeam year and she continues to do so today. When asked how many hours a week she works, Rachel could scarcely fathom an answer. After pausing to come up with an answer, she conceded, “I don’t know. If a kid has a need … I don’t know how you put a number on it.”

Research Questions Revisited

Themes associated with research question 1: How do highly-effective secondary school STEM teachers involved with InvenTeams perceive their capacity and sense of efficacy? The thematic analysis conducted in response to Research Question 1 resulted in the following three generalizable themes:
• Grit. Chelle, Randa, and Rachel are all extremely gritty; they persevere to reach goals they set for themselves and their students.

• Resource-savvy. Chelle, Randa, and Rachel are experienced at reaching out for all types of resources to help themselves and their students reach goals.

• Strong instructional beliefs. Chelle, Randa, and Rachel are experienced STEM teachers who have developed strong instructional beliefs over time.

Each of these themes is discussed below.

**Grit.** Robertson-Kraft and Duckworth (2014) defined grit “as perseverance and passion for long-term goals” (p. 2) and noted that grit is different from resilience, which is “generally accepted to be a multidimensional construct describing successful adaption to overwhelming adversity and stress” (p. 9). Discussions and research about grit in education are more numerous with respect to students, but Robertson-Kraft and Duckworth (2014) researched grit in new teachers with respect to an increase in teacher effectiveness and retention. Chelle, Randa, and Rachel are far from new teachers, with nearly 80 years of combined teaching experience. Their shared stories, however, illuminated instances of perseverance and passion for long-term goals—grit—in many aspects of their lives, including their perseverance and passion for their InvenTeam projects.

The three high school STEM educators shared stories of their earlier lives in which they persevered. Chelle persevered with a difficult history book while attending a rigorous European school, and her experiences teaching on an Apache Reservation with a lot of adversity also illustrated her perseverance. Randa’s family relocated to south Florida from Lebanon when she was in Grade 6, and she persevered to learn English such that she was placed in higher level, English-speaking classes by Grade 7. Rachel persevered when working on dual masters’ degrees
while teaching full-time. Setbacks were not mentioned. Giving up on anything was not a behavior exhibited by these three educators.

The one-year-long InvenTeam grant challenged Chelle, Randa, and Rachel in different ways. Chelle was more challenged by fundraising. Randa was challenged with keeping 14 high school students focused and productive with the ebb and flow of long-term project work that included, but was not limited to, technical design and build work. Rachel was, perhaps, the most technically challenged of the three teachers with an invention project that included technology and science, about which she knew nothing. Both Randa and Rachel thought that someone else would have been better suited to facilitate their InvenTeams. Randa’s persistence was apparent in her words, “I didn’t want to quit anything,” while Rachel attributed her actions and confidence in completing the team’s invention although “she had no idea how it was going to come together” to her stubbornness. In short, these were three very gritty teachers.

Resource-savvy. Chelle, Randa, and Rachel were all extremely resource-savvy inside and outside of their respective schools. Being resource-savvy inside their schools included corralling personnel, tools, and workspace that were necessary to build a working invention prototype. Chelle partnered with the physical therapists in her school to provide information about the physically fragile youth their chair invention was being designed for. She also was able to arrange weekends in the school’s instructional kitchen to make tamales for a major fundraiser. Another example of Chelle’s inside assistance came from fellow teachers raising funds through matched donations. Randa received assistance from a physics teacher and the evening welding shop instructor. She was provided a workroom for the project that still bears the name “Lemelson-MIT Room.” Rachel’s inside resources came from a multitude of administrators who made sure she had what she needed for the InvenTeam to be successful. In
one instance, an administrator quickly arranged for a van so Rachel could transport the team to and from a 3D printing company.

All three teachers were quite savvy in marshaling resources outside of the school to assist them in many different ways. Chelle, Randa, and Rachel developed and utilized extensive networks of technical mentors. Parents assisted in fundraising efforts (e.g., parent-led tamale making and selling for Chelle’s team), assisted the team technically (e.g., parent and computer scientist mentored Rachel’s team), and made important introductions (e.g., a parent knew a patent agent and introduced Chelle). Businesses in the community assisted teams. One of the most unique instances of assistance was from the personnel at an auto shop that opened its doors to Chelle’s team to instruct, share tools, and help the students fabricate their invention.

Community leaders helped support InvenTeams’ efforts, including fundraising, technical feedback meetings, and public venues for students to hone their presentation skills with live audiences.

**Strong beliefs.** Chelle, Randa, and Rachel are caring educators who work long hours and maintain positive attitudes toward their profession, students, and administrators. There was no mention in any interview with these three teachers regarding difficult classroom disciplinary climate or problems with co-workers and administrators. On the contrary, the three educators spoke respectfully—and at times affectionately—of their students and parents, coworkers, and administrators. Chelle, Randa, and Rachel shared their strong beliefs about STEM instruction. Their beliefs, while not exactly the same, were similar and complementary with respect to facilitating inquiry-based projects and differentiated learning.

Davidson and Jensen (2009) reported from The Teaching and Learning International Survey (TALIS) conducted by Organization for Economic Co-operation and Development
(2009) that “stronger beliefs about instruction are related to stronger self-efficacy regardless of
the type of belief” (p. 234). No doubt, all three educators have strong beliefs about instruction
and have a high sense of self-efficacy. Chelle was very strong in her discussion about the
importance to offer a variety of experiences for her students. “I try to put all the materials on the
table and have [students] figure it out,” is one way Chelle described an instructional preference.
She learns by doing things; she also prefers to teach in a hands-on manner, but recognized the
need to differentiate instruction. Randa strongly offered how important it is for her to push
students beyond what they perceive is their own capacity. She offers challenges and fun
discovery. Personally, Randa likes to learn by reading and then she likes “hands-on.” Rachel
teaches what she most loves to learn about: anatomy and psychology. She strongly believes that
if students see how she is inspired by the topics she teaches, then the students have a greater
chance of being inspired. She likes to see and touch things, and provides varied instruction for
her students. Her favorite lab in her AP Anatomy class is a cat dissection; she does this lab “to
make it real.”

Themes associated with research question 2: How have teachers’ experiences with
the InvenTeams contributed to their students’ engagement and learning in STEM? The
thematic analysis conducted in response to this research question resulted in the following five
student-centered themes:

- Students are active participants in the process of inventing. Students on InvenTeams
  are actively involved in all aspects of the processes necessary to conceptualize,
design, and build a technological product invention.

- Students lead. Students step into leadership roles while teachers facilitate.
• Students choose. Students decide what problem they want to solve with a technological product invention.

• Students design their own solutions. Students work through scenarios and design technical and project management solutions.

• Students are resourceful. Students seek out what they need to be successful.

Each of these themes is discussed below.

_Students are active participants in the process of inventing._ A constructivist approach permeates the InvenTeam initiative, since neither the educator nor the students have experiences in inventing technological solutions. Students are empowered by the grantor and their teachers to assume leadership roles in the process of inventing. There is no passive transmission of knowledge from the teacher to the students. Knowledge and skills are learned, shared, and applied in a just-in-time manner between all team members: teachers, students, and mentors. The InvenTeam recruiting information promotes inquiry-based learning. Excite Award recipients—finalists for an InvenTeam grant—have the opportunity to observe the engagement of InvenTeam students and teachers when they visit EurekaFest and view the InvenTeams’ showcase of working prototypes at MIT. Excite Award recipients choose to “opt in” to this constructivist approach when they submit a final InvenTeam application.

_Students lead._ Chelle, Randa, and Rachel did not disagree with the term “facilitator” as the role they played on their InvenTeam. They were not teachers. Chelle neither agreed nor disagreed with the description, though she could not offer a better descriptor than facilitator. She commented, “We just did it.” She was a team member who worked alongside her students. Randa thought that the word “facilitator” was “on target” and added the term “coordinate,” too. She concluded with “facilitate … is right on the money because I know I probably knew the least
about engineering in the group.” She said that she and the students were all discovering at the same time. In one instance, Randa commended the leadership of one of the girls on her team who recognized team strife and put in place a much-needed team-building afternoon at a local park. “She was so right,” said Randa. “It was just an absolutely fun day at the park…. and it was really needed.” Rachel, too, mentioned learning along with the students. She made a joke out of her lack of technical knowledge, often asking students for feedback on how well she explained a technical situation. She definitely let the students lead the project, but she knew her strengths were organizing, pulling everyone together, directing, and coaching.

Students choose. Randa was the most outspoken of the teachers about the importance of choice and its effect on high school students’ engagement. She had always included some aspect of choice so students could decide how they wanted to demonstrate their understanding. She thinks that if students have a sense of “I choose this’ then it is a little more fun” and students do not feel like they are “being made to do it.” She thinks students become “more vested” when they choose to do something. Randa added hands-on projects to a new research class based on InvenTeams, and included EPICS (Engineering Projects in Community Service). She will have students this year go beyond choosing their project from a defined list to actively searching to find their own project that is meaningful for them and their community. Randa reflected on the InvenTeam project that the students picked; she does not think that the 14 students “would have stuck with it as much” had they not conceptualized the project and its beneficiaries in earthquake-ravaged Haiti. She added, “They were really motivated by [the InvenTeam project].” She desires that her students in the new research class will be similarly motivated.

Students design their own solutions. None of the teachers taught invention during their InvenTeam year. Their professional development as an Excite Award recipient (before receiving
a grant) taught them about inspiring students rather than offering a lock-step process for students to invent solutions or solve problems. While there were many design problems to overcome with each team’s invention (e.g., designing a transportable box that housed a bicycle-powered water purification system for 25 gallons of water, a physical therapy chair to assist therapists working with fragile youth, and a wearable breathalyzer for young adults to assess the effect of their drinking), there were also problems to overcome that dealt with project management. Time management, financial expenditures, communicating with community members, presenting to school administrators, and reporting progress to the Lemelson-MIT Program were all necessary project tasks to be managed. These tasks came with a multitude of their own small problems to be managed by students. Chelle, Randa, and Rachel, at times, had to simply support the students’ desired outcome. Chelle offered this one example about her students preparing a presentation for EurekaFest at MIT:

I had in my head what it would look like—I’d been to EurekaFest and I showed [the team] those kind of things—and they decided they were going to make a timeline….

“Um, can we do that? Is that how you do presentations?” And, [they said], “This is how we’re doing this one,” … I just let it ride. It was their decision and their work…. I just said, “OK. Get going.”

Students are resourceful. Students on all three InvenTeams had excellent role models in Chelle, Randa, and Rachel on how to be resourceful. The students could learn and observe vicariously, and they were actively encouraged to be resourceful. Even before the InvenTeam project, Rachel’s students were resourceful. They actually found the InvenTeam grant online and organized the application for the grant, which included recruiting Rachel and getting the school’s principal to provide documents in support of the grant application. Students were
resourceful in creating team-building experiences, as was the case with Randa’s team. Students built models before prototypes, using found materials like PVC and pool floatation devices, as in the case of Chelle’s team. Students also determined the materials they needed to have ordered for their invention. One funny quote from Rachel was when the students told her that the team needed to order breadboards. “What’s a breadboard?” she asked. The students showed her pictures on the Internet and spent time educating her. The InvenTeam grant allowed students to experience their own resourcefulness. Funds were provided on a VISA® card issued through MIT’s Purchasing Department, preloaded with the grant amount, which allowed for quick and easy purchases and returns. While the teacher was the only one allowed to use the card, students could source and recommend the materials needed and make purchase recommendations to the teacher.

**Discussion of themes associated with research question 3: How have the teachers’ experiences with the InvenTeams impacted their capacity and self-efficacy to enact cutting-edge change in STEM education in their schools?** The thematic analysis conducted in response to this research question resulted in the following three generalized themes:

- Teachers viewed their students as being even more capable. Chelle, Randa, and Rachel realized that they could expect even more from their students when they were engaged.

- Teachers changed structures in their schools to support project-based inquiry learning. Chelle, Randa, and Rachel added programs, classes, and clubs to support invention education and similar types of projects.

- Teachers continued to build efficacy and gain confidence in their own abilities to facilitate teams of students working on STEM projects. Chelle, Randa, and Rachel
continue to accomplish new things that positively affect their capacity and self-efficacy.

Each of these themes is discussed below.

**Teachers viewed their students as being even more capable.** Chelle, Randa, and Rachel were all strong believers in their students. Randa was most outspoken of the three educators on her students’ capabilities. As an AP instructor and science fair mentor, she mentioned that she “liked to push students beyond what they perceive … is their own capacity because [she believed] that they usually don’t know what they are capable of doing.” It was not uncommon for Randa’s students to win science fairs at the state and international level. Two of her InvenTeam students received highly-coveted scholarships, including the Gates Millennium Scholarship and the Lenore Annenberg Scholarship, in the year after their invention project and just prior to the White House Science Fair. Chelle and Rachel’s students, too, were going to college, though neither of them mentioned specific scholarships, science fairs, or other competitions during their interviews. Chelle relayed that her former student, Jesus, is at Stanford and that she helped another student, Carlos, with his ASU paperwork. One of Rachel’s InvenTeam students, Andrew, is at MIT, and she mentioned that another, Daniel, will be attending UCLA.

These three STEM educators worked to develop the capabilities of their students prior to InvenTeams, yet they upwardly adjusted their views of their students’ capability after going through experiences with the InvenTeam initiative. Chelle and Randa both thought that technological invention and patents were reserved for people different from them and their students. “I thought that [patenting] was for people like Einstein. I didn’t know a commoner, or a group of kids, could file a provisional patent,” Rachel shared. Chelle similarly commented, “I
used to think that inventing was something that you had to have really sophisticated education or experience to do.”

When the researcher asked Chelle if the InvenTeam project changed the way she teaches, she replied “[i]t totally changed my expectations of kids, like the limits I used to hold for them.” Rachel reflected on changes in the way she teaches since her InvenTeam experience. She thinks that if she invested more time in developing stronger relationships with students in her classroom—like she did with InvenTeam students—she could “get more” from the students since there would be more “willingness to trust that [she’s] taking them on an adventure” that will be worth it and not too hard. Rachel summed up, “They can do it.” Randa, who already liked to push her students beyond what they thought they were capable of, learned to what extent challenging projects, like the InvenTeam project, made students more vested and motivated; she has since implemented a new class that is required of all STEM magnet students that includes challenging, non-science-fair projects.

**Teachers changed structures in their schools to support project-based inquiry learning.**

Chelle, Randa, and Rachel all made changes to school structures to offer more project-based inquiry learning; all three teachers have great support from their administrators. Chelle, who has been affiliated with the Lemelson-MIT Program the longest of the three teachers, and is a non-AP instructor, has made the most changes to her school’s structure. She has been able to create an integrated STEM program titled “Science Seminar and Engineering.” The two-year-old program offers 100-150 students a continuum of elective class offerings. She has two sections of Science Seminar for freshmen, two sections of Engineering Sciences, and one section of Advanced Science Seminar in which students work on FTC robotics, EPICS, and invention projects. She now purposefully teaches invention, including the use of tools and materials, to
build solutions to problems. Students are challenged with going out in their community to find
problems that “we can solve.” She includes herself as a team member and helps to come up with
solutions alongside her students. Her approach is interesting: when students bring in problems to
solve, they assess whether or not the problem meets the “benchmark for inventing.” A problem
proposed by a student is not discarded, however, if it does not meet the benchmark. Rather,
Chelle says they consider it if “we can still build something for somebody or create a device for
somebody to use to make their lives better.”

Randa, an AP instructor and science fair mentor, also has a two-year-old Science and
Engineering Seminar class designed somewhat similar to Chelle’s. However, the class is a
required stand-alone program that supports the school’s magnet program, and unlike Chelle’s
class, there is not an emphasis on building solutions. Randa and a physics teacher have teamed
up to lead the Science and Engineering Seminar class, and like Chelle, they are utilizing EPICS
as a proxy for mini-Lemelson-MIT projects. Randa lamented that she does not think the seminar
class is as successful as she would like because students are required to take the class, which
removes some of the motivational aspect of choice. Ninety percent of the students work on
community engineering projects and 10% work on science fair projects during the seminar.

Rachel, an AP teacher, could not find common time during the school day for her
InvenTeam students to work collaboratively on the InvenTeam project. She thinks her students
are spread thin between their high school and community college classes. However, she still
continues with the InvenTeam Club that meets before school one day a week. The club accepted
six new sophomore members in the fall of 2015 and kicked off the year with a pool party at the
home of one of the original InvenTeam members whose father was a team mentor. The team has
devised supporting apprenticeship roles for new members and leading roles for upperclassmen.
Students are focused on long-term goals with the InvenTeam Club and recognize that this year will be a “think tank” year; next year will be a building year. Rachel has already begun to think about fundraising during the next school year, as they start the building process all over, but without grant funding from the Lemelson-MIT Program.

**Teachers continued to build efficacy and gain confidence in their own abilities to facilitate teams of students working on STEM projects.** A quote from Randa summarized her gain in confidence. Randa said, “You just have to be willing … no one is just a born expert at this stuff. You just have to be willing to work hard and learn.” Her quote can be extended to Chelle and Rachel, too. All three of these teachers willingly work in excess of 60 hours per week. Each teacher has continued to add to her experiences that have performance accomplishments. They actively learn alongside their students, and they institute new programs, classes, and clubs focused on engaging and motivating inquiry-based projects for the benefit of others.

Chelle, Randa, and Rachel continue to be guided by constructivist beliefs throughout their experiences. Randa specifically said that she wants to be even more constructivist in her teaching, though this is difficult with prescribed AP curriculum. Davidson and Jensen (2009) reported that “[t]eachers with stronger constructivist beliefs about instruction are significantly more likely to report higher levels of self-efficacy in all TALIS countries except Brazil, Bulgaria, Malaysia, and Mexico” (p.234). These are three teachers who, with close to 80 years of combined teaching experience and with a bent toward constructivism, continue to add to their experiences and build efficacy in their own abilities to facilitate students working on integrated STEM projects through invention. Their experiences include working to change challenging school structures such as limited time and space. Project-based learning is time-consuming and
requires appropriate space for students to fabricate technological solutions to real-world problems.

Chelle, the non-AP educator and the one who has been affiliated longest with the Lemelson-MIT Program, has designed a model curriculum supported with an expansion of fabrication space for building and storage of projects. She stated that this year she has “attracted some of the top kids, like the valedictorian in the senior class and a number of the top students of the senior class.” However, Chelle does not have a goal to recruit only the top students. She also wants to “attract the kids that might not be interested in going to a four-year university that … haven’t been real successful in school and would like to go into something technical.”

Randa has made changes to curricula to include project-based learning and has adopted a team-teaching approach with a physics and engineering teacher. Her school’s technical magnet programs now include industrial biotechnology and alternative energy, and she is helping to guide growth of the technical magnet school. One recent, new experience that Randa shared with the researcher was being included in a computational science grant with her Grade 9 students through a professor in the Engineering and Computer Science School at Florida Atlantic University. This connection was made through a technical mentor established during the InvenTeam year.

Rachel is an AP teacher with the least amount of flexibility in time within the school day, as compared to the other two participants. Nevertheless, she has added an InvenTeam Club that meets outside of the school day, and the club has recruited six new members who are sophomores. Rachel has not had to consider adding fabrication facilities to support technological projects because her school is on a community college campus that has shops for fabrication. Also, her school has recently created two feeder middle school academies with “maker space”
opportunities. These fabrication shops and maker spaces require Rachel to facilitate relationships for her InvenTeam Club to have access, rather than create space from the ground up.

**Conclusion**

The participants in this exploratory study shared their life stories, replete with experiences from growing up, becoming a teacher, and facilitating an InvenTeam project. Chelle, Randa, and Rachel are great STEM teachers. They are caring, hard workers who have high expectations for their students. The stories were analyzed through several coding cycles. Themes emerged and were generalized across all three participants. These research findings will be discussed in the following final chapter with respect to the study’s theoretical foundation, implications in light of the literature, implications for practice, and the study’s limitations. The study will conclude with a statement of significance.
Chapter V: Discussion of the Research Findings

Revisiting the Problem

High school STEM educators are being tasked to change the way they teach and to adopt different pedagogical practices, such as the inclusion of inquiry-based learning, crosscutting science domain concepts, student-centered classrooms, and multi-disciplinary capstone projects. All of these cutting-edge pedagogical practices are exemplified in the domain of technological product invention—a precursor to innovation—currently undertaken by a very small fraction of secondary STEM educators in the United States. These STEM educators who have tackled invention projects have been observed by the researcher to continually develop their sense of self-efficacy throughout the experience of inventing products with teams of high school students.

There is very little formal education, pre-service training, or in-service professional development on how to undertake technological product invention in schools. Yet, some high school STEM teachers have pursued these practices and have been highly successful in facilitating teams of students engaged in invention. Specifically, the participants in this research are three highly-efficacious secondary STEM educators and former grantees of the Lemelson-MIT InvenTeam national grants initiative. They did not have experience with technological product invention prior to facilitating an InvenTeam. The three participants have taught for almost 80 years, combined. This qualitative narrative inquiry study explored the life experiences of Chelle, Randa, and Rachel. The specific three research questions that guided this study were:

1. How do highly-effective secondary school STEM teachers involved with InvenTeams perceive their capacity and sense of self-efficacy?
2. How have teachers’ experiences with InvenTeams contributed to their students’ engagement and learning in STEM?
3. How have the teachers’ experiences with InvenTeams impacted their capacity and self-efficacy to enact cutting-edge change in STEM education in their schools?

**Review of Methodology**

A narrative inquiry study was conducted to explore how three high school STEM educators developed the capacity and self-efficacy that supported their participation in InvenTeams, a nationally-competitive grants initiative, through facilitating technological invention projects and, ultimately, enacting cutting-edge practices in high school STEM education. Their student teams conceptualized, designed, and built useful and unique inventions that they showcased at MIT and the White House. The goal of the research was to be fresh and “discover new themes and explanation” (Rubin & Rubin, 2012, p. 16).

The three participants—Chelle, Randa, and Rachel—were recruited through a stratified purposeful sampling strategy. The researcher purposefully selected these individuals and sites for the study because they inform an understanding of the research. The participants in the study were employed by different school districts in three U.S. states as high school science, technology and engineering teachers, and have worked with teams of students on yearlong technological product invention projects through the grants initiative, InvenTeams. Each team had culminating experiences in a national showcase of the inventions at MIT and at White House Science Fairs. Participants are female high school STEM teachers who single-handedly facilitated InvenTeams from schools in which over 40% of students are eligible to receive free and reduced-price meals.

The researcher’s positionality was fully disclosed, and positions the researcher as a co-participant. The researcher has been employed for almost a decade as the invention education
officer at the Lemelson-MIT Program, and was the administrator of the InvenTeam grant that each of the participants applied for and received.

**Discussion of Major Findings**

Analyzing Chelle’s, Randa’s, and Rachel’s stories illuminated the fact that all three teachers possess a certain amount of grit, are resource-savvy, and hold strong beliefs about teaching and learning that affect their sense of efficacy. Additionally, they have accumulated experiences (e.g., performance accomplishments) that serve as storehouses of efficacy and enabled them to tackle cutting-edge practices in STEM education, such as technological invention projects. Facilitating an InvenTeam project contributed to their students’ engagement with STEM learning in a multitude of ways that were constructivist in nature and student-centered. Finally, successful performance accomplishments, such as InvenTeam projects that were prominently showcased, produced an even greater capacity and self-efficacy, which contributed to the ability of the study’s three participants to enact additional cutting-edge change in STEM education in their schools. Each grouping of themes associated with the research questions is briefly summarized in the next three sections.

**Grit, resource-savvy, and strong beliefs.** Grit was not a word mentioned by the three participants but there was ample evidence of this trait throughout their shared stories. Chelle, Randa, and Rachel are “extremely gritty” as determined by the researcher based on observations over time and utilizing the 8-item Short Grit Scale published online from the University of Pennsylvania School of Arts and Sciences for use by researchers and educators (The Duckworth Lab, 2015). A couple of examples of grit included Chelle’s “We just did it” statement about how they invented a physical therapy chair that is now patented, and Rachel’s outrageous goal of
showcasing their alcohol detection bracelet invention at MIT on every team members’ wrist before they had fabricated one bracelet.

“Resource-savvy” was another theme that emerged from the interviews. This theme encompassed two of Bandura’s seven subscales, developed in 1998, to help assess teacher efficacy. These two subscales were efficacy to enlist parental involvement and efficacy to enlist community involvement. All three teachers were adept at identifying, reaching out to, and enlisting the help of parents, other educators, and community members. This savviness was necessary to marshal resources that did not exist within the schools. Chelle brought parents into the project, who made and sold tamales to raise travel funds. Randa enlisted the assistance of the evening school’s welding instructor, who allowed her team to fabricate on-site. Rachel’s personal connections brought technical mentors from a local defense contractor in to work with her students on miniaturization of electronics. Funding, fabrication, and knowledge acquisition were requisite for the teachers to successfully facilitate their invention projects.

Finally, all three teachers possess very strong beliefs about student learning and their teaching. All are cognizant of multiple learning styles. All are constructivists in their approach to teaching. All are hardworking. Chelle and Randa both said that they work at least 60 hours a week, while Rachel could not even put a number on how many hours she works. Chelle, Randa, and Rachel are compassionate and caring educators who seek to provide the best possible experiences for their students. Chelle works with her students and their families on college applications and the process of applying; most of her students would be the first generation in their families to attend college. This work sometimes includes trips with the student’s family to the local college admissions office to troubleshoot paperwork problems. Randa works diligently with students in preparation of science fair projects, and continues to follow their successes in
college and in life. She still has an InvenTeam reunion during the December holiday break; her InvenTeam students are now graduating from college. Rachel’s interviews during this research were filled with words of compassion and tears of joy for what her students were accomplishing.

Students are active participants. They lead. They choose. They design solutions. They are resourceful. Teachers are facilitators of InvenTeam experiences. Students and teachers often learn many of the technical and engineering aspects of an invention by working side-by-side. Rarely in the invention process was there a direct transmission of information to the students. Inventing a technological solution for a real-world problem does not come replete with correct answers: learning from failure is part of the invention process mantra. In the constructivist realm, teachers may model procedures and facilitate the process, but students lead the way to solving a real-world problem. Students research the approaches. They are resourceful in identifying and selecting tools and materials, and they recommend tools and materials to purchase. Students think up and design their own solutions. Finally, they build their prototype after choosing among various solutions. Students on InvenTeams embrace and become engaged with learning STEM. Piburn, Kraft, and Pacheco (2011) summed up a similar type of learning experience in the geosciences when they concluded “[w]e know that students learn best when they are engaged with real objects or phenomena, working in cooperative groups, solving complex problems, and interested in what they are learning” (p. 19). This quote from the sciences can be paired with a quote from the engineering perspective. Svinicki (2011) commented that “active learning and specifically active problem solving can be unquestionably confirmed as the best learning situation for learning the skills of both problem analysis and engineering design” (p. 15). Chelle, Randa, and Rachel all recounted stories of their teams’ cooperative process of inventing to solve complex problems that integrated science and
engineering while utilizing mathematics and technology to design solutions; the outcome engaged students to be actively involved in their own learning. Chelle’s InvenTeam sought to help physical therapists offer services to physically fragile youth in their school by designing a unique chair that would assist with limb movement. Randa’s InvenTeam, motivated by the desire to help people in earthquake-ravaged Haiti, built a bicycle-powered emergency water filtration system. Rachel’s InvenTeam designed and built a blood alcohol detection wristband—a mini-breathalyzer—for responsible adults after the death of a student in their community from a drunk-driving accident.

Teachers viewed their students as being even more capable, changed some structures in their schools to support project-based inquiry learning, and continued to build their efficacy. Chelle, Randa, and Rachel all had strong beliefs in their students’ abilities before the InvenTeam experience. However, their belief in abilities increased following the multitude of experiences that culminated in their students’ successful showcasing of working inventions at MIT, their students being perceived as celebrities in their schools and communities, applying for intellectual property protection, and being awarded a U.S. patent. Given the educators’ successes with InvenTeam projects and other project-based inquiry learning, two of the three educators were able to establish a new integrated STEM program or class. Chelle, the non-AP educator, started an integrated STEM program for Grades 9 to 12. Randa, an AP instructor, added a Science and Engineering Seminar class that supported her school’s bioscience magnet program. Rachel, the other AP instructor, teaches at an early-college high school with significant demands on her students’ time to attend high school and community college classes in addition to AVID instruction. Lacking time during the school day, their InvenTeam with new
members continues to meet in a club setting before school. Chelle, Randa, and Rachel all continue to add experiences (e.g., performance accomplishments) that build their efficacy.

**Discussion of Findings in Relation to the Literature**

**Self-efficacy and teacher efficacy.** Bandura (1977) conjectured four major sources of efficacy expectations and their diverse modes of induction. These four modes, ranked by effect on efficacy expectations, included: (a) performance accomplishments, (b) vicarious experience, (c) verbal persuasion, and (d) emotional arousal (p. 80). Bandura (1977) purported that “performance accomplishments provide the most dependable source of efficacy expectations” (p. 81). Bandura stated that the most powerful source of efficacy expectations evolved from mastery of an “authentic experiential base”—a performance accomplishment (Bandura, 1977, p. 82). Repeated successes in one’s actions raise expectations of future accomplishments.

Additional distillation of data focused on the large number of big experiences evident in Chelle’s, Randa’s, and Rachel’s lives through the stories they told. These big experiences incorporate Bandura’s social learning theory and expectations for high self-efficacy. Their major big experiences were included in the stories about

- changing out a transmission (Chelle),
- teaching up on the reservation (Chelle),
- opening a new school (Chelle and Rachel),
- working on an InvenTeam project (Chelle, Randa, and Rachel),
- making tamales (Chelle),
- the White House Science Fair (Chelle, Randa, and Rachel), and
- being recruited to teach at two schools (Rachel).
These big experiences, however, were not the only experiences that the three educators discussed. They discussed unique experiences growing up, as adults, and as educators. It became evident to the researcher that the educators’ lives were replete with rich and memorable experiences. Most of their experiences could be classified in the context of Bandura’s (1977) most dependable source of efficacy expectation: performance accomplishments (p. 81).

Interestingly, only Rachel mentioned being scared very early in the invention process, while attending EurekaFest as a grant finalist. However, the fear was not debilitating and she responded boldly with action, rather than being overtaken by the emotional arousal.

The data also indicated that Chelle, Randa, and Rachel exhibited evidence of having a high capacity and sense of teacher efficacy in addition to self-efficacy. Bandura (1977) identified “teacher efficacy as a type of self-efficacy—a cognitive process in which people construct beliefs about their capacity to perform at a given level of attainment” (Tschannen-Morgan, Hoy, & Hoy, 1998, p. 203). Tschannen-Morgan, Hoy, and Hoy (1998) stated that Bandura continued working on his social cognitive theory and developed a Teacher Self-Efficacy Scale in 1997. This scale included seven subscales and informed the interview questions for this study. The subscales were:

- Efficacy to enlist parental involvement,
- Efficacy to enlist community involvement,
- Instructional efficacy,
- Efficacy to influence decision making,
- Efficacy to influence school resources,
- Efficacy to create a positive school climate, and
- Disciplinary efficacy.
Efficacy enlisting parental and community involvement were discussed in detail by the study participants and emerged as a major theme associated with Research Question 1. Instructional efficacy emerged in themes associated with Research Question 2. Efficacies to influence decision makers and influence school resources emerged in themes associated with Research Question 3. School climates were rarely mentioned and there was no mention of disciplinary problems by Chelle, Randa, or Rachel. Therefore, Bandura’s last two subscales are not discussed in the research findings.

Chelle, Randa, and Rachel discussed a multitude of experiences, some of which were deemed “big experiences” in the thematic analysis by the researcher. However, when the qualitative data was distilled further, all of their experiences supported self-efficacy and teacher efficacy expectations. The researcher posits that the educators’ many experiences produced a storehouse of efficacy from their successful authentic experiences. Their storehouses of efficacy enabled Chelle, Randa, and Rachel to overcome doubts, lack of confidence, and even fear in the case of Rachel, when facilitating an invention project. In turn, their successful InvenTeam projects and White House Science Fair experiences continued to add to their storehouses of efficacy.

A final distillation of the data for Bandura’s four sources of efficacy expectations revealed that, while the educators discussed mostly performance accomplishments, there were some mentions of verbally persuasive events and vicarious experiences. There was only one mention of emotional or physiological arousal. Educators mentioned verbally persuasive events with MIT professors, school and district administrators, and their peers. They also mentioned vicarious experiences through Excite Award training at MIT, other in-service professional development, and from their parents who were role models. Emotional arousal to the point of
debilitating fear did not exist with these educators but Rachel mentioned being scared. Evidence from interviews with Chelle, Randa, and Rachel that helped fill their storehouses of efficacy are included in the table below:

<table>
<thead>
<tr>
<th>Performance Accomplishments</th>
<th>Vicarious Experiences</th>
<th>Verbal Persuasion</th>
<th>Emotional Arousal</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 years of teaching Made tamales for</td>
<td>Worked in a soup kitchen</td>
<td>“Professor Wallace says”</td>
<td>“I was scared.”</td>
</tr>
<tr>
<td>fundraising</td>
<td></td>
<td>“Mike encouraged me to apply”</td>
<td></td>
</tr>
<tr>
<td>“We just did it.”</td>
<td>Worked in an auto shop</td>
<td>“It was always his hope for articulation”</td>
<td></td>
</tr>
<tr>
<td>“Let me help fix things”</td>
<td></td>
<td>“Inspired by being told”</td>
<td></td>
</tr>
<tr>
<td>Ran varsity cross country while in middle</td>
<td>Replaced a car transmission</td>
<td>“My mom always said…”</td>
<td></td>
</tr>
<tr>
<td>school (equivalent) in Germany</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freedom to do</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submitted a design patent</td>
<td>Coached club volleyball</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New research and engineering class</td>
<td>SSP fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“I knew if we asked for help, we’d get it”</td>
<td>New STEM program</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hold a provisional patent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work out problems by myself first</td>
<td>Water pumped through the invention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taught full time while earning dual master’s</td>
<td>Filed provisional patent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>degrees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graduated from college at 20</td>
<td>Got job at current high school directiy out of teacher prep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taught at community colleges</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International Community Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Articulated high school to college classes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contributing text book author</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**STEM Pedagogical Practices.** This exploratory research study brought to the forefront relatively new areas in the pedagogy of STEM education that were not apparent during the literature review, but gained in importance as the research continued. Implications for theoretical research may not be common for scholar-practitioners, but the researcher offers two
areas for additional research that she perceives as important to build a theoretical basis of STEM teacher efficacy with respect to project-based inquiry learning. The first area of new theoretical research may seek to integrate the modes of “facilitation” versus “teaching” student-centric projects and determine the effect of grit in relation to the consequences of STEM teacher efficacy. A second area of new theoretical research may seek to incorporate pre-service and in-service teacher socialization and their effect on STEM teacher efficacy.

Tschannen-Moran et al. (1998) formed the following framework for teacher self-efficacy, which is rooted in Bandura’s four sources of self-efficacy: mastery experience (e.g., performance accomplishments), vicarious experience, verbal persuasion, and physiological arousal (e.g., emotional arousal).

![Diagram](image)

Figure 2: Framework of the teacher self-efficacy formation by Tschannen-Moran, Woolfolk Hoy, and Hoy (1998, p. 228)

This framework was the basis of Yoon, Evans, and Strobel’s (2012) development of a teaching engineering self-efficacy scale (TESS) for K-12 teachers, presented at the American Society of Engineering Educators Annual Conference. Tschannen-Moran et al. (1998) centered the framework on teachers’ perceived performance in class, which included an analysis of
teaching task and an assessment of personal teaching competence. Project-based inquiry learning, however, is not focused on teaching tasks. This 1998 framework may work well with direct transmission of content but may be less flexible with constructivist beliefs that include active learning. Also, consequences of teacher efficacy in the Tschannen-Moran framework included “goals, effort, persistence, etc.” Where does grit fit into this framework? How synonymous are grit and persistence? Robertson-Kraft and Duckworth (2014) defined grit “as perseverance and passion for long-term goals” (p. 2) and noted that grit is different from resilience, which is “generally accepted to be a multidimensional construct describing successful adaption to overwhelming adversity and stress” (p. 9). To be more contrarian, this researcher posits that the personality trait “grit” may not even be a consequence, opening up the question as to where does grit enter into this framework?

**Invention as inquiry-based integrated STEM learning.** Chelle, Randa, and Rachel are exemplary STEM educators who have facilitated teams of high school students to conceptualize, design, and build technological solutions to real-world problems. They facilitated teams of high school students in a manner that has been recently recommended for undergraduate science and engineering courses. Kober (2015) recommended undergraduate science and engineering classes use philosophical and pedagogical approaches like process oriented guided inquiry learning or student-centered active learning environments with upside-down pedagogies to engage students in their learning. Kober (2015) interviewed college professors about how they are engaging students. She discussed an approach to getting started and included quotes from her interviewee:

> Several of the instructors interviewed … started out by using curriculum materials developed by others, an approach that is time-efficient and cost-effective. “Stand on the shoulders of giants,” emphasizes Noah Finkelstein, a professor of physics at Colorado.
He offers this analogy: Although lasers are used in his physics classes, he does not have to build a laser system from scratch. “I build on the work that others have done on that system…. I go to the laser expert; I don’t want to have to become the laser expert.” (p. 45)

Chelle, Randa, and Rachel took this same approach. They utilized the materials provided by the Lemelson-MIT Program. While not curriculum, per se, the materials offered the process with which to guide inquiry learning that is student-centered. Being resource-savvy, Chelle, Randa, and Rachel stood on the shoulders of giants, found the experts, and marshaled resources that their students needed to successfully build and showcase an invention that solved a real-world problem. These three STEM teachers are out in front of other high school teachers. They have figured out how to facilitate this type of instruction—one that is not prevalent, but has been identified for many years as a way to engage students with their learning.

The literature review noted that Washton (1956) surveyed science-teaching literature from 1938-1955. His survey concluded with 16 changes that would lead to a “more economical, effective, and inspirational program of science” (p. 385-386). Chelle, Randa, and Rachel are utilizing the majority of Washton’s changes, including that students plan studies of choice, clubs (out-of-school-time) offer opportunities to gain scientific understanding, a multidisciplinary approach is used for teaching and learning, and community problems produce favorable results. Washton’s subsequent textbook, *Teaching Science Creatively in the Secondary School* (1967), stated that two of the major purposes of the textbook were to “help [science teachers] to modify or to adapt new science programs to fit into the needs of the community, the students, and the teacher” and “to provide the guiding principles and methods of teaching science creatively through inquiry” (p. vii). Fast forward to 2011 and three generations later in which the National
Research Council reported that successful K-12 STEM education remained an exception, but has students working on real-world problems, carrying out scientific inquiries, and designing engineering projects. Two of the three successful approaches to STEM education were included in Washton’s list; designing engineering projects was a new addition not included on Washton’s list.

The Lemelson-MIT Program has demonstrated since 2003 that almost 200 teams of high school teachers, students, and mentors can implement technological product invention projects to such a level that the inventions may be patentable. Technological product invention incorporates Washton’s list of 16 characteristics of inspirational science programs, and the National Research Council’s (2011) short list of three characteristics of successful K-12 STEM education. There is still a lack of attention to invention in science curricula in the United States, as Plucker (2002) noted. The importance of invention and the creation of value from invention through bringing innovations to market remains “a crucial determinant of the global competitiveness of nations” (OECD, 2007, p. 3). The Lemelson-MIT Program is poised to address the need for invention education.

**Visions of exemplary STEM Learning and Teaching.** Shifts toward a constructivist view for student and teacher science learning were evident over half a century ago in Washton’s (1956) list of characteristics of inspirational science programs. These characteristics included students and teachers co-creating classes, real-world connections, and integration of concepts across subjects. Washton (1956) clearly laid out in the pre-Sputnik era 16 characteristics that would have a positive effect on the teaching and learning of STEM. Many of these interdisciplinary, real-world, inquiry-based changes are included in the Next Generation of Science Standards introduced in 2013. The PISA math, reading, and science results for 15-year-
old students in the United States have been consistent—stagnant—since the inception of PISA in 2000. Finley, interestingly, asserted in 2000 that teachers teach how they were taught. Pre-Sputnik Washton to Next Generation Science Standards, stagnant PISA scores, and a sixteen-year-old assertion that teachers teach how they were taught—these are indications of a Groundhog Day effect in STEM learning and teaching. STEM learning and teaching has changed little over time.

Cutting-edge changes were evident in the learning and teaching with InvenTeams. Finley’s (2000) assertion that teachers teach how they were taught was published in the same time frame that the youngest of the three participants earned her undergraduate degree; Rachel earned her bachelor of science in biology education in 2001. During the interview about how she learns and teaches, Rachel recounted to the researcher a story about learning to teach that speaks directly to Finley’s assertion. She and the researcher discussed how she learns, which led into a discussion of how she learned to teach. She explained,

[When] I first started [to teach], I was a 90% lecture teacher. But that’s what I received primarily as a student…. I didn’t know any different. And then as you see the kids’ eyes rolling back in their heads and they’re like, “Oh my gosh, please make this hour end,” It made me think, “Yeah, this isn’t working, and by the way, I didn’t like it this way either,” and you just learn as you go.

A decade before Rachel earned her undergraduate degree in teaching science, and when Finley asserted that teachers teach how they were taught, Zeichner and Gore (1990) assimilated research on the development of teachers’ occupational socialization and conceded, “In the minds of many, little could be done to overcome the powerful effects of prior experience” (p. 335) of teaching while growing up being parented and schooled. Rachel’s teacher socialization, which
included the powerful effect of being taught one way—by lecture—was eventually overcome by the “learn as you go” method. Zeichner and Gore (1990) pointed to yet another major problem that existed with research on teacher socialization. Research focused on the individual teacher and “ignored the collective aspects of socialization into teaching” as “gendered subjects who are members of particular generations, races, social class groups, and who teach particular subjects at specific levels in the system of schooling” (p. 334). Individual changes in teaching, like what Rachel was able to do on her own, are positive: she had an effect on her students. However, the system of teaching that includes a collective aspect must be addressed. A broad transformation is necessary. Educational research is rife with opportunities to explore the transformation of additive STEM teachers to constructivist facilitators of STEM learning, socialization of constructivist STEM facilitators, and the development of efficacy of constructivist STEM facilitators.

**Discussion of Findings with Implications for Practice**

The researcher is a scholar-practitioner. Her position at the Lemelson-MIT Program affords her the opportunity to put into practice some of the learnings from this exploratory research conducted as narrative inquiry. There are three specific implications for practice that are an outgrowth of this research, and that may be viable and warrant additional consideration. These implications are:

- Technological product invention projects can be successfully facilitated by high school STEM teachers with no prior experience in invention.

- Performance accomplishments as a source for efficacy can contribute to a strong foundation for enacting cutting-edge practices in secondary STEM education.
• Vicarious experiences and verbal persuasion as sources for efficacy can contribute to a foundation for enacting cutting-edge practices in secondary STEM education.

The Lemelson-MIT Program can make readily available to non-grantee educators the proven process of invention that Chelle, Randa, and Rachel followed. Technology can be utilized to scale invention education activities. The researcher envisions a new initiative in which former educator grantees can be virtual peer mentors for teachers who desire to be more constructivist and include technological product invention in their STEM programs. Making the process of invention readily available may include an invention massive open online course, adding learning modules to the program’s website, or partnering with online learning portals to host invention education learning modules. Content and professional development can be supplemented by webinars from MIT and hosted by former grantees like Chelle, Randa, and Rachel who have experience facilitating large-scale invention projects with students.

Performance accomplishment foundation. Chelle, Randa, and Rachel had strong performance accomplishments that served as a foundation for them to consider facilitating a technological product invention project with a team of students. Again, the three participants in this research had almost 80 years of combined teaching experience that added scaffolding to the many life experiences in which they had been successful. These successful experiences helped create efficacious teachers.

This study informs pre-service and in-service professional development practices for high school STEM teachers where there is a goal to increase self-efficacy and teacher efficacy in new pedagogical practices in STEM. Changes in the way STEM teachers teach begin with how STEM teachers are taught. Novice teachers, certified teachers that are “developing greater effectiveness” (U.S. Department of Education, 2012, para. 4), need to be taught how to enact
cutting-edge practices in STEM education to engage students. Technological invention projects can be an exceptional mode of learning that creates experiences for teachers to facilitate a student-centric inquiry process that solves real-world problems, identifies and utilizes resources in their communities to aid the process, and more fully develops their strong beliefs for student learning.

Reflecting back to one of Chelle’s stories found among the multitude of her early performance accomplishments, she commented on how she was proactive with regard to how she was taught to teach. She sought out a degree in teaching mathematics and physics “where her professors encouraged creativity and application of content through real-world experiences.” She has encouraged creativity and the application of content throughout her 25 years of teaching. Novice teachers, less perceptive than Chelle, need to be taught and offered opportunities to experience successful performance accomplishments in enacting cutting-edge STEM practices.

The researcher has conceptualized a second new grants initiative in partnership with national science and engineering organizations such as the National Science Teacher Association and the International Technology and Engineering Educators Association to prepare STEM educators who have been in the classroom more than three years and are still developing their instructional practices. The Lemelson-MIT Program has a cadre of efficacious teachers in addition to the study participants who have ably facilitated InvenTeam projects. This cadre of teachers may be utilized to prepare and mentor STEM educators, thus aiding in the creation of performance accomplishments. Novice teachers would be paired with former InvenTeam teachers in a mentor capacity for one year to design and implement invention projects in an integrated secondary STEM class. Novice teachers and mentors would design their projects during a one-week summer session. Novice teachers would implement the project during the
school year with mentors continuing to work collaboratively with grantees throughout the year. The project would be summarized and made available to other teachers with dissemination through a regional teachers association meeting as well as through the Lemelson-MIT Program’s website. The overarching goal of this second grants initiative would be to add to a foundation of performance accomplishments to enact cutting-edge practices in STEM education for grantees and interrupt the Groundhog Day effect.

**Vicarious experiences and verbal persuasion.** Lopez (1990), a children’s book author, implored readers to take good care of the stories that come to you “and learn to give them away where they are needed” (p. 60). There are many more stories in addition to Chelle’s, Randa’s, and Rachel’s, available from former InvenTeam educators across the nation who are enacting cutting-edge practices in high school STEM education. Case studies—stories—of how this cadre of teachers have designed enhancements to STEM courses that include invention projects and other cutting-edge practices may serve as vicarious experiences. These powerful stories of gritty, resourceful teachers need to be given away to other teachers who may lack the confidence to enact a new practice or to change the way they instruct. The Lemelson-MIT Program has venues across the country, as well as a web platform that can be utilized for “story telling,” so that modeling behavior, coupled with verbal persuasion, may move a teacher toward a performance accomplishment—thus increasing self-efficacy and teacher efficacy.

**Limitations of the Study**

This study has been conducted with fidelity. However, the researcher acknowledges three limitations of this exploratory research that preclude generalizability of the results. The first two limitations focus on the small sample size and individual nature of this research; the third limitation focuses on the system of STEM education. The first limitation is that the
narrative inquiry included only female STEM teachers with many years of teaching experience; therefore, there may be gender issues not apparent in this research. While the researcher purposefully selected three female teachers, two thirds of InvenTeam teachers are male. Secondly, Davidson and Jensen (2009) found female teachers to be predisposed to constructivist beliefs about instruction, and teachers with constructivist beliefs had higher self-efficacy. The three participants held constructivist beliefs and had a high sense of self-efficacy even before facilitating an invention project. This research did not seek to determine how predisposed Chelle, Randa, and Rachel were to enacting cutting-edge practices.

Thirdly, the researcher, as a scholar-practitioner, works on an individual teacher level and not on the collective organizational level with regard to the system of STEM education. The participants in this study intuited and interpreted their enactments of cutting-edge STEM practices. They have recognized the potential for engaging their students by facilitating a student-centric inquiry process that solves real-world problems. However, their individual STEM practices have yet to be interpreted, integrated, or institutionalized such that they are routine in STEM education (Crossan, Lane, & White, 2009).

**Significance of the Study**

This narrative inquiry study is important to the field of high school STEM education because it highlights how Chelle, Randa, and Rachel—three great STEM teachers with many years of teaching experience and multitudes of performance accomplishments—are enacting cutting-edge practices that engage students with their learning. The study participants exhibit possibilities in STEM education and provide relief from the Groundhog Day effect where little change takes place within the system of high school STEM education. Referring back to the fact that the President’s Council of Advisors on Science and Technology (2010) failed to outline *how*
STEM teachers become great STEM teachers, the council’s report lamented the lack of rigorous research and stated that it may require 20 years of research to know how to “recruit, prepare, and retain” knowledgeable and inspiring STEM teachers (p. 65). Without evidence of “definitive research” on how best to prepare STEM teachers, the President’s Council of Advisors (2010) reported, “it is possible to act wisely now based on a combination of best available evidence, professional judgment, and common sense” (p. 65).

This current exploratory study is a common-sense study. Finley (2000) noted the changing role of the teacher and lamented 16 years ago, “translating policy coherence into improved instructional coherence and student learning seems more elusive and complex” (p. Introduction). President Obama has continuously highlighted the importance of STEM education throughout his two terms in office. One way he emphasized STEM’s importance was through the White House Science Fairs. Science was the major subject area assessed by PISA in 2015 (Program for International Student Assessment, para. 3). The last time science was the major subject area assessed by PISA was in 2006—two years before President Obama was elected. What will the 2015 PISA results reveal about 15-year-old students’ outcomes of learning science in the United States during a period in time when the administration promoted STEM?

Changes in educational direction and, therefore, policy are apparent in late 2015. There has been a rebalancing between state and federal control of education, reformation of No Child Left Behind is in process, and there has been a call from the White House for Congress to put a 2% cap on instructional time for mandatory testing, based on results from a study conducted by Hart et al. (2015) for the Council of the Great City Schools. Hart et al. (2015) found no correlation between mandated testing time and National Assessment of Educational Progress
(NAEP) results—increased test time does not improve academic performance. Testing may be reduced, but it will not go away. In fact, NAEP’s Innovation Lab is considering how to assess clusters of 21st-century skills such as critical thinking, problem solving, and collaboration—all skills utilized in the process of inventing a technological solution to a real-world problem (NAEP looking ahead, 2012). John B. King became the Acting Secretary of Education on January 1, 2016, replacing Arne Duncan who stepped down as the Secretary of Education. President Obama’s bully pulpit will disappear with the election of a new president in 2016.

There is much information that can be gleaned from Chelle’s, Randa’s, and Rachel’s rich stories, which provide a view to possibilities in STEM education with great teachers. There are opportunities for additional qualitative and quantitative research in the areas of educational theory and practice with respect to enacting cutting-edge STEM practices. However, waiting 20 more years for longitudinal study results only propagates the Groundhog Day effect. Common sense should prevail to show teachers how to enact cutting-edge practices in high school STEM education such that they build their self-efficacy and teacher efficacy through performance accomplishments, vicarious experiences, and verbal persuasion while managing negative emotional arousal or fear that can accompany change. This exploratory research on enacting cutting-edge practices in high school STEM education is significant because it affords scholar-practitioners the opportunity to vicariously view the events and influences in the lives of three female STEM teachers who aided their development of self-efficacy and teacher efficacy to enact practices that ultimately changed STEM education in their schools.
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Appendix 1

E-Mail Text for Recruitment of Educator Participants

Dear [Educator Name],

As you know, I am enrolled in a doctoral program at Northeastern University and am in the process of completing the dissertation stage of the program. My research is focused on enacting cutting edge STEM practices in high school education in the U.S.

Using the qualitative method of narrative inquiry, I plan to collect, analyze, and retell the thematic stories of three high school educators who have demonstrated a capacity and self-efficacy to enact cutting edge practices through the Lemelson-MIT InvenTeam grants initiative whose experiences culminated in participation in a White House Science Fair. The research process will involve an initial 90-minute interview that will be digitally recorded. Educators will be asked to review the interview transcripts for accuracy with a follow-up 30-minute digitally recorded conversation. Finally, educators will be asked to review the study’s summary. All interviews and reviews will be completed by November 2015.

Narrative inquiry methodology allows for the researcher and the educators to co-construct and retell stories. Co-constructed stories will inform an understanding for other STEM educators who may perceive a lack of capacity and self-efficacy to undertake cutting edge STEM practices in their schools. Combined themes and generalizing beyond each individual educator may lead to suggestions for professional development for STEM teachers to help develop a greater capacity and stronger self-efficacy in other STEM teachers leading to the inclusion of integrated STEM learning, such as invention, in secondary school teaching and learning in the U.S.

[Educator Name], would you consent to be one of the educator participants in this study? Your participation is entirely voluntary; you must contact me to volunteer. Though confidentiality will be maintained, due to the nature of this program, I cannot guarantee confidentiality. If you do wish to volunteer, please contact me directly at 413-544-4686 or e-mail me at estabrooks.l@husky.neu.edu. The chair of my committee at Northeastern University, Dr. Christopher Unger, can be reached at 857-272-8941.

Kind regards,

Leigh Estabrooks
Appendix 2

Informed Consent Form

Northeastern University, College of Professional Studies
Investigator Name: Principal Investigator, Dr. Chris Unger. Student Researcher, Leigh B. Estabrooks
Title of Project: Enacting Cutting Edge Practices in High School STEM Education: A Narrative Inquiry

Informed Consent to Participate in a Research Study

Why am I being asked to take part in this research study?
You are being asked to participate in this narrative inquiry because you have been a grantee of the Lemelson-MIT Program with the InvenTeam initiative. In addition to being a grantee, your team participated in a White House Science Fair with its invention project.

Why is this research study being done?
The goals of this research is to collect, analyze, and retell the thematic stories of three high school educators who have demonstrated a capacity and self-efficacy to enact cutting edge practices in STEM.

What will I be asked to do?
The researcher will be looking for you to participate in the following ways:
1. Participate in an interview session that will be digitally recorded.
2. Review and clarify interview transcripts with a follow-up 30-minute, digitally recorded conversation.
3. Review, edit, and clarify the study’s summary prior to final submission.
4. Provide supporting documentation such as documents, images, and videos that chronicle the inventing process.

Your participation is voluntary, and you can opt out at any time.

Where will this take place and how much time will my participation in the study take?
Interviews and conversations will be scheduled at your convenience and will utilize an on-line conferencing technology and may take two hours. Reviewing transcripts may take two hours. Reviewing the study’s findings may take five hours. Providing supporting documentation may take two hours. In total, your participation may involve around 10 hours over six months.

Will there be any risk or discomfort to me?
There are no significant risks involved in being a participant in this study. However, there is a risk of the participants’ names and schools of not being confidential.
Will I benefit by being in this research?
Benefits to you may include the opportunity to reflect on factors that have led to your capacity and self-efficacy to enact cutting edge STEM practices in your school. With the re-telling of your stories, your participation could potentially impact other educators and support professional development to assist educators to enact cutting edge STEM practices.

Who will see the information about me?
Your part in the study will be completely confidential, if you so desire. Pseudonyms can be used for study participants with only the researcher aware of the participants' identities. If requested, no reports or publications will use information that can identify you in any way. However, the potential pool of participants is very small and much of InvenTeams and the White House Science Fair are public so the student researcher cannot guarantee confidentiality.

If I do not want to take part in the study, what choices do I have?
You are not required to take part in this study. If you do not want to participate, you do not have to sign this form.

What will happen if I suffer any harm from this research?
There are no significant risks involved in being a participant in this study.

Can I stop my participation in this study?
Participation in this study is voluntary, and your participation or non-participation will not in any way affect other relationships (e.g., master educator, employer, school, etc.). You may discontinue your participation in this research program at any time without penalty or costs of any nature, character, or kind.

Who can I contact if I have questions or problems?
Leigh B. Estabrooks
169 Monsignor O’Brien Highway
#610
Cambridge, MA 02141
Cell # 413-544-4686
E-mail: estabrooks.l@husky.neu.edu

Christopher Unger, Ed. D.
College of Professional Studies
360 Huntington Avenue (BV 20)
Northeastern University, Boston
Cell # 857-272-8941
E-mail: c.unger@neu.edu

Who can I contact about my rights as a participant?
If you have any questions about your rights as a participant, you may contact Nan Regina, Director of Northeastern University, Human Subject Research Protection. Her e-mail address is n.regina@neu.edu. Her telephone number is 617.373.4588. You may call anonymously if you wish.

Will I be paid for my participation?
There is no compensation for participation in this study.

Will it cost me anything to participate?
There is no cost to participate in this study.

I have read, understood, and had the opportunity to ask questions regarding this consent form. I fully understand the nature and character of my involvement in this research program as a participant and the potential risks. Should I be selected, I agree to participate in this study on a voluntary basis.

____________________________________
Research Participant (Printed Name)

_______________________
Research Participant (Signature) Date
Appendix 3

Interview Protocol Form

Institution: Northeastern University

Interviewee (Name and Title): ___________________________________________________

Interviewer: Leigh Estabrooks

Date of Interview: _____________________________________________________________

Location of Interview: __________________________________________________________

Part 1: Build rapport, describe the study, answer any questions, and review/sign the informed consent form.

As a researcher in STEM education, I am interested about the development of your sense of self-efficacy – your self-confidence – in facilitating invention project, like your InvenTeam project, with your high school students. As a teacher, you have been a grantee with a national grants initiative focused on invention yet you had, at most, one day of professional development on facilitating invention projects prior to receiving the grant. You successfully facilitated an invention project based on your team’s participation in an invention showcase at MIT and in a White House Science Fair. The questions that follow will ask you to discuss your experiences that facilitated or inhibited your self-confidence relative to facilitating invention projects.

Because your responses are important and I want to make sure that I capture everything that you say, I would like to record our conversation today. Do I have your permission to record our conversation? [If yes, thank the participant and turn on the recording device.] I will also be taking notes during the interview. Following the interview, I will have your responses transcribed. I assure you that all responses will be confidential and only a pseudonym, should you desire, that will be used when quoting from the transcript. I will be the only person privy to
the recordings and transcriptions. To meet our human subjects requirements at Northeastern University, you must sign the form that I have provided to you [provide the form for signature].

Essentially, this document states that: 1) all information will be held confidential, 2) your participation is voluntary and you may stop at any time if you feel uncomfortable, and 3) I do not intend to inflict any harm. Do you have questions about the interview process or this form?

I have planned for this interview to last about 90 minutes. During this time, I have several questions that I would like to cover. If time runs short, I may interrupt you in order to move forward and complete all of the questions. Do you have any questions of me at this time?

Since this study is a narrative inquiry, I will enlist your assistance in reviewing the transcript of today’s recorded interview, and will seek your input in the analysis of the research.

Part 2: Obtain the participant’s insights, in his/her own words, into the experiences that led to their development of self-efficacy.

Prefatory Statement: I would like to hear about your experiences facilitating an invention project and other experiences from which you have developed a sense of self-efficacy and capacity as a STEM teacher. Your responses may include both academic and non-academic elements as appropriate. Can we start by filling me in on your background?

Q1) Please share your philosophy of teaching.

Q2) What do you teach? How long have you been teaching? How long have you been at the school where you are currently teaching? Are you with the same school you were at when you facilitated the invention project?

Q3) Describe the way you learn.

Now that we have discussed your background, let's discuss the Invention Project.
Q4) What was the timeframe for the invention project? Was the project considered a formal (in school) or informal (out of school) project?

Q5) Why did you apply for a grant to fund an invention project?

Q6) How confident were you when you applied for the grant?

Q7) Describe the challenges of facilitating the invention project.

Q8) Reflecting on challenges of facilitating the invention project, how could you gauge the students’ engagement? Their learning?

Q9) How would you describe the way you facilitated the project? Did you facilitate the project similarly to how you facilitated your classroom?

This next set of questions will focus on the Invention Project and its impact on your confidence.

Q10) Did your confidence in facilitating the project stay the same throughout the project?

Q 11) How about when the project was introduced to the public locally?

Q 12) What was your level of confidence when your students showcased the invention at MIT? To the President of the U.S. during the White House Science Fair?

Q 13) Has the invention project impacted your self-confidence today?

Q 14) Did you adopt new or different pedagogical practices to facilitate the project?

Q15) Did the invention project change the way you teach today?

To complete this interview, can you discuss what you attribute your self-efficacy and capacity to?
Appendix 4

Coding Examples of Data from Chelle, Randa, and Rachel

Interviewee: Chelle
Interviewer: Leigh Estabrooks
Date: Aug. 4, 2015
Locations: Chelle in Arizona and Leigh in Massachusetts
Digital Format: Transcribed from digital audiofile

because we were in Germany. And I had trouble with the textbook. And it
was at the college level because they don’t have high school level German
history textbooks – why would they? We don’t teach that here in the
United States. Um, and I remember going to my dad for help. And he
said, “Well, what don’t you understand?” And I said, “OK, never mind.
I’ll go back and … I’ll figure it out.”

(both laugh)

Chelle: because I figured if he knew – neither one of my parents finished
college – and, so, I figured if he could read this book then I could figure it
out.

Leigh: Interesting.

Chelle: And I went back and with hard work and determination … But
my dad would show me how to fix things. Or, not show me how to fix
things but I would get to help him fix things if they broke around the
house.

Leigh: OK. Like what?

Chelle: Like a dishwasher. And a toaster. I had a, a, um, a car – my first
car was in need of repair all the time – we shouldn’t have bought that…
but it was the best thing that ever happened to me. Because my dad made
the decision and then felt responsible to help me fix it all the time. So I
learned a ton from him.

Leigh: Were you back in the states at that point?
Interviewee: Randa
Interviewer: Leigh Estabrooks
Date: August 27, 2015
Locations: Randa in Florida and Leigh in Massachusetts
Digital Format: transcribed from digital audio file

thoughts: How did Randa get beyond not knowing and not teaching?

In-vivo Coding

facilitate & coordinate

"I probably knew the least about engineering in the group..."
"I shouldn't say that... I definitely knew less than two or three of my students."

"I think with research projects I have to do some teaching with the students to get them up to speed on like molecular biology and biochemistry."

"I feel like with research projects I know a lot more... more than the kids do so I could definitely help prepare and guide them."

would use that fits the way you worked with your InvenTeam better than that word?

Randa: (pause) Um, no. I think that word is on target. I think facilitate was—probably a little bit of coordinate—(laugh) coordinate, facilitate in

there is right on the money because I know I probably knew the least about engineering in the group (soft laugh)—now I shouldn't say that—um, I definitely knew less engineering than two or three of my students.

(both laugh)

Randa: They were really great.

Leigh: So did you facilitate an InvenTeam similarly to how you facilitate say, um, a research project? Or was it somewhat different?

Randa: Oh, a research project...? Um, (pause)

Leigh: Are you more of a mentor on a research project?

Randa: I think that with research projects I have to maybe do some teaching with the students and get them up to speed on like molecular biology and biochemistry. So, I feel like with research projects I know a lot more (soft laugh) you know, more than the kids do so I could definitely help prepare them and guide them. With the Lemelson-MIT project I don't feel like I knew—I didn't feel like I really—we were all like discovering at the same time. Um, does that make sense?

Leigh: Yeah, it does.

"With the Lemelson-MIT project... we were all like discovering at the same time."
Interviewee: Rachel  
Interviewer: Leigh Estabrooks  
Date: August 5, 2015  
Locations: Rachel in California and Leigh in Massachusetts  
Digital Format: Transcribed from audio recording  

really gonna be good because there is nothing like it out there” and it’s something that we can do. It solves a problem.

Leigh: uh hum…

Rachel: And we’re going to put the work in to make it happen. So we all felt really confident that it was going to work…

Leigh: Yeah, that’s such a good story. Thank you for your honesty.

(light laughter from both)

Leigh: But but you came to MIT… I mean, you didn’t run away from a difficult task…

Rachel: I was scared. I was really scared because I knew I had no business hanging out with engineering people.

Leigh: (just barely audible) oh my gosh

Rachel: and man and I knew that someone was going to ask me about our invention and I couldn’t even explain it because it didn’t even make sense to me so how am I gonna represent my team you know…

Leigh: Oh Rachel…

Rachel: Oh man, I was so nervous…

Leigh: I had no idea.

Rachel: We didn’t really know each other then. You were the lady that e-mailed me and said, “Rachel, you need to get to Boston.” So it worked out. It happened just the way it was supposed to.